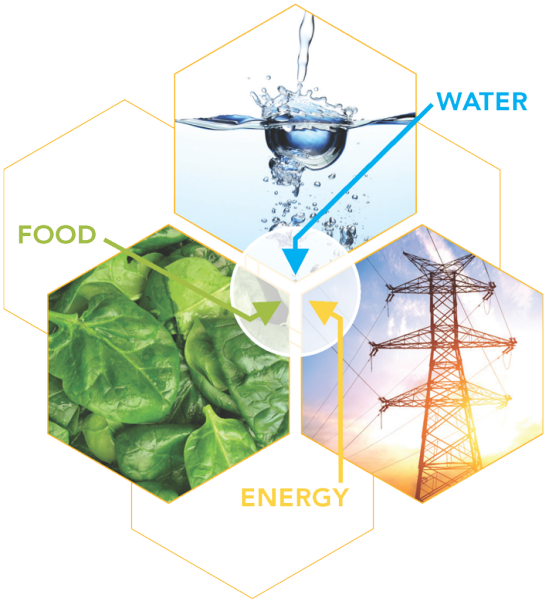
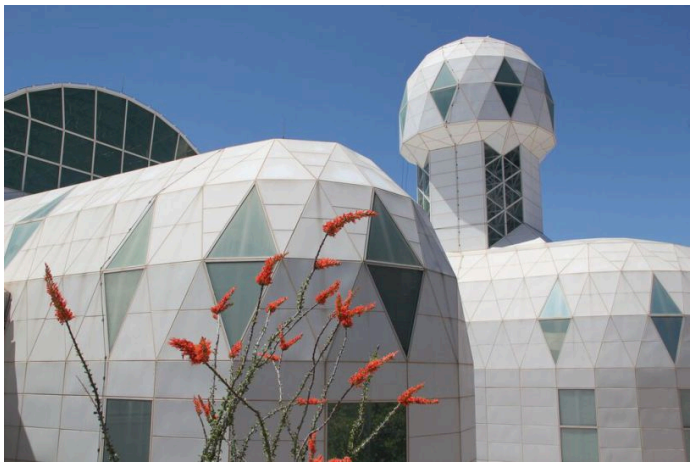
Enabling Resiliency in Energy, Water and Food Systems for Society

Addressing the Scientific, Technological, and Societal Challenges of the Energy, Water, and Food Nexus

A report on the NSF workshop.

April 15–17, 2015
University of Arizona
Tucson, Arizona





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Preface

About NSF
The National Science Foundation (NSF) is an independent federal agency created by Congress in 1950 "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…" With an annual budget of $7.3 billion (FY 2015), we are the funding source for approximately 24 percent of all federally supported basic research conducted by America's colleges and universities. In many fields such as mathematics, computer science and the social sciences, NSF is the major source of federal backing.

About ORD
The University of Arizona Office of Research & Discovery supports world-class research and discovery by University faculty, staff, and students, who are asking bigger questions and generating better answers every day. As Arizona's premier research university, the University is ranked among the top 20 of public research universities nationwide and is a member of the prestigious Association for American Universities (AAU). While such rankings are important marker of our success, it is the impact of our research that matters most. Our research is creating the next generation of knowledge – and is translated and applied to society's grand challenges – to enhance economic development and promote a rich quality of life. Through research experiences in and out of the classroom with our award-winning faculty, students have unparalleled opportunities to discover, learn, and to be prepared for the competitive global economy

About UAREN
The University of Arizona Renewable Energy Network (UAREN) is a university-wide initiative designed to support the expanded regional, national, and global development and use of abundant, clean, and economical renewable energy. UAREN fosters trans-disciplinary research, discovery, training and outreach efforts at The University of Arizona that lead to pioneering advances in sustainable energy systems, new approaches to energy-efficient water re-use and purification, and new partnerships between producers and consumers of energy. Anticipating the challenges arising from a growing population requiring secure energy and water resources, UAREN thinks globally, predicts regionally and acts locally, to simultaneously enhance our local and regional economies and our environment.

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Executive Summary

On April 15-17, 2015, the University of Arizona (UA) convened a workshop at Biosphere 2 near Tucson, Arizona focused on:

"Addressing the Scientific, Technological and Societal Challenges of the Energy, Water, and Food Nexus (EWF): Enabling Resiliency in Energy, Water, and Food Systems for Society"

The April 2015 workshop was among the first of several discussions to foster collaborations and build a network of experts that can respond to proposals and provide organized responses and perspectives to these critical issues. The goal of the workshop was to establish an interdisciplinary, broad-based approach to addressing the scientific challenges in energy, water, and food systems that impact society.

With support from the National Science Foundation (NSF), the UA Renewable Energy Network (UAREN), and the UA Office of Research and Discovery (ORD), the University convened representatives from academia, government, and industry to identify the top scientific questions that address the pressing global need to secure the availability of energy, clean water, and secure food supplies for future generations. This report summarizes the findings from that workshop.

Given the heterogeneity of the attendees present at the workshop, the expectation was that common themes would be diverse and difficult to track. However, common ideas emerged in the areas of resource scarcity, new technologies, data and information management strategies, and cooperative policy development.

The focus of the workshop was on the interrelationships between developing, producing, and using energy, water, and food in developed nations, and the challenges embedded in addressing these interrelated areas that have traditionally been developed in isolation. The attendees concurred that current policies do not address the imbalance of supply and demand of resources that are perceived to be at risk; however, supporting opportunities for cooperation in this area could yield some of the highest and near-term gains.

Foundational Themes

The workshop on the Energy, Water, and Food Nexus resulted in five specific themes that we submit will stimulate basic research and provide key foundational knowledge:

i. ***Situational scarcity***. Energy, water, food, and the materials that underpin our economic viability (e.g. strategic minerals and fuels), can be extremely scarce in localized regions and at different periods of time, affecting the well-being of large portions of the U.S. This type of situational scarcity is likely to be amplified as a result of increasing climate variability, inadequate management of local and regional water, energy and food supplies, expanding populations,

and a lack of coherently developed, deployed and integrated technology and policy solutions.[12] Research initiatives are needed that address these situational scarcity challenges, whether at the molecule-, material-, or system-scale, with a clear evaluation of their anticipated economic and societal impacts.

ii. ***New materials, new technologies, and unit operations.*** New materials platforms and systems-level technologies are needed which are flexibly targeted to:

- energy-efficient water reuse and purification for municipal, agricultural, mining, and energy production sectors;
- economical, distributed energy sources and energy storage platforms; and
- widely dispersed, multi-analyte sensor platforms.

Development of these new materials and technologies must be underpinned by an atomic- and molecular-scale understanding of separations, molecular recognition, and charge transfer and catalysis. The resultant new technology platforms will most effectively be targeted to integration into "precision communities," where energy and water quality and balance, and waste production and management, are tightly and continuously monitored and controlled.

iii. ***Smart data and decision-making.*** Achieving a tightly integrated level of precision in dealing with situational scarcity will be linked to measurement, analysis, and optimization (control) of chemical and physical parameters on previously unrealized scales. The result will be in the generation of massive data sets for which we will require new modes of transmission, storage, access, and robust links to policy and decision-making processes.

iv. ***Policy Response.*** To advance the implementation of these complex and critical solutions and overcome the acquired inertia in large institutional infrastructure and practice a focus on the following areas is essential:

a) bottom-up integration of both new science and new technology with policy development, decision-making and support, and education and awareness;
b) revitalization of local community, human resource, and workforce development;

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[1] Shlomi, D., ed. *Beyond Resource Wars: Scarcity, Environmental Degradation and International Cooperation.* Massachusetts Institute of Technology (MIT), 2011. Print.

[2] Graedel, T.E., et. al. "On the Materials Basis of Modern Society." *Proceedings of the National Academy of Sciences (PNAS).* May 19, 2015. www.pnas.org/cgi/doi/10.1073/pnas.1312752110 .

c) development of policies that transform the regulatory and market environment;
d) integrated and coordinated planning across sectors and public and private organizations.

v. **Regional Test Beds and Private/Pubic Partnerships**: A lack of adequate demonstration and testing to help reduce development costs and mitigate technological risks for investors has been a limiting factor in the deployment of new technologies and business models in the past. To advance innovation in energy, water, and food systems and increase R&D support through a policy of deployment by industry and others, there is a significant need for regionally specific test beds that integrate public and private interests and investment. Characteristics of potentially successful sites include; a) large and complex enough site to challenge the integration of new energy conversion, storage and energy management systems, new water purification and re-use platforms, and new precision agricultural systems; and b) small enough to be easily isolated so that sufficient control can be achieved to make credible and verifiable research results possible. The University of Arizona Biosphere 2 facility appears to have the potential to become one of these research sites, but other regionally appropriate model sites will be needed and should be pursued.

Results of the workshop, along with with copies of the presentations and images are available on the dedicated web site: http://energywaterfoodnexus.wordpress.com

Introduction

As recently outlined in 2014 NSF[3]and Department of Energy (DOE)[4] reports, transformative changes in our production of secure and sustainable energy, food, and water sources, and in the efficient use of energy, have become one of the most significant challenges of the 21st Century. An integrated and aggressive approach is required to solve these problems, especially in regions like the southwestern U.S. stretching from southern California to eastern Texas, this region contains nearly one-third of the U.S. population and is experiencing severe drought conditions produced by low streamflows and reservoir levels, shrinking ground water supplies, and unprecedented pressures on the food system. These problems affect the entire U.S., but this region in particular is home to many communities that are vulnerable to these changes. At the same time, we are surrounded by an abundance of conventional and renewable energy sources, mature and increasingly sophisticated agricultural and mining and energy production economies, and abundant but non-potable water sources (e.g. seawater, municipal, and agricultural waste streams).

Thus, this region is the perfect "laboratory" for addressing the convergent problems of developing secure and sustainable energy, sustainable supplies of clean water, sustainable development of sources of strategic materials, and a safe and secure food chain. These are problems that require an unprecedented level of new basic science and technologies, integrated from the outset with assessment of their impact on local and regional economies and societies, and coupled with workforce training. The proposed solutions cannot a priori require more energy (and water) than they deliver, which has been the more typical approach to solving technological problems in the recent past.

We detail below our recommendations from the workshop, and then discuss the motivations and structure of the workshop, along with a selection of individual findings.

Recommendations from the Workshop

1) Situational Scarcity

Motivation: Secure supplies of clean water and energy, for municipal, agricultural, mining, and manufacturing uses, are increasingly "situationally and geographically scarce."

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[3] NSF Mathematical and Physical Sciences Advisory Committee-subcommittee on Food Systems. "*Food, Energy, and Water: Transformative Research Opportunities in the Mathematical and Physical Sciences*". July 2014. http://www.nsf.gov/mps/advisory/mpsac_other_reports/nsf_food_security_report_review_final_rev2.pdf

[4] U.S. Department of Energy. "*The Water-Energy Nexus: Challenges and Opportunities*". June 2014. http://www.energy.gov/sites/prod/files/2014/06/f16/Water-Energy%20Nexus%20Report%20Executive%20Summary%20June%202014.pdf

Recommendation/opportunities:

i. Co-location and integration of "smart" energy generation and water reuse/purification (see below), for agriculture, mining, manufacturing, and municipal uses appears to offer significant advantages in mitigating situational scarcities, especially for water.
ii. Integrated resource planning of new electricity generation projects are envisioned that minimize water use, coupled with improved integration of renewable energy into the grid and extensive use of the implementation of energy efficiency methods and materials and demand management tools.
iii. Right sourcing water to minimize the amount of energy required to purify water prior to use is an advantage since all applications, such as cooling towers, industrial process waters, and irrigation, do not require high purity water.

Optimal Result: Significant reductions in long-distance water transport, or tapping of deep subterranean water resources (to the point of exhaustion), would be alleviated, and economic growth would be fostered and maintained, in regions of the U.S. experiencing extreme climate variability and changes in population density.

2) New Materials, New Technologies, and Unit Operations

Motivation: Water reuse and purification is extremely site specific (situational), and impurities vary widely depending upon the surface or subterranean source(s); the previous agricultural, mining, manufacturing, energy production, or municipal use; the total amount and flow rates needing purification; and a wide range of other variables.

Recommendation/opportunities:

i. Modular purification technologies and combined unit operations appear achievable including multiple membrane separation modules for nanofiltration, coupled with pre- or post-chemical, electrochemical, or photoelectrochemical contaminant oxidation, or reactions to simultaneously produce energy or reduce CO_2. New separation technologies and new catalysts for each module type are required, and their design and implementation needs to consider their incorporation into flexible, continuous purification systems, capable of operating at close to the maximum thermodynamic efficiency. Since water sources vary, molecular-level understandings of separation, catalysis, and photocatalysis in complex environments must precede and underpin many of these technological advances.
ii. Non-traditional purification strategies may be possible using naturally occurring biological or bio-inspired systems (e.g. bacteria, algae), which are less energy intensive in their production, use, and recycling, more easily dispersed, and more easily tailored to local water systems. Extensive research is needed to determine whether these approaches are better choices than the more conventional technology development pathways, and if there is any benefit to combining approaches (i.e. biological and chemical).

iii. Captured waste streams (especially from mining and manufacturing water sources) may in many instances contain high-value components, which might find integration into other industrial processes, thereby enhancing the energy efficiency of both processes.

iv. Modular sensor platforms need to accompany modular purification platforms. Real-time, online sensors, capable of good sensitivity and selectivity, that are easily integrated into networks and respond to a wide (and variable) array of biological, organic, and inorganic contaminants, are necessary. Single analyte sensors have been widely researched but their application in complex environments challenge their selectivity and, therefore, their utility. Molecular, recognition-based sensing platforms, if sufficiently robust, promise to provide the needed performance metrics.

Optimal Result: Highly flexible and easily implemented water purification and reuse systems will become available that can be integrated into local (renewable) energy generation platforms, accompanied by rigorous testing of water quality to standards that provide confidence in the end-user community that water supplies are both safe and secure.

3) Smart Data Acquisition, Archival, Information Processing and Analysis linked with Real-Time Decision Making.

Motivation: Energy, water, and food production in the future will require a level of modularity, integration, and precision, with combinations of artificial and biological technologies and unit operations not currently attainable with today's stand-alone, regionally-isolated platforms. Widely dispersed sensing and control appears to be required at unprecedented levels, especially in highly populated regions experiencing extreme situational scarcities.

Recommendation/opportunities:

i. New modes of data transmission, archival as partially analyzed data, robust storage, and widespread access by researchers, decision makers and the public will be required to handle the massive data sets arising from optimized and controlled energy conversion/storage/transmission, water purification/re-use, precision agricultural and mining systems. Furthermore, there are associated opportunities for the development of standards and new methods for data acquisition, sensor networking and analysis.

ii. Real time decision making and optimization requires cooperation among stakeholders involved in bottom-up design of these new massively integrated control and optimization strategies, across the entire EWF. It is strongly recommended that these new integrated systems also provide transparent and robust links to policy- and decision-making processes.

Optimal Result: Regional scarcities in energy, water, and food can be ameliorated with much faster response times to increasingly variable climate conditions and externalities

that drive availability, price, and quality of these commodities, without undo changes to quality of life in the U.S.

i. ***Tools for the evaluation of new technology in decision-making and policy-making.*** Models that integrate energy, water, and food systems can be useful for decision- and policy-makers when they are evaluating new technological advances. Also useful are translational methods that are similar to the integrated assessment processes utilized in environmental policy that combine a regional economic model of markets with a model of water availability and food productivity.

ii. ***An information and data platform that provides real-time response to changing conditions*** and combines integrated water and energy system information and usage requests. This platform will enable efficient use of resources at a local and regional scale that produces higher output per unit input and meets growing demand.

4) Policy Responses

Motivation: It is recognized that not a single policy or technology is sufficient to meet the challenges in the energy, water and food systems facing the Nation and in order to catalyze transformative changes, a predictable policy environment built around long-term policies is necessary.

Recommendation/opportunities:

i. ***Identify key costs and benefits of distributed energy, water, and food systems.*** This process needs to incorporate previously externalized costs that impact personal health and the environment.

ii. ***Models that show the results of robust scenario-planning for the future, based on multiple sources of data from different sectors.*** This will require an in-depth understanding of the entire landscape of data resources and secure pathways of accessibility to this data. Additionally, integrating community perspectives in the development of system solutions, where different cultural and societal values can dictate the acceptance and perception of the value of proposed systems and ensure sustained development and deployment of successful systems.

iii. ***Development of integrated strategic planning processes*** between energy and water and agricultural management, institutions that haven't worked together traditionally in the past. This type of planning allows decision-makers to access and plan deployment and consumption of mixed resources, price externalities, and resources and involve a broader sector of the community.

iv. ***Identify the barriers associated with the social acceptance of new technologies.*** These include novel approaches that integrate low-energy solutions in the water treatment and reuse process, assessing the accumulation and potential concentration of emerging contaminants in recycle systems, and overcoming challenges to co-location and co-production of integrated systems.

Optimal Result: Overcome the inherent inertia in decision-making in institutions that have traditionally worked separately to solve problems and develop pathways to educate the public and decision-makers about the role of new technologies in solving fundamental issues associated with improved access to energy, water, and food resources

Regional Test Beds and Facilities for Increased Research Capacity

Motivation: There are currently insufficient test beds and micro-sites that are large and complex enough to provide for proof-of-concept evaluation of the new technologies, massive data integration, and decision making/optimization, and are also not critical parts of municipalities or industries where "islanding" or isolation would not be disruptive.

Recommendation/opportunities: Small energy and water intensive sites, which are large enough to model small cities, farms, etc., need to be identified where federal research support, coupled with industrial participation, can be combined in an accessible experimental platform. These sites will provide a basis for widely variable capabilities for evaluation of new technologies, new data acquisition and analysis, coupled with real-time optimization and decision making.

Optimal Result: New technologies, and new data and decision-making solutions, can be evaluated quickly, speeding up the time to market and incorporation into viable energy, water, and food technologies that provide maximum benefit in a world of increasing variability of climate and critical resources.

Objectives of the Workshop

This workshop addressed five foundational topic areas at the **Energy, Water, and Food** Nexus:

i. *New energy sources for water and food,* including advanced materials and technologies for photocatalysis and water purification, new energy conversion and storage platforms, and creation of alternative fuels coupled with creation of new food sources;
ii. *Energy use and efficiency in water treatment systems* including desalination, wastewater treatment, water reuse, and quality and mineral recovery;
iii. *Energy, water, and food systems* including plant genomics (drought tolerance, controlled environment agricultural systems), seasonal forecasting and sensor networks, and remote sensing and systems-level modeling;

iv. *Economics, policy, business, and society* including R&D and technology development, policy assessment, investment decisions and strategies, policy, economics and law, and socio-economic development and impacts; and
v. *Technology and infrastructure* including integrated modeling, risk, and uncertainty assessments, energy, water, and food systems integration, data modeling and analysis, and distributed systems and symbiotic infrastructures.

Each of these focus areas was framed by presentations and discussion, led by at least one expert from academia, industry, or government laboratories.

Structure of the Workshop

The workshop was divided into three sessions to address the key topic areas of the nexus. Each session included 10-minute presentations, designed to frame the issues, from representatives from academia, industry, and government. The presentations were followed by in-depth, roundtable, working-group discussions with a series of framing questions utilizing modified café-style facilitation. This type of facilitation enabled a large group of attendees with different backgrounds to have an in-depth discussion on the key challenges and opportunities of each topic area, and stimulate innovative thinking. Participants were divided into pre-defined subgroups, mixed by their skills and expertise to ensure that each group had representation from industry, academia, and government.

Framing questions that addressed the problems, approach, challenges, and impact of the topics were developed prior to the workshop. Groups were asked to identify key scientific, technological, and societal questions associated with topics in the nexus and work through a *gap analysis* evaluation of each topic. The gap analysis discussions developed a series of recommendations for the types and priorities of research and development needed to enhance and improve outcomes in topic areas. Discussions were facilitated by subject matter experts and supported by graduate students who recorded the main points. The outcomes from the sessions were summarized in a plenary session, where the group discussion of the outcomes informed the final observations and recommendations.

Session 1: Systems Level – Energy, Water, Food

This session considered the interrelationships between producing energy, water, and food, as the demand for adequate and safe supplies of these resources increase. The session focused on a systems analysis approach, and defined some of the technology gaps associated with optimization and control of systems, techno-economic modeling, and understanding the important social and policy implications of systems integration. On the unit-operations level, specific areas for discussion included:

- Low energy water and wastewater operations;
- Water reuse and recycling;

- Waste heat and alternative energy methodologies for water and wastewater purification;
- Recovery of byproducts from waste; and
- Scale-up and validation of new technologies.

Session Lead: **Kim Ogden, Ph.D.,** Professor Environmental and Chemical Engineering, University of Arizona
Session presentations:

- **Dan Schwartz, Ph.D.,** Director, Clean Energy Institute, Boeing-Sutter Professor of Chemical Engineering. University of Washington
- **Stanley Reynolds, Ph.D.,** Eller Professor of Economics, University of Arizona
- **Michael Sheehan** – Director, Resource Planning, Tucson Electric Power Company (TEP) & Unisource Energy Services (UNS)
- **Susan Butler** - Strategic Planning and Environmental Resources Specialist, CH2M Hill

Moderated breakout group sessions – all participants

Keynote Speaker: **Colby A. Foss, Ph.D.,** Director, Chemical Measurement and Imaging Program, Division of Chemistry, Mathematical & Physical Sciences Directorate, National Science Foundation

Session 2: Food Systems and Productivity

This session built on the systems-level discussion in Session 1 to examine the influence of the availability of water and energy on food systems productivity. Particular emphasis was placed on the role of modulations in the climate and real-time operational data, focusing on an understanding of the implications of advances in agricultural technologies. As the food value chain becomes stressed due to changes in energy, water, and climate, advanced agricultural practices will become increasingly critical for optimizing the genetic potential of crops and maintaining the global food supply. Break-out sessions addressed issues related to: a) the development of advanced sensor technologies to provide early warning of plant anomalies in open field; and b) climate, weather, and hydrological models needed to support decisions regarding which crops to grow, when and how much to water, and how to maximize the use of renewable energy in food production. The unique challenges facing developed countries for integrating water, energy, and food production and critical structures for economic and policy frameworks to support growing demand were examined.

Session Lead: **Parker Antin, Ph.D**., Associate Dean for Research, College of Agriculture and Life Sciences, University of Arizona

Session Presentations:

- **Gene Giacomelli, Ph.D**., Director, Controlled Environment Agriculture Center; Professor of Agriculture & Biosystems Engineering, University of Arizona
- **Brent Massmann**, Senior Manufacturing Technologist, Monsanto, Inc.
- **Alan Stephens**, State Director of Rural Development/Arizona, US Department of Agriculture
- **Michael Hanemann**, Ph.D., Director, Center for Environmental Economics and Sustainability Policy, W.P. Carey School of Business, Arizona State University

Moderated breakout group sessions – all participants

Keynote Speaker: **Michael Hoffmann Ph.D.** - Professor of Environmental Chemistry, California Institute of Technology

Session 3: Integrating Basic Science and Energy, Water, Food Systems

This session considered the role of basic science in the ability to create scalable and affordable energy conversion, such as solar electric, solar fuels, and energy storage technologies that can easily be integrated with water reuse, water purification, and precision agriculture. New technologies, when coupled with arrays of networked sensor platforms, have the potential to optimize energy flow, water consumption, nutrient use, and minimization of contamination and waste, but only with an enhanced understanding and control of matter at nanometer-, mesoscopic-, and macroscopic-length scales, and dark and photo-induced charge transfer. Attention was given to new materials and processing approaches that are needed to optimize water purification with minimal energy inputs and minimal costs in environments. This addresses circumstances where conventional energy sources are more difficult to integrate (greenhouses for instance) and responsiveness toward changing environmental conditions is necessary. Methods for measuring the efficacy of the proposed scientific and technological breakthroughs were discussed, and the pressure points associated with social benefit and acceptance of these new technologies were also considered.

Session Lead: **Neal Armstrong, Ph.D.,** Associate Vice-President for Research and Regents Professor of Chemistry and Biochemistry

Session Presentations:

- **Shane Snyder, Ph.D.**, Professor Chemical and Environmental Engineering, Co-Director, Water & Energy Sustainable Technology Center (WEST)**,** University of Arizona
- **Pete Crozier, Ph.D.,** Professor School for Engineering of Matter, Transport and Energy, Arizona State University
- **Fernando Temprano-Posada, Ph.D.,** Director of Technology, Repsol, S.A.
- **Nathan R. Neale, Ph.D.**, Senior Scientist, Group Manager, Molecular & Catalysis Science, Chemistry & Nanoscience Center, National Renewable Energy Laboratory (NREL)

Moderated breakout group sessions – all participants

Keynote Speaker: **Tracy Young**, Global Application Development Leader, Dow Water and Process Solutions, The Dow Chemical Company

Summaries of Workshop Presentations

Key considerations and recommendations from Session 1 presentations included the importance of integrating community perspectives in the development of system solutions, where different cultural and societal values can dictate the acceptance and perception of the value of proposed systems. Solutions developed for the needs of one geographic location with specific economic and social structures will not be universally acceptable or useful in all applications. The need for an integrated strategic planning process between energy and water management institutions, organizations that haven't worked together traditionally, was a consistent theme. The need to access and plan the deployment and consumption of mixed resource, price externalities, and resources (water), and involve a broader sector of the community, would be the results of such planning.

Session 1: Systems Level – Energy, Water, Food

"Searching for Questions that Move the Needle on Energy – Water – Food"
Dan Schwartz, Ph.D., Director, Clean Energy Institute, Boeing-Sutter Professor of Chemical Engineering. University of Washington

Dr. Schwartz addressed the issue of acceptable modes of inquiry and customary problem-solving approaches versus the need to expand the traditional engineering approach that focuses on the scientific and technologic advances required to address a water- and energy-related problem. This approach examines the "exchanges between mass and heat with the surroundings". At smaller scales where water and energy are linked in the process of production, such as fuel cells, the model produces acceptable results but "scale can disrupt the success of this approach." He used the example of a hydro-electric dam, where traditional models are used to determine the impact on energy generated, water availability for irrigation and farming, and economic impacts of industrialization, but overlook the impact to indigenous people and the ecosystem where it resides.

Dr. Schwartz stressed that engineering needs to fit into the surroundings in an integrated social, economic, technical, and environmental system, where research questions reveal new relationships in this system, their interactions, and scale dependencies. The example he used to illustrate the point was the possibility of linking ecological restoration with bioenergy production by finding a market for invasive tree residues, based on a technological innovation via a new type of kiln.

"Session One: System Level Panel"
Stanley Reynolds, Ph.D., Eller Professor of Economics, University of Arizona

Dr. Reynolds established that the installed capacity of solar photovoltaics has increased with a 60% annual growth rate in the U.S., driven by favorable government-based incentives and regulations. This growth rate in the U.S. and abroad has contributed to lower costs for photovoltaics in the current market, with a value to the economy that is measured by a levelized-cost structure that provides a clear price/cost per unit of electricity generated. He clarified how this cost structure does not dig deep enough into the true costs and benefits of renewable energy and needs to include environmental impacts of energy generation and the timing of renewable energy generation compared to load (demand) requirements.

The inherent intermittency of the power quality from renewable energy poses risks to reliability of the grid at high penetrations, but opens up an opportunity for more types of integration and innovation in energy storage and demand-side management to capitalize on the benefits of renewable energy. Dr. Reynolds pointed out that traditional thermo-electric generation requires tremendous amounts of water, and if water is underpriced it could lead to investments inefficient investments in water-intensive generation. Models that integrate energy, water, and food systems can be useful for decision- and policy-makers when they are evaluating new technological advances. He proposed a model that is similar to the integrated assessment models utilized in climate policy, which combines a regional economic model of markets with a model of water availability and food productivity.

"Power Generation and Water Use in the Desert Southwest"
Michael Sheehan – Director, Resource Planning, Tucson Electric Power Company (TEP) & Unisource Energy Services (UNS)

Mr. Sheehan began by describing the California drought conditions that will have the cumulative effect of increasing the reliance on in-state natural gas resources and imports of power from out-of-the state to meet their current electrical energy demand. He illustrated how most of the traditional thermo-electric generation sources in Arizona use a wet-cooling system and derive their water from surface water resources in the Mountain Plateaus of Arizona, at the Utah border. One exception is the Palo Verde Nuclear Generating Station, located to the West of Phoenix, which utilizes 65,000 acre-feet of reclaimed water from the city of Phoenix with zero liquid discharge. He showed how current low-water-use technologies, such as wind and solar energy and natural gas systems (combustion turbine and combined cycle), currently comprise a small part of the resource portfolio in Arizona compared to nuclear and coal steam generation.

Mr. Sheehan outlined the current regulatory impacts on future water use in Arizona, including reductions in NOx and CO2 emissions (Clean Power Plan and Regional Haze) and increased energy efficiency and renewable energy standards, which will have a regional impact of reducing coal-powered generation in the next ten years. These reductions will also contribute to an annual water-usage reduction of 20% in the next ten years, but will mean that while there is a decrease in coal-steam generation in the Mountain Plateau, there will also be an increase in capacity of natural gas systems nearer

urban centers, and will require groundwater resources for cooling in the Desert Basin Region. He recommended that more studies are needed to assess the impacts of water usage in the generation shift from surface water to groundwater resources. He also recommended siting new generation projects that utilize low water technologies or reclaimed water, and continue to improve the integration of renewable energy into the grid, coupled with energy efficiency demand-management tools.

"Perspectives on Water"
Susan Butler - Strategic Planning and Environmental Resources Specialist, CH2M Hill

When considering water-use policy in the U.S., the public and private sector share a number of criteria when determining impacts of decision-making, such as life-cycle costs and return on investment, certainty, reliability, and regulatory risk, public acceptance, and health and safety. Ms. Butler pointed out that the U.S. is currently faced with chronic and acute scarcity of water, caused in some part by population increases in meta-regions, aging infrastructure, and reduced federal funding support. Competing uses for water, exacerbated by climate variability and a growing awareness of water risks, have also contributed to the perception of scarcity.

These trends have led to progress in conservation, recycling, and reuse and desalination of water resources, but can still benefit from planning for water use that looks at future availability versus historic models and utilizes innovative funding solutions that combine the private and public sectors. Ms. Butler recommended building on water-resource planning that integrates community values and technical criteria, and utilizes scenario-based planning that considers uncertainty, to promote a portfolio management approach. The example she used was to consider the Masdar City plan in Abu Dhabi, UAE, which combines zero waste with carbon neutrality and low environmental impact.

Key questions that still need to be addressed to reach effective integrated planning include shifting the development of water supplies from largest customer needs to regionalization, and decentralization in planning that potentially addresses more significant environmental concerns and delivers more equitable water resources. Resolving technological challenges such as: a) identifying the emerging constituents of concern (ECC) for agricultural applications as well as potable reuse; b) cost-effective water recovery systems for oil and gas industry; c) processes that reduce the energy demands of desalination and make it affordable for agricultural purposes; d) and increasing the commercial viability of recovered minerals from concentrate are identified as critical steps to overcome the scarcity of water resources.

At the government level, Ms. Butler recommends studying the policy frameworks that create incentives for private investment in water infrastructure, and overcome the possible international conflicts over shared water resources by reframing the conversation to prioritize investments in ecological infrastructure, and focus on collaboration leading to resilience rather than conflict resolution.

Session 2: Food Systems and Productivity

"Food Production: Precision Agriculture and Controlled Environment Agriculture"
Gene Giacomelli, Ph.D., Director, Controlled Environment Agriculture Center; Professor of Agriculture & Biosystems Engineering, University of Arizona

Dr. Giacomelli highlighted the ability of green plants to convert solar energy into energy-rich plants that can sustain the current quality of life on earth. To extend that quality of life into the future we need to combine current field production agriculture that has optimized breeding, nutrition, water-use, and mechanization practices, with enhanced precision agriculture that uses information about each plant in the field and its environment, to improve production and reduce resource use. The benefits include water and nutrient savings, pesticide and herbicide reduction, and efficiencies in labor use. This type of "smart farming" could increase margins in the agricultural sector by providing real-time information about harvesting, planting, and yields that can predict crop value.

At a smaller scale, Controlled Environment Agriculture (CEA) eliminates the uncertainty of seasonal output and provides consistency in production quality, water, and energy use, and nutrient capture and recycling. The systems are efficient in their ability to be transportable, work in urban areas (vertical farming), function on poor quality lands, and integrate the efforts of the community. Dr. Giacomelli estimates that the edibles market from U.S. greenhouses or CEA's will grow to over $4 billion by 2020. The closed-loop greenhouse system maximizes crop production, water capture from plant transpiration, and reuse. Opportunities for heating and cooling with renewable energy and integration of energy efficient appliances, such as LED lighting, can resolve prohibitive cost barriers inherent in greenhouse systems (high heat loads and cooling demand) in arid environments.

"Enabling Resiliency for Food Systems"
Brent Massmann, Senior Manufacturing Technologist, Monsanto, Inc.

Mr. Massmann outlined the increasing anthropogenic impact of population growth in the world. A doubling of the population in the past 50 years has meant that ~15% of the food grown in cultivation since the dawn of agriculture (12,000 years ago) has been grown during that time, ~35% of all exosomatic energy use occurred, and ~70% of the anthropogenic increase in atmospheric CO_2 took place. He pointed out that complex systems are inherently unstable when perturbed, producing an unpredictable cascade of effects and feedbacks. However, over the last 50 years, market reforms in the shape of regulated free markets rather than planned economies, innovation, and globalization have dampened the effects of population perturbation and avoided widespread famine. While the trend is showing a decline in the number of undernourished people in the world, 840 million people still do not have access to enough food. The ongoing challenges are an increase of three billion people in the next 50-100 years, coupled with an increase in per capita consumption. The cascade of effects of the current perturbations will push external costs into the future and discount future utility of non-renewable resources, essentially

pushing the current problems of access to food by millions of people to the next generation.

To address the need of creating sustainable food systems for the future, Mr. Massmann recommends that cutting food loss and waste in half by 2050 could close the gap by 20%. Additionally, currently available technologies can work together to increase efficiency and include: crop protection, breeding for stress tolerance, biologicals and biotechnology that control for viruses, weeds, and insects, and precision agriculture. In addition, artificial technologies that provide field-by-field and meter-by meter data, optimize farm management practices combined with biological advances, such as the use of microbial organisms during seeding increase the nutrient uptake of a plant's life. These technological improvements will provide the capability to grow enough food far into the future, but the impacts to land and water use and energy production are not well understood.

Mr. Massmann stipulates that further market reform, through science-based regulation to extend the use of these technologies, is necessary to overcome these impacts. Global collaboration in waste reduction, control of plant genomes, and data collection, with information technology towards the use of increased precision agriculture, are necessary to provide sustained food resources for the growing population.

"Energy, Water, Food"
Alan Stephens, State Director of Rural Development/Arizona, USDA

Mr. Stephens discussed a number of programs that USDA has in place to address the challenges of climate change to rural communities and forests in the U.S. The USDA manages seven "climate" hubs that deliver information about climate change and weather variability in an effort to assist in adaptation to these changes. He stated that the USDA has strived to preserve and map genetic differences in forest and rangeland plant species to overcome some of the risks to biodiversity. This network of hubs has connected scientists with landowners to aid in the decision-making process and has provided regional data on adaptation planning.

Integrating new technology and shifting to local, community-based farmers' markets, rather than relying on large distribution systems, has reduced environmental impacts of this system and provided local produce to schools and retail organizations. The USDA has promoted policy in the form of increases in federal funding for local food enterprises, providing transportation alternatives for local farmers to bring their goods to these new markets, and the integration of renewable energy in food warehouses that have decreased the cost of local, distributed, community-based enterprises.

"Climate change and U.S. agriculture"
Michael Hanemann, Ph.D., Director, Center for Environmental Economics and Sustainability Policy, W.P. Carey School of Business, Arizona State University

Professor Hanemann stated that climate change will reduce crop yields and harm crop production in the coming decades. Tremendous increases in crop yields have occurred in the past 70 years and the role of climate change in sustained increased yield is yet to be determined. There is currently a divergence between crop models and statistical models based on actual data. Crop models show less severe impacts of drought and need to account for the effects of high temperature that may be induced by a failure to track "vapor pressure deficits." To better assess the impacts of climate change on crop yield, models that incorporate variables such as daily versus annual weather predictions, precipitation versus temperature, extremes versus averages, and climate data are needed.

Dr. Hanemann illustrated how statistical analyses revealed an increase in farmland values in Northeastern and northern areas east of the 100th meridian in the next 100 years. This was compared to substantial decreases in the majority of mid to southern states in the same time period. These changes were attributed to sustained increases in higher temperature degree-days and precipitation. These models also show an asymmetric relationship between temperature and crop yield, where yield is fairly flat as temperature increases and then sharply declines beyond an upper temperature threshold (about 32°C). The proportion of net economic loss to U.S. agriculture, due to changes in precipitation and degree-days over 34°C, are projected to be between 80 and 90% before 2049 and 60% between 2070 and 2099.

Session 3: Integrating Basic Science and Energy, Water, Food Systems

"Water Reuse: Opportunities for Innovation"
Shane Snyder, Ph.D., Professor Chemical and Environmental Engineering, Co-Director, Water & Energy Sustainable Technology Center (WEST)

Dr. Snyder explained that only 5-6% of wastewater created in the U.S. is reused, but that California has mandated increases in reuse followed by Arizona, Florida, and Texas. The process of creating potable water through reuse has a much lower energy intensity than seawater desalination, but equal to or greater than brackish groundwater desalination techniques. One of the most significant challenges to greater use of reused water is overcoming the public perception of its threat to public health. Water contains contaminants with both chemical and microbial origins; oxidation, disinfection, and membrane fouling reduction are all methods to reduce existing contaminants. However, up to 69.9% of the Disinfection Byproducts (DBP), or disease-causing organisms or pathogens, are not yet fully identified. Techniques, such as Cellular Bioassays and Embryonic Assays, are currently in use, and integrated systems toxicology with systems analysis of pathways and dose response is underway in the next 20 years.I Implementation of predictive, pre-clinical toxicology and a sustained testing architecture will be necessary to fully assess contaminants in potable water sources.

Technological advancements, such as real-time sensor networks that optimize chemical doping, mixing, and speed automation, can bring significant cost savings to the process while ensuring water quality and treatment integrity. Dr. Snyder described the ideal sensor as both a physical and chemical sensor that transforms chemical information, such

as concentrations of a specific sample to total composition analysis, into an analytically useful signal. The sensor platform could be labeled as a "lab-on-a-chip" (LOC) that comprises a microfluidic device integrating several laboratory functions (sampling, mixing, reaction, and separation) with biosensors that combines a biological sensing element into a transducer onto a single small chip. The necessary infrastructure to support the sensor platform will be a "smart water grid" that integrates sensor-based monitoring, data analysis, and operation at a local and regional level.

Dr. Snyder recommended that support for innovations in water treatment include advanced oxidation processes to remediate newly-emerging organic pollutants, resource recovery and optimization from oil sands, sewage and radioactive wastewater, and mining and groundwater treatment. Recent developments in magnetic, palm-based activated carbon may be an effective and economic sorbent for emerging contaminants.

"Repsol Science and Technology"
Fernando Temprano-Posada, Ph.D., Director of Technology, Repsol, S.A.

Dr. Temprano-Posada defined Repsol as a global energy company with headquarters in Spain that is structuring its science and technology arm to produce and support the development of "smart" energy. This shift in direction has been motivated by faster and more disruptive changes in the need for energy, food, and water, brought about by population growth, increased urbanization, shifts in geopolitical balances, and increased complexity in energy supply chains. The need to deliver more oil and gas means greater investments in subsurface screening, identifying analogs, geological 3D modeling, and cognitive systems to optimize current assets. Greater consumption of oil and gas contributes to increased CO_2 emissions that could be offset by increasing the biotechnological abilities applied to processes from any carbon source. This includes computational biology, metabolic pathways, microbiology, and protein engineering.

The increased cost, environmental impacts, and political challenges of increased drilling and production of fossil fuels has led to an expansion of Repsol's energy portfolio to include electrification of mobile transport by supplying energy storage for transport and evolving the company structure to take advantage of disruptive technologies in this area. The company currently supports infrastructure with over 300 charging stations for electric vehicles, and continues investigation into alternatives such as renewable distributed power, biofuels, chemically and electrically condensed energy, and the use of CO_2 as a raw material.

"Fundamental Challenges in Coupling Fuel-Forming Photocatalysis with Water Purification"
Nathan R. Neale, Ph.D., Senior Scientist, Group Manager, Molecular & Catalysis Science, Chemistry & Nanoscience Center, National Renewable Energy Laboratory (NREL)

Dr. Neale clarified that current water and energy use in the U.S. requires 30.2 billion kWh for public water supply and treatment, and 40% of freshwater withdrawals are used for cooling thermoelectric power plants. The key challenges in reducing water use is to develop cooling techniques that don't require any water, and reducing organic and inorganic contaminants in the water purification process. The current process to prevent eutrophication of water supply and fouling of power plant cooling towers is a two-step process comprised of organism-impregnated filters that require aeration, and organic donor input (methanol) in an energy-intensive system where over 60% energy savings could be recognized. Introducing solar-driven nitrification and denitrificaion can act as a direct analog to photocatalysis and water splitting; high-temperature solar thermal can produce \$3-5/kg H_2 and photoelectrochemical processes with 15% efficiency can yield \$4/kg H2, but require engineering innovations and new synthetic materials.

Dr. Neale described PEC H_2O splitting concentrator schemes compatible with NH_4^+/NO_2^- water-purification methods for a 5% STH $BiVO_4$/Si PEC/PV Tandem PEC Device, and an anammox mechanism that is a solar-driven nitrification/denitrification process for solar water splitting. He proposed a research and development pathway that would identify the basic understanding of electrocatalytic ammonia cycles in aqueous environments using artificial catalysts and the development of an artificial, light-driven analog to the dark anammox process.

Key Discussions During the Breakout Sessions

Following the invited speakers, participants were divided into pre-defined groups of 8-10 to brainstorm a series of key questions formulated to encourage discussions. The organizers identified groups that had representation from each sector and specialty at each table, encouraging a diverse discussion. Each individual rotated to three distinct groups and questions. Moderators and note-takers were assigned to each table, and then reported to all participants during the plenary sessions. The following represents the key findings and discussions as they were reported to all participants. Suggestions for further research are those of the community present at the workshop.

Session 1: Systems Level – Energy, Water, Food

Discussion topics in this session involved issues and opportunities surrounding gross water use, "waste" recycling and reuse, infrastructure and distribution of systems, public perceptions, and efficiencies in the nexus. The following represents a summary of the discussion, suggestions, and directions for potential research.

i. Gross water usage should to be considered for all processes in food and energy generation systems to ensure maximization of available supply. In particular, secondary or tertiary uses require additional research. For example, a "waste" water or energy stream from one process may be of sufficient purity or value for use in a secondary process. However, there are trade-offs at every scale of implementation that require consideration. A reoccurring theme throughout the discussion sessions was that "one solution does not fit all." For example, there

are some energy production technologies available that do not require as much water to run, like air-cooled systems. However, the largest barrier remains the cost associated with implementing a new system when there is not sufficient incentive to do so. In addition, the legacy cost of water is typically too low to justify the change to more efficient systems. The group acknowledged that legacy costs of water are associated with complex public policy and the individual right to water; additional discussion did not occur.

ii. There is a deficiency of policy to support implementation of integrated resource planning and scenario planning. This could be attributed to the lack of communication between sectors regarding the data collected and maintained by each sector. Overall, there is a need for better access and sharing of systems data to plan for the future. Data sharing could lead to integrated systems models to optimize and control food, energy, and water systems.

iii. In order to maximize utility and resolve situational scarcity of water, further understanding of the quality of water required for successive use is needed. Thus, there is a need for matching the treatment level to the use, which requires the development of real-time sensors and control strategies. These controls could 1) identify the level of water quality required in the successive use, and 2) monitor and assure the water quality during treatment. In addition, sensors could provide real-time pathogen detection in all phases of water treatment. Understanding the resource inventory and economic viability of several different sources of previously processed water sources, such as municipal and industrial effluents, landfills, storm water runoff, and agricultural runoff or residuals, may be an important part of the water reuse portfolio. The challenge is to recognize costs and benefits at small and large scales where typical volumetric processing is more effective.

iv. There are research opportunities to address the accumulation and potential concentration of emerging contaminants in recycled systems while determining if there is a potential secondary use for those contaminants. Essentially, the group aspired to eliminate "waste" from the discussion. In addition, research opportunities include identifying low-energy solutions to recycle and reuse wastewater and waste streams, the integration of reclaimed water into landscape water supply and demand models, heat transfer technologies, and co-location.

v. The group suggested there may be opportunities to learn from the oil and gas industry's produced water and co-produced hot water (low temperature energy production) methods. In addition, these techniques require research related to understanding the benefits of batch processing, or batch purification of water, when using waste heat as well as an alternative source of energy. Particularly, development and optimization of water purification systems that operate at 70-90°C.

vi. Co-located facilities, particularly related to energy and water, offer additional opportunities; however, the group realized this has its own challenges in terms of land, technology, and policy requirements. Developing systems with lower footprints to add-on to existing utilities is one opportunity, especially for urban settings. Co-location may present innovative opportunities to even out loads on the grid. Remaining questions include:
    - Can more water be purified at night when energy demands are low if co-located with nearby storage facilities?
    - How best can renewable sources of energy be optimized to produce potable water, particularly in an urban setting?
    - Could co-locating energy production and water treatment facilities alongside agricultural crops enable more efficient food production?

vii. Currently, appropriate infrastructure does not exist to connect and support co-location, particularly as associated with water reuse; thus, additional planning in terms of retrofitting existing sites to co-locate is challenging. However, there is an opportunity for future facilities to evaluate the feasibility of co-location through additional economic analysis. Co-location costs should be considered in the replacement costs for utilities as replacement costs to implement new technologies is currently a challenge.

viii. Understanding the regulatory drivers for improving treatment and reuse are required. An ongoing challenge associated with co-location and water reuse is public understanding and acceptance of reuse strategies. Researchers and policy-makers require an additional understanding of the social barriers. A potential solution for increasing public awareness is the publication of use cases as public information. For example, the Palo Verde Nuclear Generating Station outside of Phoenix, AZ includes a model water/wastewater system.

ix. In addition to public perception and cost, there is a shortage of modeling efforts to understand the benefits and challenges associated with co-location and large systems. This discussion led to the acknowledgement of the complexity associated with local versus federal government funding, support of long-term planning, and balancing the immediate needs of the public.

x. Multiple participants asked, “Why do we grow crops where there is not sufficient water?” This of course is a complex question with broad implications for the communities affected. To maximize food production, additional research on the opportunities and markets for controlled environment agricultural systems is suggested, as further discussed in the next session.

xi. Discussions at several levels focused on development of complex communications platforms that integrate sensor networks. In particular, optical sensing platforms easily integrated into fiber-optic communications will be a premium platform for many applications. Sensing platforms connected by RF (“wireless”) communication platforms also lend themselves to ease of massive

integration – lab-on-cell phone! Questions of public acceptance of the use of enhanced sensor networks and the conflict of privacy must be addressed but training opportunities for students in development, deployment, and networking of sensing technologies across the EWF with end users and customers is a distinct path forward to address these issues.

Session 2: Food Systems and Productivity

The group in Session 2 determined that improving food productivity will involve more intensive farming; i.e., more agricultural output per input of land, nutrients, water, and energy, while minimizing negative environmental impacts. Increased productivity will require a better understanding of how environmental influences, such as climate, affect agricultural output. Additional research and technological advancement in precision agriculture, or utilization of models and sensor technology, in open (field) and controlled (greenhouse) environments, may improve understanding of environmental influences and will likely lead to higher food output, lessen environmental impacts, and reduce food loss and waste. Food loss and waste, in this instance, primarily refers to production loss, such as spilled or spoilt food prior to retail consumption. Although, it was acknowledged that a better understanding of retail consumption may allow for improved production processes.

i. As discussed in the previous section, water usage should be considered. As reclaimed water becomes more widely used in agricultural production, ensuring a clean and verifiable water supply will be essential. Utilizing advanced sensors, a clearer understanding of the type of water quality acceptable for varying crop production will help minimize the energy intensity of the reclamation process. Differential water use, or the treatment level required for crop growth and food production, is key to resilient crop management. Additional inquiry is needed on how the quality of reclaimed water for agriculture affects the quality of the food, as health risks are currently not well identified.

ii. In addition to sensors and real-time detection of water impurities, remote sensing may lead to advances in agriculture. For example, remote sensing can indicate an area of the field where the plant is overheating and thus, require additional water consumption. Remote sensing may also identify areas of nutrient deficiency or pesticide abundance.

iii. It was recognized that climate variability introduces risks and uncertainty in the ability to adequately produce food for a growing population. Identifying which agricultural production practices will have the most effective ability to reduce that vulnerability is essential to sustained production. Research has shown that agricultural production is far more sensitive to increasing temperature than to suboptimal amounts of water. However, the research on adapting crops to increasing temperature through breeding has thus far proven unsuccessful. Additional investigation is required to breed heat resistant plants, as well as plants that can withstand high salinity (or other impurities) in the water.

iv. Crop management processes will benefit from climate and weather predictions that provide information of the impacts of increased temperature, moisture, precipitation, and extreme events, particularly at the regional level. Regional expertise, based on local historical, or paleo-derived, climate data is required to address the current deficiencies in regional-scale modeling. Coupling regional climate data with the aforementioned advanced technology may provide the missing linkages for more precise modeling and forecasting.

v. Climate variability impacts the ability for food producers to more efficiently plan for planting scenarios. Adequate models that are developed with local and regional expertise, and integrate near-term forecasting with longer-term climate forecasts, are needed to understand impacts to food production and the availability of water resources and energy needed for efficient distribution.

vi. Advances in agriculture-related technologies requires a new level of data collection and handling. The increased data volume presents challenges in ownership, storage, and analysis, as well as efficient delivery of the data (or data products) to the end users. Sharing and analyzing data at regional and national levels, to better understand the impact to resource availability, was identified as a gap in an effort to better address less resource intensive crop production.

vii. Fundamentally, the group identified that energy, water, and possibly food, are not priced correctly; prices probably do not reflect scarcity, or even subsidized real costs. Unregulated and incorrectly priced water and energy (e.g. California) has led to many of the current scarcities – choices of crops to be grown has only exacerbated the current crisis – although scarcity and the perception of scarcity has already led to more effective policy making to conserve resources. Currently, larger communities with centralized power and water systems are to some extent better equipped to deal with energy and water scarcity and the links to food production. However, development of smaller and decentralized communities have demonstrated the ability to address environmental risks and adopt more leading-edge technologies to sustainably ensure access to adequate resources (examples include Denmark, the UK, and other island communities).

Session 3: Integrating Basic Science and Energy, Water, Food Systems

This session focused on identifying the basic science solutions to some of the issues identified in previous sessions, specifically water usage and co-location. For example, participants identified linkages between energy conversion and storage and water-purification technologies, in the form of advanced membranes and data collection and analysis. Adopting the concept of precision agriculture, the group coined the term “precision living” for the network of technology related to ensuring secure and efficient use and storage of water, energy, and agricultural products. Precision living requires networked sensor arrays on previously unheard-of scales

that provide both sensitivity and selectivity toward a large array of potential contaminants and desired products, energy input and outflow, and a responsiveness toward rapidly changing environmental conditions.

i. Every analyte and complex sensing environment requires development of a new, unique sensing platform. Selectivity, sensitivity, and reliability are all equally important and there is a critical need for "modular" sensing approaches that can be rapidly adapted to new sensing modalities. The group suggested there might be opportunities for learning and advancement based on current practices at power companies. Power companies already make extensive use of control technologies to optimize energy production, heat loss, and water use and reuse. A clear first step would be identifying the best methods and practices that can be extrapolated to food and water sectors. This could lead to the creation of "systems" that link sensors, energy inputs, water inputs and reuse, and food production for control and optimization for the sustained use of resources in the future. Similar to the discussion in Session 1 on public perceptions of water reuse, the group indicated acknowledgement of the importance of public education regarding advances in basic science.

ii. Scalable and affordable energy conversion, such as solar electric, solar fuels, and energy storage technologies, which can easily be integrated with water reuse, water purification, and precision agriculture, are beginning to emerge. These new technologies, when coupled with arrays of networked sensor platforms, have the potential to optimize energy flow, water consumption, and nutrient use, and minimize contamination and waste. The new technologies are only available through an enhanced understanding and control of matter at nanometer-, mesoscopic-, and macroscopic-length scales, and dark and photo-induced charge transfer.

iii. The group discussed water transport, recycling, and reuse, identifying separation technologies, specifically membrane technology, as a primary opportunity for advancement. Membranes that allow for the removal of organic materials from water with high salinity, aided by low-efficiency transport, such as solar power (external) and photocatalytic (internal) sources, can increase output per unit of energy used. Those that target strategic impurities and separation of gases will aid in the delivery of specific types of water quality for exact uses. Biologically engineered "living membranes" and genetically engineered plants and root systems were identified as paths for possible removal of biological contaminants with high specificity and efficiency that can provide purification and active transport, particularly when coupled with aquaporins and genetically engineered algae to capture specific metals and remediate waters.

iv. Prolonging the life of membranes to reduce costs through processes that easily clean and restore, such as dialysis membrane and pre-treatment with nanofiltration, should be explored. A potential solution to overcoming the challenge of power utility acceptance of improved membrane technology is

developing a standardized method of matching technology with water sources and contaminants in addition to disposing of byproducts.

v. At the molecular level these materials are likely to be polymeric or ceramic, or composite materials with molecule- or ion-specific adsorption/chelation or transport sites that are designed to provide: high transport efficiency while retaining good selectivity, molecule-scale modularity, system-scale modularity, and long lifetimes and good overall energy efficiency.

vi. At present many single contaminant membrane systems are approaching their maximum thermodynamic (energy) efficiency. This will become problematic as more complex, large-scale, water-reuse systems are imagined. In order to remove multiple contaminants, the molecule-scale modularity is critical as the group deemed that the scalability of removing multiple contaminants would not occur without this modularity. The ability to "piggy-back" membranes in an integrated system would also assist in addressing scalability.

vii. Utilizing renewable energy in the water purification process is highly desirable to recognize the benefits of low carbon-emitting energy sources and adaptability in scale and modularity of the systems. However, solar energy is quite dilute, and there may not be enough photons to effectively assist in water purification without some sort of light concentration. Alternatives such as utilizing colloidal oxides, such as TiO_2, have been used widely to "photoelectrochemically" treat water systems. However, scaling up the technologies and overall efficiencies, or methods to reduce corrosion, have not been identified. Efficient water purification has been demonstrated using photovoltaic and integrated chemical battery systems to drive the appropriate electrochemical reactions in the dark, as demonstrated in Dr. Hoffman's presentation. These direct (dark) approaches to electrochemical purification may be aided by new catalyst design, nano-texturing of electrode surfaces, and other methods to enhance overall efficiency. Water splitting is easier to do than CO_2 reduction, but contaminant remediation may be easier, even though hydrogen (H_2) is the most desirable product and a vector toward other products.

viii. To achieve these kinds of advances, development of combined electrochemical and membrane pre-treatment methods will be required. Identifying new abundant, low-cost catalysts (nano-scale) that can drive both oxidation and reduction reactions at close to their thermodynamic potentials (low overpotentials) with enhanced overall efficiencies. These technologies however, are dependent upon the success of the sensor networks deployed to ensure complete contaminant removal.

ix. As in Session 1, co-location was offered as a solution, specifically for minimizing entropic losses for cost effective output. Multiple, highly-scalable solar energy conversion platforms are emerging which portends electricity production at the point of use—including wind, PV, and photothermal—and

requires efficient integrated storage to efficiently overcome inherent intermittency. These local, distributed systems may provide experimental platforms to understand the ability to recover waste heat. The group suggested that greenhouse agriculture might be the easiest, fully-integrated system for research purposes. Controlled environment agriculture provides a contained system, amenable to optimized energy use, water reuse, and purification, with distributed, networked energy conversion and storage systems.

x. To recognize the benefits of deploying these systems at smaller scales, advances in energy production technology will have to occur. Low-cost, roll-to-roll printable PV systems are emerging which appear to go below the $1 per watt threshold and may be robust enough to integrate into controlled agriculture systems. Several new PV technologies are being developed which wavelength select for electricity production, heat capture, and plant growth of normal interior light. New Li-battery technologies are emerging which lend themselves to roll-to-roll processing and scalability. However, scalable, low-cost energy conversion and energy storage systems still require developing materials that either don't currently exist, or that exist but are difficult to integrate into large area arrays that are compatible with end use such as new semiconductors, new nanoparticle light absorbers, and new anode and cathode materials for batteries and super-capacitors.

xi. Although there is an apparent intrinsic distrust of new technologies (e.g. energy production, energy-use optimization, water reuse and purification, and sensing platforms) that adds to the complexity and cost of resources, it is an area where development of educational programs and outreach that address both scientific and non-scientific audiences will have immediate impacts. The role of perception of value in making decisions is critical to the success of implementation; bias in science, industry, and the public towards perceived cost-effective solutions may in fact not be resilient. This will require the need for translation of scientific phenomena, the value of technological innovations, and the inherent challenges in the system such as entropy and its consequences. Avenues for discussion of all societal implications and education of the public are required.

Workshop Conclusion

The final session reviewed the outcomes and recommendations of the workshop, including the proposed information for this report. An optional tour of the University Arizona Biosphere 2 facility provided attendees the opportunity to view the unique facility. During the tour, participants began generating additional research collaborations and concepts.

ATTENDEE BIOGRAPHIES

Tom Acker, Ph.D.
Professor of Mechanical Engineering
Northern Arizona University
Dr. Tom Acker is a Professor of Mechanical Engineering at Northern Arizona University, where he has been since 1996 after receiving a PhD in Mechanical Engineering from Colorado State University. He is currently the director of NAU's Sustainable Energy Solutions Group, and teaches and performs research related to energy systems and renewable energy. Acting on behalf NREL, he is the "Operating Agent" in charge of leading an international effort to study wind and hydropower integration for the International Energy Agency. His recent research activities include wind power integration, wind flow modeling via meso-scale and micro-scale (CFD) methods, wind assessment, water/energy projects, Native American applications of renewable energy, and agricultural/energy projects. He also recently led an effort at NAU to plan a new Master's of Science in Engineering degree with an emphasis in Sustainable Systems Engineering.

Michael Baldea, Ph.D.
Assistant Professor, McKetta Department of Chemical Engineering
University of Texas, Austin
Michael Baldea is Assistant Professor in the McKetta Department of Chemical Engineering and Affiliated Faculty in the Institute for Computational Engineering and Sciences (ICES) at The University of Texas at Austin. He received his Diploma (2000) and M.Sc. degree (2001) in Chemical Engineering from "Babes-Bolyai" University in Cluj-Napoca, Romania and obtained a Ph.D. in Chemical Engineering from the University of Minnesota in 2006. Prior to joining The University of Texas, he held industrial research positions with Praxair Technology Center in Tonawanda, NY and GE Global Research in Niskayuna, NY. He has received several research and service awards, including the NSF CAREER award, the Moncrief Grand Challenges Award, the ACS Doctoral New Investigator award, the Model-Based Innovation Prize from Process Systems Enterprise and the Best Referee Award from the Journal of Process Control. His research interests include the dynamics, optimization and control of process and energy systems, areas in which he has co-authored one book, three book chapters and over 60 peer-reviewed journal and conference articles.

Ardeth Barnhart,
Director, Renewable Energy Network (REN)
University of Arizona
Ardeth directs the UA Renewable Energy Network (UA-REN), an initiative to connect the public, industry, and government to the UA's research and education in renewable energy. The goal is to support the expanded regional, national, and global use of abundant, clean, and economical solar-based renewable energy. Her work includes the development of a UA renewable energy policy program focusing on economic and policy development for innovation. She specializes in the design and implementation of strategies for the adoption of renewable energy, both in Arizona and nationally, through increased support for trans-disciplinary research and analysis of renewable energy systems that integrate and synchronize, from their initial stages, policy design and technology development. Prior to her appointment at the Institute of the Environment in 2010, Ardeth was the co-director of the Arizona Research Institute for Solar Energy (AzRISE) at the UA.

Jennifer Barton, Ph.D.
Associate Vice President for Research
University of Arizona
Jennifer Barton serves as Associate Vice President for Research, specifically engaged in research development activities. She is setting up programs that seed faculty research, nucleate teams, and create resources for proposal preparation. She heads Research Development Services which directly assists

faculty in obtaining grant resources for their research. She is Professor of Biomedical Engineering, with additional appointments in Electrical and Computer Engineering, Optical Sciences, and Agriculture and Biosystems Engineering.

In previous administrative roles, Dr. Barton served as Interim Vice President for Research, Assistant Director of the BIO5 Institute, inaugural Department Head of Biomedical Engineering, and Chair of the BME Graduate Interdisciplinary Program. She is a fellow of SPIE- the International Optics Society, and a fellow of the American Institute for Medical and Biological Engineering. She is a UA "Leading Edge Researcher", a College of Engineering Da Vinci Fellow, and has been awarded the AZBio Michael A. Cusanovich Bioscience Educator of the Year Award.

Sandra Begay-Campbell
Principal Member of Technical Staff
Sandia National Laboratories
Sandra Begay-Campbell is a Principal Member of the Technical Staff at Sandia National Laboratories where she leads Sandia's technical efforts to assist Native American tribes with their renewable energy developments. Sandra received an Associate of Science – Pre-Engineering and Bachelor of Science - Civil Engineering degree from the University of New Mexico. She worked at Lawrence Livermore National Laboratories before she earned a Master of Science - Structural Engineering degree from Stanford University. Sandra also worked at Los Alamos National Laboratory right after graduate school. For over 22 years, Sandra has been with Sandia National Laboratories. Sandra is a recent recipient of the American Indian Science and Engineering Society's Lifetime Achievement Award; the University of New Mexico's 2007 Zia Alumnus Award; the 2005 UNM School of Engineering Distinguished Alumnus Award and Stanford University's 2000 Multicultural Alumni of the Year Award. Sandra was also selected as a recipient of the Governor's Award for Outstanding Women from the New Mexico Commission on the Status of Women.

Carol Bessel, Ph.D.
Deputy Division of Chemistry Director
National Science Foundation
Carol A. Bessel is the acting Deputy Division of Chemistry Director and Team Lead for the Chemical Catalysis within the Chemistry Division of the National Science Foundation (NSF). She has also served as Program Manager in the Chemical Sciences, Geosciences and Biosciences Division of Basic Energy Sciences at the U.S. Department of Energy overseeing the Fuels from Sunlight Energy Innovation Hub as well as a portion of the Energy Frontier Research Centers portfolio.

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University Distinguished Professor of Atmospheric Sciences
University of Arizona
Dr. Betterton is a University Distinguished Professor in the Department of Atmospheric Sciences and in the Institute of Atmospheric Physics, where he is currently the Head and Director, respectively. He also holds courtesy appointments in the Department of Chemical and Environmental Engineering, and in the Division of Community, Environment and Policy, Zuckerman College of Public Health.

Born and raised in Zimbabwe, Dr. Betterton studied chemistry in South Africa, and environmental science at Caltech. Along the way, he worked in the platinum mining industry, and in cement and lime manufacturing. He joined the University of Arizona in 1988. His research in the laboratory and in the field is focused on environmental pollutants, especially those found in the air and water that might affect people. For example, he studies toxic metals in airborne dust, the chemistry of rain and snow, and the environmental fate of sodium azide, the propellant used in certain automobile airbags.

Paul Brierley
Director, Yuma Center of Excellence for Desert Agriculture
University of Arizona
The UA's College of Agriculture and Life Sciences has named Paul Brierley the inaugural director of its recently launched Yuma Center of Excellence for Desert Agriculture. The center, based in Yuma, is a public-private partnership between the college and the Arizona and California desert agriculture industry, dedicated to addressing "on-the-ground" industry needs through collaboration and research. Brierley will oversee the center's research activities. He joins the UA after more than a decade of executive service to the Arizona Farm Bureau, where, as the bureau's director of organization, he helped agricultural producers improve their industry by actively identifying and solving problems.

R.D. Castillo
Corporate Relations Associate, Tech Launch Arizona
University of Arizona
As Corporate Relations Associate, R.D. Castillo is responsible for managing a portfolio of strategic company relationships, exploring and assessing new research and business opportunities, prospecting and developing new company partnerships, and supporting a range of activities related to expanding industry sponsored research at the University of Arizona.

A native Tucsonan, R.D. spent several years in Business Development with a local contract manufacturing company. His previous experience included ten years in sales and management positions in the banking industry. He received a B.S. in Business Management and a Master of Business Administration (MBA) degree from the Eller College of Management at the University of Arizona. R.D. is active in the community, serving as a board member and classroom volunteer for Junior Achievement.

Zachary Clement
General Engineer
US Department of Energy
Since 2013, Zachary Clement has acted as a General Engineer for the Office of Energy Policy and Systems Analysis at the US Department of Energy, where he provides legislative, technological and market analysis of all forms of energy and fuel. Before that, he worked as a General Engineer for the Bureau of Safety and Environmental Enforcement, examining various types of offshore energy sources. He earned a BS in Environmental Systems Engineering from Penn State in 2010 and an MS in Environmental Engineering from Virginia Tech in 2014.

Benedict J. Colombi, Ph.D.
Associate Professor of American Indian Studies
University of Arizona
Benedict J. Colombi, Ph.D. is Associate Professor of the American Indian Studies Program and Affiliate Assistant Professor of the School of Anthropology and the School of Natural Resources and Environment. He also holds a Faculty appointment in the newly formed, Institute of the Environment, a center for disciplinary and interdisciplinary environmental and climate change research at The University of Arizona.

Kat Compton
Department of Geosciences
University of Arizona

Andrea Corral, Ph.D.
Post-Doctorate
University of New Mexico

Joel Cuello, Ph.D.
Professor of Agriculture & Biosystems Engineering
University of Arizona
Joel Cuello focuses his research on applying engineering to put biological systems to work. His collaborative research projects, which have been sponsored by DOE, NASA and USDA, among others, are divided into two major thrusts: Bioprocess Engineering and Controlled-Environment Engineering. With bioprocess engineering, Dr. Cuello's concentrations are on design and scale up of bioreactors for production of biofuels and biochemicals from algae, plant cells and organs. Also, he explores the optimization of algae and cell-culture productivity through biochemical and environmental strategies. Also, he attends to wastewater treatment using algae, microbial mat and hydroponics. In regard to controlled-environment engineering, Dr. Cuello's concentrations -- for both Earth and Space applications -- are on design of novel lighting systems, including hybrid solar-electric lighting systems, light-emitting diode arrays, and water-cooled high-intensity discharge lamps. He complements this work with trying to design bioproduction systems, including a hybrid hydroponics-and-aquaculture system.

Alex Dely
Contracts Manager
Raytheon Missile Systems
Alex Dely was born and attended high school in Gent, Belgium and immigrated to the United States in 1976, becoming a proud US Citizen in 1983. He did his undergraduate work in engineering physics at Illinois State University (highest honors) and the University of Chicago (Laboratory for Astrophysics and Space Research, NASA Fellowship). He did doctoral work at the University of Arizona Graduate School in Physics as a DuNuoy Fellow (materials science, solar physics, national security issues), and while an adjunct professor of physics, also attended the University of Arizona Law School (strong focus on international, technology and intellectual property law). At Raytheon Alex serves as a Contracts Manager, with focus on Value Engineering, Adjacent Markets, and IDIQ Contract Vehicles throughout Raytheon Missile Systems. And within the RMS Advanced Security & Directed Energy Systems Product Line he supports the DARPA, Energy Surety, IO/IA Cyber Security and Homeland Security Directorates.

C. Meghan Downes, Ph.D.
Assistant Professor in Economics
New Mexico State University
Dr. Meghan Downes has her Ph.D. in Environmental and Natural Resource Economics from the University of New Mexico, and completed a post-doc at the University of Georgia for the US Forest Service on the valuation of recreation on National Forests. She is currently an Assistant Professor in Economics at New Mexico State University, and is the Director of Economics for the National Alliance for Advanced Biofuels and Bioproducts, a US DOE funded consortium. Her research expertise in non-market valuation of environmental and natural resource economics, economic development, energy, and renewable energy.

Elizabeth A. Eide
Director, Board on Earth Sciences and Resources
National Research Council
Elizabeth A. Eide is director of the Board on Earth Sciences and Resources at the National Research Council (NRC). Prior to joining the NRC as a staff officer in 2005, she served as a researcher, team leader, and laboratory manager for 12 years at the Geological Survey of Norway in Trondheim. While in Norway, her research included basic and applied projects related to isotope geochronology, mineralogy and petrology, and crustal processes. Her publications include more than 40 journal articles and book chapters, and 10 Geological Survey reports. She has overseen 11 NRC studies. She completed a Ph.D. in geology at Stanford University and received a B.A. in geology from Franklin and Marshall College.

Claudio A. Estrada Gasca, Ph.D.
Renewable Energy Institute

National Autonomous University of Mexico (Universidad Nacional Autónoma de México)
Dr. Estrada is a physicist from UNAM and has a PhD degree in Mechanical Engineering from New Mexico State University, in the United States. Dr. Estrada has worked for the Institute of Renewable Energy of UNAM since June 1988 and his areas of specific interest are transport phenomena in solar systems, mainly in solar concentration systems.

John Finley, Ph.D.
Professor of Food Science
Louisiana State University
Dr. Finley is interested in foods which enhance health, particularly related to obesity and reducing the side effects of obesity. Specific interests are in the development of culinary quality in low calorie foods and ingredients. Additionally, he has an active program on reducing chronic inflammation with dietary intervention. Inflammation is the basis of any of the side effects of obesity and diabetes. Food ingredients and altered diet can reduce or delay these adverse side effects.

Kevin Fitzsimmons, Ph.D.
Professor, Department of Soil, Water and Environmental Science
Director, College of Agriculture and Life Sciences International Programs
University of Arizona
Kevin Fitzsimmons extension responsibilities include working with operating aquaculture farms across the state. He also works with farmers and investors who are considering aquaculture. There are now 20 high schools in Arizona with aquaculture units on their campuses. He works with students and faculty to develop their aquaculture systems and curriculum in the schools.

His research is directed primarily toward production techniques of tilapia and shrimp in the desert and in integrated systems. Multiple use of water for aquaculture and irrigated agriculture has been a focal point. A second broad area of resesarch is control of aquatic nuisance species.

Jeffrey Goldberg, Ph.D.
Interim Dean, College of Engineering
University of Arizona
Dr. Jeffrey Goldberg is Dean of the College of Engineering and he took this position in January 2009. He received his Ph.D. from the Michigan, in Industrial and Operations Engineering in 1984, and the Master of Engineering and BS from
Cornell in Operations Research and Industrial Engineering in 1980 and 1979 respectively. He came to the University of Arizona in 1985 in the Systems and
Industrial Engineering Department. His main research area is the design of emergency response systems. He has helped design ambulance systems in more than 10 metropolitan areas in the US and Canada.

Lucio Guerrero
Director of Research Communications, Office for Research & Discovery
University of Arizona
Lucio Guerrero has worked at the University of Arizona's Office for Research and Discovery as Director of Research Communications since 2014. Before that, he has worked in the communications realm for Feeding America, Cook County Health and Hospitals System, and the Office of the Governor of Illinois, among other posts.

Jesús González Hernandez, Ph.D.
Director General, Research Center for Advanced Materials
Consejo Nacional de Ciencia y Tecnología (CONACYT)
Jesús González Hernández is a physicist, professor, researcher and academic based in Mexico. He specializes in the research of materials with amorphous structure for use in photovoltaic and optical recording systems. He is co-author of 20 patents in Mexico and the United States concerning solar devices, optics beam x-ray and biomaterials.

Shannon Heuberger, Ph.D.
Director, Federal Legislative Affairs
University of Arizona
Shannon Heuberger earned her Ph.D. and M.S. in Entomology from the University of Arizona. She has worked as a congressional intern for former Congresswoman Gabrielle Giffords, and as a Legislative Science Fellow for a year in the US Senate. Her current role is Director for Federal Legislative Affairs at the University of Arizona.

Lisa Henderson
Community Program Manager for the Community Energy Program
Arizona Governor's Office of Energy Policy
Lisa Henderson has served as the community energy program manager for the Arizona Governor's Office of Energy Policy for 4 years. Over the past 25 years, her experience in project management and grant administration has resulted in many successful energy-related projects including projects in the rural communities seeking traditional preservation of limited resources.

Rebecca R. Hernandez, Ph.D.
President's Postdoctoral Fellow, Energy and Resources Group
University of California, Berkeley
The work of Rebecca R. Hernandez examines processes where human and natural systems interact and those that elucidate the functioning of the Earth system. Answering pure ecological research questions and solving critical environmental problems through applied work are important to her. Her research program to date is comprised of three interconnected themes: energy, geography and development; global change in aridlands; and soil ecology and biogeochemistry. She earned her Ph.D. in Environmental Earth System Science at Standford University in 2014 and her M.S. in Biology at California State University, Fullerton in 2009.

Giovanna Hesley
Agricultural & Biosystems Engineering
University of Arizona

Gerardo Hiriart le Bert, Ph.D.
Invited Researcher, Engineering Institute (Instituto de Ingeniería)
National University of Mexico (Universidad Nacional Autónoma de México)
In 2005, Dr. Gerardo Hiriart became an Invited Researcher at the Engineering Institute at UNAM, leading a mega-project entitled "Desalination of sea water with renewable energy". He is an alternate Mexican representative at the Executive Committee of the implementing agreement for Ocean Energy Systems at the International Energy Agency (IEA-OES) and a representative of the Institute of Engineering of UNAM at the World Energy Commission. He received his Ph.D. and M.S. in Mechanical Engineering.

William Holmgren, Ph.D.
Post Doctoral Research Associate, Department of Atmospheric Sciences
University of Arizona
Dr. William Holmgren is a post-doc in the Department of Physics at the University of Arizona. His research interests include technologies that enable high penetrations of renewable power on utility grids, relationships between weather prediction and energy use and generation, and energy policies from local to international scales to encourage reliable, low-cost clean energy.

Kerry Howe, Ph.D.
Associate Professor, Civil Engineering Department
University of New Mexico
Kerry Howe is an associate professor in the Civil Engineering Department at UNM. His areas of specialty include environmental engineering, physical and chemical processes for water and waste treatment, desalination, membrane processes for environmental treatment (including microfiltration, ultrafiltration, nanofiltration, and reverse osmosis), water chemistry, and engineering design. Current research projects are

investigating the use of membranes in water and wastewater applications, including the fouling of reverse osmosis membrane when used for tertiary wastewater treatment for indirect potable reuse applications, selective recovery and beneficial use of salts and minerals from desalination concentrate, increasing the recovery of reverse osmosis by minimizing scaling, removal of fluoride from groundwater using aluminum coagulation and membrane filtration, and removal of pharmaceuticals during tertiary wastewater treatment using either reverse osmosis or ozone/biofiltration

Keith Hutchenson
Senior Research Fellow, Central Research & Development
DuPont Company

Jani Ingram, Ph.D.
Professor of Analytical Chemistry
Northern Arizona University
With NAU since 2002, Professor Jani Ingram researches solutions for cancer disparities among Native Americans while teaching the next generation of researchers who can, in turn, boost the health of their home communities. A tribal member herself, Ingram's research addresses how environmental exposure of uranium on Navajo communities affects drinking water and dust, as well as how uranium may work as a carcinogen.

Kathy Jacobs
Director, Center for Climate Adaptation Science and Solutions
Professor, Department of Soil, Water and Environmental Science
University of Arizona
Katharine Jacobs is Director of the Center for Climate Adaptation Science and Solutions (CCASS) at the University of Arizona, in the Institute of the Environment, which was established in 2014. From January 2010 to December 2013, Jacobs worked in Washington DC at the Office of Science and Technology Policy, where she directed the third National Climate Assessment and served as the Assistant Director of OSTP for Climate Assessment and Adaptation and as lead water advisor to the President's Science Advisor. She is also a professor in the University of Arizona Department of Soil, Water and Environmental Science at the University of Arizona and a joint professor in Hydrology and Water Resources.

Murat Kacira, Ph.D.
Associate Professor of Agricultural & Biosystems Engineering
University of Arizona
Murat Kacira received his B.S. degree in Agricultural Engineering from Cukurova University, Adana, Turkey in 1991. He received both his M.S. (1996) and PhD (2000) degrees in Food, Agricultural and Biological Engineering from The Ohio State University, Columbus, Ohio. His research has involved the areas of greenhouse and plant energy balance studies, plant growth and health monitoring using image processing and machine vision applications, design and development of continuous plant monitoring systems, automated data acquisition and instrumentation, optimization of greenhouse natural ventilation using computational fluid dynamics applications. Dr. Kacira joined Agricultural and Biosystems Engineering faculty at University of Arizona in October 2007.

Dale Keairns, Ph.D.
Executive Advisor
Booz | Allen | Hamilton
Dr. Keairns is an executive advisor at Booz Allen Hamilton. He has over 40 years experience in industry, consulting, teaching and service through professional society initiatives. In the last ten years he has focused on energy systems analysis and planning activities to guide technology R&D needs; supporting energy research programs; management of strategic energy projects; and supporting development of technology roadmaps for future energy systems.

Carey W. King, Ph.D.
Assistant Director, Energy Institute
Research Associate, Center for International Energy and Environmental Policy

University of Texas, Austin
Dr. Carey W King performs interdisciplinary research related to how energy systems interact within the economy and environment as well as how our policy and social systems can make decisions and tradeoffs among these often competing factors. The past performance of our energy systems is no guarantee of future returns, yet we must understand the development of past energy systems. Carey's research goals center on rigorous interpretations of the past to determine the most probable future energy pathways.

Michelle Kostuk
Graduate Student, School of Journalism
Environmental Communications Intern, UA Renewable Energy Network
University of Arizona

Raymond Kostuk, Ph.D.
Joint Professor of Electrical and Computer Engineering; Optical Sciences
University of Arizona
Raymond Kostuk leads the Photonics Systems Lab, where the primary goal is to investigate and demonstrate photonic concepts that allow new capability for medical imaging, solar energy conversion, optical communications, and sensing applications. The core technology of his group is holography and holographic optical elements. His group's research involves theoretical investigation of new optical techniques, experimental demonstration of new concepts, and development of instruments and systems using new optical capabilities.

Col. Patrick T. Kumashiro
Commander, 309th Aerospace Maintenance and Regeneration Group
Davis-Monthan Air Force Base
US Department of Defense
Col. Patrick T. Kumashiro is the Commander of the 309th Aerospace Maintenance and Regeneration Group (309 AMARG), Davis-Monthan Air Force Base, Arizona. He leads an 800-person workforce dedicated to aerospace storage and preservation, aircraft parts reclamation, aircraft regeneration, depot-level maintenance overflow, and aircraft disposal in support of the Department of Defense and other government agencies including NASA and the Department of Homeland Security. The group encompasses 2,600 acres, providing secure storage for 4,000 aircraft, strategic missiles, and production tooling valued at $31 billion. Colonel Kumashiro directs financial activities for an annual operating budget of approximately $122 million in both operations and maintenance (O&M) and the depot maintenance activity group (DMAG).

Lloyd LaComb Jr., Ph.D.
Research Professor of Optical Sciences
University of Arizona
Dr. LaComb graduated from Stanford University in 1989 with a Ph.D. in Applied Physics where he developed acoustic and atomic force microscopes. His recent research focuses on novel laser systems, holographic imaging systems, and holographic elements for near-to-eye displays and solar collections systems. During most of his career, he managed teams of scientists and engineers developing commercial high precision imaging and metrology products for the semiconductor, medical and research markets. He has managed over 15 product development programs that have resulted in commercially successful products generating over $1B in revenue. Later in his career, he transitioned to general management and led a multi-site domestic and international organization developing new atomic force and interferometric metrology products.

Kevin E. Lansey, Ph.D.
Department Head, Hydraulics & Hydrology
Department of Civil Engineering and Engineering Mechanics
University of Arizona
Kevin E. Lansey is a Professor in the Department of Civil Engineering and Engineering Mechanics and an adjunct faculty in the Department of Hydrology and Water Resources at the University of Arizona. Dr.

Lansey has conducted research on a range of water resources problems with emphasis on water distribution and systems analysis. This work has resulted in over 100 publications and based on his contributions he was awarded the ASCE Huber Civil Engineering Research Prize for Young Researchers in 2002. For five years, he served as Associate Editor for the ASCE Journal of Water Resources Planning and Management including working as co-editor on the special issue on Water Distribution Systems. Dr. Lansey has been recognized with three teaching awards.

Ron S. Lee
District Director
Office of U.S. Representative Ann Kirkpatrick
Lee has 14 years of professional experience in public affairs, government and tribal relations, public policy and administration. An independent consultant for 8 years in government relations and legislative affairs, he represented clients in K-12 and higher education, telecommunications, healthcare, economic development and cultural issues. Lee was executive director of the Arizona Commission of Indian Affairs for six years and worked on communications and relations with Arizona's 22 Indian tribes and nations. He is a member of the Navajo Nation.

Peiwen (Perry) Li, Ph.D.
Associate Professor, Aerospace & Mechanical Engineering
Director, Energy and Fuel Cell Laboratory
University of Arizona
Dr. Li is the Director of the Energy and Fuel Cell Laboratory at the University of Arizona, which studies the composition, properties and costs of new molten-salt-based HTFs. He is also an Associate Professor in the Department of Aerospace and Mechanical Engineering.

Bob Lotts
Water Resource Manager
Arizona Public Service Company
Bob Lotts joined APS at the Palo Verde Water Reclamation Facility (WRF) in June 1982. During the next two years the WRF completed the facility's start-up activities and went operational, producing 90 million gallons per day of cooling water for the nation's largest nuclear power plant. During his more than 26 years at the Palo Verde WRF, Bob held various positions including serving as Plant Manager from 2002 to early 2009. In light of the continuing issues within the electric utility industry regarding water needs and power generation, APS created Water Resource Management Department. Lotts assumed the role as the manager of this newly formed department in March 2009.

Jordan Macknick
Energy and Environmental Analyst
National Renewable Energy Laboratory
Jordan Macknick is an Energy and Environmental Analyst in the Strategic Energy Analysis Center at the National Renewable Energy Laboratory (NREL). His primary work addresses the environmental impacts of electricity generating technologies, with a particular focus on issues related to the energy-water nexus. In his capacity in the Energy Forecasting and Modeling group at NREL, he analyzes national and regional implications of different electricity scenarios. He holds a bachelor's degree in Mathematics and Environmental Studies from Hamline University and a Master's of Environmental Science from the School of Forestry and Environmental Studies at Yale University

Ann McGuigan, Ph.D.
Director, Research Development Services, Office for Research & Discovery
University of Arizona
Ann McGuigan is Director of Research Development Services. She has Ph.D. in Educational Psychology from Washington State University with expertise in program evaluation and assessment in higher education. She has over 25 years experience in research development and senior level research administration. Ann has built research development offices at three major research universities including overseeing development of successful large, complex proposals, limited solicitations programs, and faculty development programs. She also has extensive experience convening faculty groups and has led initiatives to identify and profile institutional capabilities for outreach to external constituents. Prior to coming to the

UA, she was Assistant Vice President for Research Development at Texas A&M University. She is a founding member, board member, and past president of the National Organization of Research Development Professionals (NORDP) and currently serves as chair of the NORDP Member Services Committee.

Casey McKeon
Environmental Manager
Resolution Copper Mining
Casey McKeon is Resolution Copper's Environmental Manager, responsible for securing and maintaining local, state and federal permits; managing the reclamation of the Superior site; and implementing a monitoring program to support the dewatering project, which reclaims water in the mine for beneficial agricultural use. Casey is also accountable for implementing the company's global environmental standards and managing Resolution Copper's ISO 14001-compliant Environmental Management System.

Gregory McNamee
Adjunct Lecturer in Economics
University of Arizona
Gregory McNamee is a research associate at the Southwest Center of the University of Arizona and a lecturer in the Economics Department of the Eller College of Management there. He is a ghostwriter for several business blogs maintained by national consumer and interest groups, and he is a behind-the-scenes consultant to numerous nonprofit organizations and private firms. He is a member of the Speakers Bureau of the Arizona Humanities Council, and he also gives courses and talks on writing, publishing, journalism, media and technology, and cultural and environmental issues.

Oliver Monti, Ph.D.
Associate Professor, Department of Chemistry and Biochemistry
University of Arizona
Oliver Monti is a graduate of ETH Zurich in Switzerland (1997) and pursued his Ph.D. as a Greendale Senior Scholar at Merton College at the University of Oxford (UK) from 1998 to 2000. From 2001 to 2004 he was a Swiss NSF Post-doc at JILA in Boulder Colorado. Since 2004 he has been a faculty member at The University of Arizona. His research interests include organic solar cells, surface physics, organic semiconductors, interfaces, ultrafast surface dynamics, steady-state and time-resolved core-level spectroscopies, and thermoelectrics.

Daniel Moseke
Program Manager
UA Renewable Energy Network
Daniel Moseke joined the Renewable Energy Network (UA REN) in 2014. As Program Manager he manages education and outreach programs for REN, including the administration of the public website and mobile apps; Student Energy Groups; and REN events such as the annual Arizona Student Energy Conference, in collaboration with LightWorks at ASU and the Institute for Sustainable Energy Solutions at NAU. Dan has worked for The University of Arizona in myriad capacities and such diverse departments as Parking and Transportation, UApresents, and Chemistry & Biochemistry. Before joining UA REN, Dan was the Program Coordinator for the Center for Interface Science: Solar Electric Materials (CISSEM), a US Department of Energy funded Energy Frontier Research Center. At CISSEM, he planned and managed an annual research conference and coordinated the Center's web site and travel programs, and provided administrative support for several faculty research groups. Dan has also worked for the University of Virginia in the office of the Provost and Vice President for Research, as well as the Dean's Office of the McIntire School of Commerce. He is pursuing an MS degree in Global Technology and Development.

Kelly Mott LaCroix
Senior Research Analyst
Water Research and Planning Innovations for Dryland Systems (RAPIDS) Program
Water Resources Research Center
Kelly Mott Lacroix is a Senior Research Analyst for the WRRC's Water Research and Planning Innovations for Dryland Systems (RAPIDS) program. She has a Ph.D. in Arid Lands Resource Sciences

and a M.S. in Environmental and Healthy Cities Planning from the University of Arizona. Prior to returning to graduate school for her Ph.D., she worked for five years as a key member of the Arizona Department of Water Resources' (ADWR) Arizona Water Atlas project. She has also worked with rural water providers in Arizona as the manager of ADWR's Community Water System Program and with diverse interests from across the state as a constituent services liaison for the Arizona State Senate. She is a Morris K. Udall Scholar, and has won a Central Arizona Project award for water research, the Arizona Water Association Fresh Ideas competition, Arizona Water Association scholarship, and University of Arizona's Institute for the Environment's top prize for a research presentation at their annual Grad Blitz.

Len Necefer
Ph.D. Candidate, Department of Engineering and Public Policy
Carnegie Mellon University
Len is an EPA STAR Fellow and Doctoral Student in Carnegie Mellon University's Engineering and Public Policy Department. After graduating from the University of Kansas in Mechanical Engineering, Len participated in aerospace research at the NASA Glenn Research Center in Cleveland, Ohio. These research areas included development of ceramic material models and supersonic vehicle control systems. A member of the Navajo Nation, Len has now focused his research and career on issues facing indigenous people in North America, which include the development of rainwater catchment systems for agricultural purposes and currently the development of a decision support framework for energy policy development.

Deborah Newby, Ph.D.
Senior Staff Scientist
Idaho National Laboratory
Dr. Newby's research foci and expertise span a broad range of areas including: development of nucleic acid diagnostics for Brucella; nonaqueous biocatalysis for value-added chemical production, the molecular characterization of methanotrophic bacteria, development of molecular detection approaches (real-time PCR assays and microarrays) for specific groups of microorganisms including thermophilic and acidophilic bacteria and Archaea (basic science - diversity of thermophiles in Yellowstone National Park hotsprings and applied science - use of these extremophiles to improve biomining of Cu, and production of ethanol from lignocellulosics); as well as the evaluation of hydrogenic activity of thermophilic carboxydotrophs. In addition, she is the algae biofuels program lead at the Mountain West Water Institute.

Melynda Noble
Assistant to Jennifer Barton, Neal Armstrong, Brian Liesveld
University of Arizona

Jonathan Overpeck
Co-Director, Institute of the Environment
University of Arizona
Jonathan Overpeck, or "Peck" as he prefers to be called, is a founding co-director of the Institute of the Environment, as well the Thomas R. Brown Distinguished Professor of Science and a Regents' Professor of Geosciences and Atmospheric Sciences. He received his BA from Hamilton College and earned his MSc and PhD from Brown University.
Peck has published more than 180 papers in climate and the environmental sciences and served as a coordinating lead author for the Nobel Prize-winning UN Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment (2007).

Peck has a strong interest in past, current, and future interactions among climate, ice sheets, and sea level, as well as in interactions between climate and ecosystems. He also collaborates in the area of environmental law. He commits significant time at the interface between science and society, both to help promote understanding of science and help scientists understand broader views, particularly those of decision makers in society who must deal with real-world climate variability and change. In this capacity, he serves as principal investigator of the Climate Assessment for the Southwest Project (CLIMAS), one of the several NOAA Regional Integrated Sciences and Assessment (RISA) programs, and as the lead

university investigator of the Department of the Interior's Southwest Climate Science Center. Peck is also supported by the U.S. Department of Defense to work with their decision makers on issues related to climate variability and change and is the lead-PI of a large collaborative U.S. National Science Foundation project focused on global drought, how well we simulate drought with Earth System models, and how information about drought can be optimized for use in society.

Kim Patten
Research Development Associate, Office for Research & Discovery
University of Arizona
Kim Patten is a Research Development Associate, specializing in Environmental & Data Sciences, at the University of Arizona. She has an M.S. in Planning from the UA and brings 10 years of experience managing projects and programs in conservation, renewable energy, and distributed data systems both nationally and internationally. Most recently she was Assistant Director for Strategic Operations at the Arizona Geological Survey and brings experience managing and conducting research on a more than $30m portfolio, including coPI on a $3.6m National Science Foundation funded project and project manager of a $22m U.S. Department of Energy funded project.

Jeanne Pemberton, Ph.D.
Regents' Professor of Analytical Chemistry
University of Arizona
Dr. Pemberton's group research at the University of Arizona seeks to develop an understanding of chemistry in several technologically important areas including electrochemistry and electrochemically-related devices, chromatography, self-assembled monolayers, surfactant systems, and environmental and atmospheric systems. Methodologies employed for these efforts include surface vibrational spectroscopies, near-field optical methods, electrochemistry, x-ray photoelectron spectroscopy, Auger electron spectroscopy, LEED, work function measurements, ellipsometry, electron microscopy, and the scanning probe microscopies AFM and STM. Molecular nanoscale imaging exists prominently in the ability to elucidate structural and mechanistic details of surface and interfacial chemistry.

Asia Philbin
Resource Coordinator, Utilities Department
Town of Marana
Asia Philbin is the Resource Coordinator for the Town of Marana Utilities Department, a municipal water and wastewater provider serving approximately 15,000 people. Prior to the starting her position with Marana in March 2014, she worked as a hydrologist for Tucson Water, where she assisted in the planning, analysis, and tracking of Tucson Water's water resources and energy portfolios. She currently serves as the Treasurer of the AZ Water Association and holds a Bachelor of Science degree from the University of Miami in Marine Science and Geology, with a Biology minor.

Mary Poulton, Ph.D.
Director, Lowell Institute for Mineral Resources
University of Arizona
Dr. Mary Poulton is a University of Arizona Distinguished Professor, Head of the Department of Mining and Geological Engineering, and Director of the new interdisciplinary Institute for Mineral Resources at the University of Arizona. She is the first woman to head an engineering department at the University of Arizona. She received her Ph.D. in geological engineering from the UA in 1990. Dr. Poulton has published numerous journal articles and conference papers on the application of computational neural networks to pattern recognition problems in the earth sciences, including geophysics, mining, mineral and petroleum exploration, hydrology, and atmospheric science. She is the author of a book on the use of neural networks for geophysical data analysis. Dr. Poulton had led or participated in research projects totaling over $21 million in funding. She is co-founder and vice president of a water and energy management company, NOAH, LLC. She recently completed two terms as chair of the Mine Safety Research Advisory Committee for NIOSH and chaired the Board on Natural Resources for NASULGC. Dr. Poulton was appointed to serve on three National Research Council Committees including co-authoring the 2007 report on critical minerals. Dr. Poulton has testified before the U.S. Congress on workforce issues in mining and petroleum engineering and helped develop the Energy and Mineral Schools Reinvestment Act which is pending in the

U.S. Senate. She is the 2009 recipient of the American Institute of Mining, Metallurgical, and Petroleum Engineering Industry Educator Award and the 2009 recipient of the Mining Hall of Fame Medal of Merit.

Jeffrey Pyun, Ph.D.
Associate Professor
Department of Chemistry & Biochemistry
University of Arizona
Jeffrey Pyun is an Associate Professor in the Department of Chemistry and Biochemistry at the University of Arizona. He leads a research group, which is focused on the synthesis and characterization of novel polymeric and composite materials, with an emphasis on the control of nanoscale structure. Recent developments in polymer and colloid chemistry offer the synthetic chemist a wide range of tools to prepare well-defined, highly functional building blocks. His team seeks to synthesize complex materials from a "bottom up" approach via the organization of molecules, polymers and nanoparticles into ordered assemblies.

Erin Ratcliff, Ph.D.
Assistant Professor
Department of Materials Science and Engineering
University of Arizona
Erin Ratcliff is an Assistant Professor in the Department of Materials Science and Engineering at the University of Arizona. She leads the Ratcliff lab, whose primary objective is to understand how the control of matter on the atomic/molecular scale via synthesis and processing impact bulk and interfacial structure, chemical composition, energetics, dynamics, and ultimately, the functionality of thin films when incorporated within applied systems. In order to accomplish this goal, her lab utilizes a fusion of fundamental aspects of engineering, material science, chemistry, and physics in both applied and basic science, with a focus on combining a molecular level perspective with a multidisciplinary and advanced measurement techniques approach.

Ysabella Rongo
Student Intern
Raytheon Missile Systems

Benjamin Ruddell
Senior Sustainability Scientist, Julie Ann Wrigley Global Institute of Sustainability
Assistant Professor, Department of Engineering and Computing Systems
Arizona State University
Dr. Ruddell is originally from Rockford, a small town in beautiful, wet, and cold West Michigan. In addition to Arizona, he has also lived in Alaska, Massachusetts, Jordan, India, Colorado, Illinois, and Georgia. Some of his extracurricular interests include aviation, conservation, sports (including adaptive sports for the physically disabled), hiking, kayaking, mountaineering, building alternative water and energy systems, architecture, and the study of history, philosophy, and religion. He has volunteered with The Nature Conservancy, Engineering Ministries International, and a variety of nonprofit charitable organizations. He is an active member of the American Society of Civil Engineers (ASCE) and the American Geophysical Union (AGU). Dr. Ruddell's research interests fall under the umbrella of Complex Systems, which are a special class of multi-dimensional systems that are resistant to traditional methods of modeling and analysis due to their nonlinear, multiscalar, and feedback-based properties.

Valentín Ruiz Santa Quiteria, Ph.D.
Technology Director of New Energy
REPSOL
Dr. Valentín Ruiz Santa Quiteria is the Technology Director of New Energy for the REPSOL Technology Division, with responsibility in bioenergy activities, CO_2 technologies, renewable power generation and electric mobility. His professional activity has been developed in REPSOL Technology for more than twenty years, in which he has led and coordinated projects related to new product and chemical processes development. He has also been responsible for the area of watching for prospective and technology. He has

a Ph.D. in Chemistry from the Universidad Complutense in Madrid, Spain, and graduated in Management and Business Administration by the I.E.S.E and Technical and Production Management by the I.D.E.-CESEM. He is co-author of scientific articles, patents and chapter books related to his activities in technology.

Garry Rumbles
Research Fellow
National Renewable Energy Laboratories
Dr. Garry Rumbles is a Research Fellow at the National Renewable Energy Laboratory (NREL). He joined NREL in 2000 and is widely recognized for his research in photochemistry and photophysics of conjugated molecular systems, energy conversion in organic light emitting diodes and organic photovoltaic devices, and nanoscale morphology. Dr. Rumbles' current research interests are in solar energy with a focus on the basic science of solar photoconversion processes and photoinduced electron transfer processes in polymer-based nanostructured interfaces. His primary research expertise lies in photochemistry and photophysics, with a specialty in kinetics.

Madeline Ryder
Research Specialist
UA Renewable Energy Network

Phil Sadler
CEO
Sadler Machine Company
Phil Sadler is the CEO of Sadler Machine Co. and maintains a small prototype fabrication shop in Tempe, Arizona where he designs and constructs hydroponic growing systems. Sadler of Sadler Machine Co. in cooperation with the UA-CEAC has designed and fabricated the UA/SMC Lunar Greenhouse. The LGH aluminum structure is property of Sadler Machine Co. on loan to the UA-CEAC for demonstration of BLSS efforts.

Christopher A. Scott, Ph.D.
Research Professor of Water Resources Policy
Professor, School of Geography and Development
University of Arizona
Christopher A. Scott is Research Professor of Water Resources Policy at the Udall Center for Studies in Public Policy, with a joint appointment as Professor in the School of Geography and Development. He is also Adjunct Professor in the Department of Hydrology and Water Resources; Department of Soil, Water, and Environmental Science; School of Natural Resources and the Environment; and Arid Lands Resource Sciences Program. His work focuses on the policy dimensions of global change (climate change and urban growth) with particular emphasis on urban wastewater and water reuse, the water-energy nexus, transboundary water resources, agricultural-urban water transfers, and binational U.S.-Mexico climate and water policy.

C. Clinton Sidle
Director, Roy H. Park Leadership Fellows Program
Cornell University
C. Clinton Sidle directs the prestigious Roy H. Park Leadership Fellows Program in the Johnson School of Graduate Management at Cornell University and has developed an award-winning approach for developing leaders who succeed while also making a positive contribution to the world. He is also a top consultant working with Fortune 500 companies and various other organizations in strategic change, leadership, executive coaching, and developing human potential.

Anna Spitz, Ph.D.
Director, Agense Nelms Haury Program in Environment and Social Justice
University of Arizona

Anna H. Spitz directs the Agense Nelms Haury Program in Environment and Social Justice. This program supports faculty chairs, visiting fellowships, student scholarships, conferences, an international prize, lectures and events, and collaborative research through a bequest from Mrs. Haury. These programs honor Mrs. Haury's life-long work by supporting individuals and activities that seek to understand and communicate the challenges facing society in a world at great risk from environmental change and loss of natural and cultural diversity to mitigate and reverse these trends. Prior to her appointment to the Institute of the Environment in 2014, Anna led education and public engagement for the OSIRIS-REx asteroid sample return mission at the University of Arizona (UA). She began employment at UA in 2000 at the Steward Observatory and worked on various projects including the Mt. Graham Observatory, the Large Binocular Telescope, the Large Optics Test and Integration Site, and Biosphere 2. She also served as the UA's Campus Coordinator for the Arizona Water Institute (AWI), the Program Manager/Managing Director of the Center for Astrobiology, and prior to joining the OSIRIS-REx mission as Education and Public Outreach Lead she was Director of Mt. Lemmon SkyCenter from 2009 to 2011. Anna worked in the environmental field for over a decade before joining Steward Observatory. She has continued to serve on local boards of non-profits and to participate in research and consulting in the environmental field as well as freelance writing activities during her years at UA. Along with Chris Impey and Bill Stoeger, she is the editor of Encountering Life in the Universe: Ethical Foundations and Social Implications of Astrobiology published in Fall 2013 by University of Arizona Press.

Robert Webber, Ph.D.
Catalysis Scientist
Pacific Northwest National Laboratories
In the Institute for Integrated Catalysis at Pacific Northwest National Laboratory, Dr. Weber leads research activities in heterogeneous catalysis. Through more than 20 years of experience with leading academic institutions, international chemical companies, governmental agencies, and consulting firms he has assisted in: developing and deploying multiscale tools for understanding and exploiting catalytic processes; connecting business strategy and planning, by evaluating the feasibility and commercial potential of emerging technologies, quantified, through detailed techno-economic models; managing and directing applied research programs to accelerate the impact and value of R&D projects and portfolios in chemical processing, fuel processing, reactor engineering and catalysis; and explaining technology issues and trends to investors, management, and the public.

Richard Wiener, Ph.D.
Program Director
Research Corporation for Science Advancement
Dr. Wiener completed a BA in philosophy at the University of California, Berkeley, in 1978 and a Ph.D. in physics at the University of Oregon under the direction of London Prize Laureate Russell Donnelly in 1991. His research interests center on nonlinear pattern formation with an emphasis on chaotic patterns in fluid flows. Recently, he has been working on the application of nonlinear dynamical models to the production of energy resources, social group competition, and conference-mediated growth of collaboration networks.

Derrick Wu
Technical Product Associate
American Institute of Chemical Engineers
Derrick Wu is a Technical Product Associate at the American Institute of Chemical Engineers and earned his Bachelor of Science in Chemical Engineering at Cornell University.

Austin Yamada
Director, Defense and Security Research Institute
University of Arizona
Austin Yamada is a senior executive with more than 36 years in national security in government, industry and academia. He currently directs the Defense and Security Research Institute at the University of Arizona and has worked at the Virginia Tech Applied Research Corporation, QinetiQ North America, ManTech and Lockheed Martin, among other appointments. He earned an M.E. in Analytical Photogrammetry and Remote Sensing at Virginia Polytechnic Institute and State University.

Douglas M. Young, Ph.D.
National Risk Management Research Laboratory
US Environmental Protection Agency

Claire Zucker
Director, Sustainable Environment Program
Pima Association of Governments
Claire Zucker directs the Sustainable Environment Program at the Pima Association of Governments. The program combines watershed and air quality planning with travel demand management to create an integrated and cohesive group poised to work with sustainability efforts throughout the region. The goal for the program is to become a resource for member jurisdictions in support of the long-term environmental, economic and social vitality of our community.

BREAKOUT SESSIONS

8:30 AM Session 1: Systems Level Energy, Water, and Food – Sahara Room

Session Lead - Kim Ogden, Professor Environmental and Chemical Engineering, University of Arizona

To assure an adequate and safe supply of clean water, energy, and food as demand for all three continues to increase, it is critical to understand the interrelationships between producing energy, water and food. This session will focus on a systems analysis approach and will include defining the technology gaps associated with optimization and control of systems, as well as techno-economic modeling and understanding the important social and policy implications of systems integration. On the unit operations level, specific areas for discussion include: i) low energy water and waste water unit operations; ii) water reuse and recycling (focus on trace contaminant build up in systems, methods to detect, remove, or react trace contaminants away, and energy optimization); iii) waste heat and alternative energy methodologies for water and wastewater purification; iv) recovery of byproducts (metals, fertilizer) from aqueous waste and v) scale-up and validation of new technologies developed.

Questions for Session 1

i) Low water use in energy fuel and power production.

- Moderators – **Ardeth Barnhart**, Program Director, UA REN and **Madeline Ryder**, Research Specialist, UAGIST/REN

1) *What are the scientific, technological and policy-related gaps that need to be addressed to catalyze a shift in energy production technologies to lower water intensive uses?*
   - *What are the analytical tools and data models required?*
   - *How do questions of scale play a role in efficient use of energy and water?*

ii) Low energy in clean water and food production unit operations.

- Moderators – **Parker Antin**, Ph.D., Associate Dean for Research, UA CALS and **Giovanna Hesley**, UA Agricultural & Biosystems Engineering

1) *What are the technological and social/policy gaps associated with optimization of energy use for clean water production?*
   - *In water use for food production?*
   - *What are the analytical tools and data models required to support optimization in these areas?*

iii) Water reuse and recycling (focus on trace contaminant build up in systems and methods to detect, remove, or react these away as well as energy optimization).

- Moderators – **Claire Zucker**, Sustainable Environment Program Director, Pima Association of Governments and **Kelly Mott – LaCroix**, Ph.D., Senior Research Analyst at the UA Water Resources Research Center (WRRC)

1) *At a systems level what are the fundamental technology gaps as well as modeling, social, and policy challenges for water recycle and reuse?*

iv) Waste heat and alternative energy methodologies for water and wastewater purification.

- Moderators – **Ann McGuigan**, Ph.D. Director of UA Research Development Services and **Andrea Corral**, Ph.D. University of New Mexico

1) *What are the fundamental challenges we face in capture and re-use of waste heat, from a variety of energy transduction (CPV, thermal) and production sources, for water purification, food production?*
   - *What are the economic questions that need to be addressed to recognize benefits in technology development in this area?*

v) Recovery of byproducts (metals, fertilizer) from aqueous waste.

- Moderators – **Mary Poulton**, Ph.D., UA Professor, Mining and Geological Engineering, and Director, Institute for Mineral Resources and **Kim Patten**, UA Research Development Services

1) *What are the fundamental challenges we face in recovery of byproducts from aqueous waste, generated during energy and food production, and mining operations as well as the unique aspects associated with systems integration?*
   - *What are the policy and economic considerations that will promote recovery of byproducts?*

vi) Scale-up and validation of new technologies.

- Moderators – **Kathy Jacobs**, Director, UA Center for Climate Adaptation Science and Solutions and **Kat Compton**, UA Department of Geosciences

1) *What are the anticipated technological, social, and economic challenges we may face in validation of new methodologies, and integration with existing systems?*
   - *What are societal implications, and socio-economic and policy implications of solving/not-solving these problems?*

2:00 pm Session 2: Food Systems and Productivity – Sahara Room

Session Lead: **Parker Antin**, Ph.D., Associate Dean for Research, College of Agriculture and Life Sciences, University of Arizona

Food systems productivity is influenced by the availability and input of energy and water, modulated by the climate, and limited by the availability of real-time operational data. Sustainable food production will require a better understanding of the relationship between these parameters and advances in agricultural technologies. Promising technologies include Precision Agriculture (PA) in open field environments, and Controlled Environment (CE) practices such as greenhouse systems. PA utilizes seasonal forecast models of historical data from sensor networks for projecting future outcomes, as well as real-time information through remote sensing technologies for determining resource inputs (water, nutrients, pest control) in food production. CE practices can reduce or eliminate the climate variability in food production of high-dollar-value vegetable crops, offer safety and security of product, and through control of the plant's aerial and root-zone environments, offer means for corrective action to realize maximum crop genetic potential, efficiency, resource recycling and savings.

Through development of advanced sensor technologies, early warning of plant anomalies in open field PA and CE environments can be obtained even before that of an experienced grower, thus improving production practices, increasing yields, and saving resources. Climate, weather, and hydrological models support decisions regarding which crops to grow, when and how much to water, and how to maximize the use of renewable energy in food production. As the food value chain becomes stressed due to changes in energy, water and climate, PA and CE practices will become increasingly critical for optimizing the genetic potential of crops and maintaining the global food supply.

Questions for Session 2

I. Topic Area 1

- Moderators. **Parker Antin**, Ph.D., Associate Dean for Research, UA CALS and **Giovanna Hesley,** UA Agricultural & Biosystems Engineering

1) *What are the challenges in understanding how food production systems are impacted by changes in the quality and availability of water and energy?*
2) *What role does climate variability play in food production now and at various times in the future?*
3) *What operational data is needed to better understand the interaction between these variables?*

II. Topic Area 2

- Moderators – **Mary Poulton**, Ph.D., UA Professor, Mining and Geological Engineering, and Director, Institute for Mineral Resources and **Kim Patten**, UA Research Development Services

1) *Climate variability introduces risks and uncertainty in the ability to adequately produce food for a growing population. Which agricultural production practices (e.g. precision agriculture, greenhouse systems, etc.) reduce that vulnerability?*
2) *What other methods increase safety and security in food production systems?*

III. Topic Area 3

- Moderators – **Ann McGuigan**, Ph.D. Director of UA Research Development Services and **Andrea Corral**, Ph.D. University of New Mexico

1) *What methods and analytic tools are needed to maximize the genetic potential of crops for more efficient production, increased yields, resource recycling and savings?*
2) *What methods associated with precision agriculture are needed to maximize crop potential?*
3) *What kinds of data are needed to maximize efficient production and sustainable crop yields?*

IV. Topic Area 4

- Moderators – **Claire Zucker**, Sustainable Environment Program Director, Pima Association of Governments and **Kelly Mott – LaCroix**, Ph.D., Senior Research Analyst at the UA Water Resources Research Center (WRRC)

1) *What key points in the food value chain (the goods and services necessary for an agricultural product to move from the farm to the final customer or consumer) are at highest risk and therefore require advanced technological solutions?*

V. Topic Area 5

- Moderators – **Elizabeth Eide**, director of the Board on Earth Sciences and Resources at the National Research Council (NRC) and **Madeline Ryder,** UAGIST/REN

1) *What are the infrastructure challenges and opportunities in ensuring future scalability for agriculture, energy and water systems?*

VI. Topic Area 6

- Moderators – **Kathy Jacobs**, Director, UA Center for Climate Adaptation Science and Solutions and **Michael Liao**, UA Department of Chemistry and Biochemistry

1) *What are the unique challenges facing developed countries for integrating water, energy, and food production, and in areas that have rapidly growing populations?*
2) *What are the economic/policy frameworks and goals for scalable results?*

Friday, April 17, 2015

8:00AM Session 3: Integrating Basic Science and Energy, Water, Food Systems – Sahara Room

Scalable and affordable energy conversion such as solar electric and solar fuels and energy storage technologies that can easily be integrated with water re-use, water purification, and precision agriculture, are only now beginning to emerge. These new technologies, when coupled with arrays of networked sensor platforms, have the potential to optimize energy flow, water consumption, nutrient use and minimization of contamination and waste. They will become a reality only with the an enhanced understanding and control of matter at nanometer, mesoscopic and macroscopic length scales, and dark and photo-induced charge transfer. Optimized water purification will arise with materials that effect separation across phase boundaries with minimal energy inputs. Large scale deployment of tailored solar energy conversion and energy storage requires new materials, and new processing approaches that enable costs well below $1/watt, and deployment in environments where conventional energy sources cannot operate (e.g. integration into greenhouse walls). Ensuring secure and efficient use and storage of water, energy and agricultural products ("precision living") requires networked sensor arrays on heretofore unheard of scales that provide both sensitivity and selectivity toward a large array of potential contaminants and desired products, energy input/outflow and a responsiveness toward rapidly changing environmental conditions.

- Session Lead: **Neal Armstrong, Ph.D.,** Associate Vice-President for Research and Regents Professor of Chemistry and Biochemistry, University of Arizona

I. Topic Area 1

- Moderators – **Ardeth Barnhart**, Program Director, UA REN and **Madeline Ryder**, Research Specialist, UAGIST/REN

1) *What are the challenges/opportunities in developing **membrane materials and technologies** that separate contaminants from water (membranes, etc.) – and that are massively scalable and economic?*
2) *What are the economic/policy frameworks and goals for scalable results?*
3) *What are the implications for social benefit and acceptance?*

II. Topic Area 2

- Moderators – **Mary Poulton**, Ph.D., UA Professor, Mining and Geological Engineering, and Director, Institute for Mineral Resources and **Jimmy Stanfill**, UA Department of Chemistry and Biochemistry

1) *What are the challenges/opportunities in developing **molecular materials** that sequester contaminants and other recoverable (high/low value) products in soil and water (heavy metal sequestration, carbon sequestration, algae)*
    a. *What are the economic/policy frameworks and goals for scalable results?*
    b. *What are the implications for social benefit and acceptance?*

III. Topic Area 3

- Moderators – **Jeanne Pemberton**, Ph.D., Regents' Professor in the Chemistry and Biochemistry Department and **Andrea Corral**, Ph.D. University of New Mexico

1) *What are the challenges/opportunities in developing massively scalable **photoelectrochemical materials and processes** that couple contaminate remediation with formation of "solar fuels" or other value-added products?*
    a. *What are the economic/policy frameworks and goals for scalable results?*
    b. *What are the implications for social benefit and acceptance?*

IV. Topic Area 4

- Moderators – **Elizabeth Eide**, Ph.D., Director of the Board on Earth Sciences and Resources at the National Research Council (NRC) and **Dan Moseke**, UAREN Program Manager

1) *What advances in **materials and methods of energy conversion, and energy storage** need to take place so that scalable distributed system integration with water re-use, purification and agriculture is feasible?*
    a. *What are the economic/policy frameworks and goals for scalable results?*
    b. *What are the implications for social benefit and acceptance?*

V. Topic Area 5

- Moderators - **Kelly Mott – LaCroix**, Ph.D., Senior Research Analyst at the UA Water Resources Research Center (WRRC) and **Claire Zucker**, Sustainable Environment Program Director, Pima Association of Governments

1) *What are the challenges/opportunities in **developing new sensors and integrated sensor platforms** that will be required throughout the energy/water/food nexus to monitor energy efficiency, water and food quality, and provide for optimization?*
    a. *How do we ensure scalability of these sensor networks for agricultural production, energy conversion, storage and us, and creation of secure and sustainable supplies of clean water?*
    b. *What are the economic/society implications of implementation of such an extensive sensor network – to provide '**precision living**?"*

VI. Topic Area 6

- Moderators – **Kim Patten,** UA Research Development Services and **Michael Liao**, UA Department of Chemistry and Biochemistry

1) *How do these advances and innovations impact industrial, municipal, rural, local processes and yield in water/energy/food production?*
    a. *Where do efficiencies need to occur?*
    b. *What methods can be utilized to measure efficacy of these proposed scientific and technological breakthroughs in production, distribution, cost and environmental sustainability?*