RESEARCH PLANNING WORKSHOP

COMMUNITY EXPOSURES TO PRODUCED WATER

August 6, 2024
Workshop Summary

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WORKSHOP SUMMARY CONTRIBUTORS

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1. MOTIVATION FOR THE WORKSHOP

Over one trillion gallons of oil and gas wastewater (i.e., produced water) are generated from onshore oil and gas production in the United States annually (ALL Consulting 2022). Typically, produced water is disposed of through injection into deep formation disposal wells. However, some challenges to managing produced water include induced seismicity, limited disposal well capacity, and transportation costs. Furthermore, much of this produced water is generated in arid states, including 38% in Texas and New Mexico alone.

Many state water managers expect to face freshwater shortages over the next decade (EPA 2019). In the Water Reuse Action Plan developed by EPA in 2019, produced water was identified as one of five potential degraded waters to be considered to meet this shortfall. Interest is growing in using produced water in arid, oil-producing areas, as demonstrated by the establishment of produced water consortia in three western states (TX, NM, and CO). These consortia seek to understand how produced water from oil and gas development may alleviate freshwater shortages by using it for a variety of uses, such as crop irrigation, aquifer storage and recharge, and road treatments. States such as Texas are starting to evaluate permit applications for produced water use and have recently issued a framework for pilot study authorization of uses that involve application of produced water to land, (Railroad Commission of Texas 2024).

A key question remains as to whether proposed uses of produced water might present risks to human health. Therefore, the Health Effects Institute's Energy Program (HEI Energy) hosted a Research Planning Workshop to identify gaps in understanding about potential community exposures associated with produced water use outside the oilfield. This report summarizes the workshop and key discussion topics with the goal of informing the HEI Energy Research Committee's deliberations about strategic research planning for 2025-2030. The intention for this discussion was not to reach consensus on any given issue. For this reason, this summary does not necessarily represent the views of workshop participants or their organizations.

2. ABOUT HEI

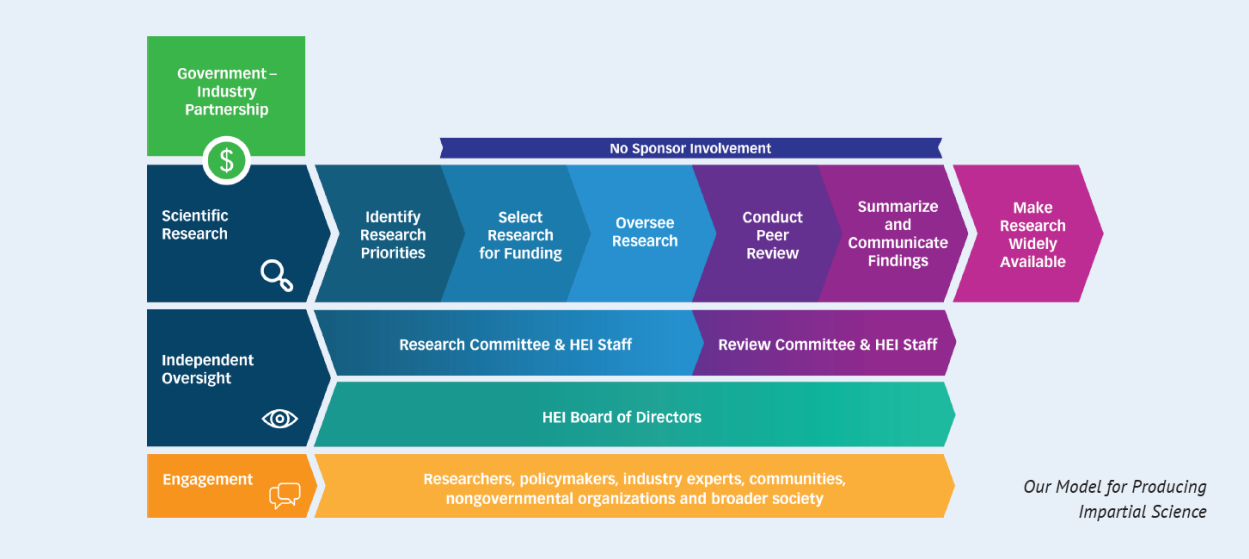
HEI was founded in 1980 as an independent nonprofit organization to address a need for impartial science that informs policy, technology, and other decisions around motor vehicle emissions. Over time, HEI's scope has expanded to meet the needs of our changing world amid evolving technologies, climate change, and the energy transition. HEI now fulfills its mission of informing decisions that foster a healthier environment and better health for all with three programs:

ENVIRONMENT & HEALTH: This is HEI's foundational program. It is focused on tracing air pollution emissions from sources to ambient concentrations to health effects and putting the findings into the context of current science and policy discussions. Launched in 2022 under this program, Community Health & Environmental Research Initiatives (CHERI) focuses on reducing environmental inequities and associated health effects for historically marginalized communities.

ENERGY: This program seeks to improve the understanding of potential community exposures and health effects associated with energy production. HEI's community engagement requirements began with this program, culminating in guidance now used for all HEI-funded research.

GLOBAL INITIATIVES: These initiatives provide science to improve understanding of health effects of air pollution, build local evidence, and strengthen scientific capacity and public awareness worldwide. State of Global Air, the flagship initiative, tracks air pollution exposures and health impacts for countries and cities around the world. Initiatives in South Asia and East Africa synthesize and communicate scientific data tailored to the stage of air quality management in each geography.

To achieve our mission, HEI implements a rigorous model of selecting, overseeing, and reviewing credible science for decision making and public understanding. The model requires oversight and review of research by expert committees that are independent of HEI's sponsors. HEI engages with those who might use or are affected by the research at key intervals. At the same time. HEI refrains from being an advocate for specific policy actions to help ensure the credibility of its work.



Together, HEI's programs are well-aligned to achieve HEI's mission by

FUNDING and supporting policy-relevant scientific research.

CONVENING independent experts to select, oversee, and review scientific research.

BRINGING TOGETHER government, industry, nongovernmental organizations, academia, and communities to help guide research priorities.

SYNTHESIZING, INTERPRETING, AND COMMUNICATING scientific evidence to audiences in the United States and around the world.

ENGAGING with HEI audiences to facilitate and incorporate the use of science in decision-making.

HEI's programs provide a cohesive body of highly credible environmental health research and interpret the research to help guide government and industry actions and inform the broader public about the health effects of pollution. Although all HEI programs work toward achieving our mission, they do so with different but complementary scopes of work. HEI's mission is fulfilled through these coordinated programs that put research findings into the context of current science and policy decisions.

3. WORKSHOP OBJECTIVES AND STRUCTURE

The objective of the workshop was to identify important research needs around potential community exposures associated with produced water management and use outside oil and gas fields in the United States. The workshop provided an opportunity for representatives from industry, academia, government and NGOs to engage and share information and perspectives, and to identify and prioritize research to inform health-protective policy.

3.1 WORKSHOP PLANNING

HEI Energy staff prepared and published a research brief on produced water in December 2023. This brief summarized the literature on potential human exposures to produced water and outlined outstanding research needs to address in the workshop. Concurrently, staff assembled a Special Panel to guide the development of the produced water workshop. The Special Panel included Drs. Alfred (Bill) Eustes, George Hornberger, Isabelle Cozzarelli, and Nathaniel Warner. The Panel met regularly with HEI staff in the months preceding the workshop to discuss potential workshop themes and structure and to identify expert speakers.

Recurring recommendations for the workshop were to have participants who represent multiple sectors, and to allow ample time for small group discussion. Taking this into consideration, HEI Energy assembled an in-person workshop, based around expert panelists and small breakout groups, to facilitate open and active discussion.

Ahead of the workshop HEI staff assembled potentially relevant reports and information on produced water, the individual state consortia, and workshop materials, and provided them via a website.

3.2 WORKSHOP PARTICIPANTS

Speakers and other workshop participants represented sponsor organizations, federal and state government, state produced water consortia, industry, academia, nongovernmental organizations, and HEI Energy's Research Committee and staff. HEI sought the participation of individuals with diverse expertise, experience, and perspectives about produced water and water management. This ensured that the Committee was made aware of relevant ongoing research and concerns of various stakeholders, as they will consider findings from the workshop in finalizing its strategic research planning. Forty-five participants from various sectors (Table 1) attended the workshop.

Table 1. Number of Participants from each Sector at the HEI Energy Produced Water Research Planning Workshop, August 6, 2024.

Sector	Number
Academic institutions	9
Government (State, Federal, and Regional)	14
Industry	8
Non-governmental organizations	3
HEI Energy Research Committee and Workshop Special Panel	6
HEI staff	5
Total	45
Note: Some participants represent more than one sector but are represented only once in this table based on their primary affiliation.	

3.3 WORKSHOP OVERVIEW

The one-day workshop provided the opportunity for participants to discuss the current state of knowledge about produced water, as well as to identify research needs for understanding the potential risks and benefits of its use. The workshop opened with an introduction to the HEI Energy Program, the HEI Energy Research and Review Committees, and the scope of work of HEI Energy by HEI Energy Director Dr. Donna Vorhees. HEI Senior Scientist, Dr. Cloelle Danforth, gave a brief presentation on produced water volumes, disposal practices, and drivers for its use outside the oilfield, including disposal challenges and ongoing and anticipated drought conditions in Western States. Dr. Danforth discussed the complex chemical composition of produced water and how the quantity of water produced from oil and gas wells varies among states.

Next, there were three facilitated panel discussions. The objectives of each panel discussion were as follows:

- Panel 1 – Introduce what is known about produced water, its chemical composition, and treatment options.
- Panel 2 – Present the uses of produced water outside the oilfield that are proposed or underway, particularly to offset the need for fresh water in water-stressed regions of the western United States.
- Panel 3 – Present case studies and general experiences about how constituents of concern found in produced water move in the environment.

Following each panel discussion, workshop participants joined multisector breakout groups to discuss the charge questions associated with each panel topic (Table 2). After reconvening, a representative from each breakout group briefly described discussions that took place in their groups. An anonymized list of these remarks is presented in **Appendix E**.

Table 2. Charge Questions for Breakout Group Discussions That Followed Each Workshop Panel.
Panel 1 • What do we already understand well about produced water composition? • What research is needed to better characterize produced water? • Do these research needs differ by location (e.g., state and basin[1])? Do they differ by anticipated use? • Is research needed on treatment options?
Panel 2 • How might people be exposed to produced water based on anticipated uses and management? • Is research needed to better characterize the fate and transport of produced water treated for a given use in the environment? • Do these research needs differ by location (e.g., state and basin)? Do they differ by anticipated use? • If research proceeds on produced water exposure, how might the community (e.g., ranchers, farmers, and Indigenous communities) be engaged?
Panel 3 • Do you think any of the exposures merit research, and if so, why? • Considering the entirety of the day, what else do you think we need to consider?

4. Overview of Panel Discussions

Panel discussions were moderated by a facilitator and intended to create open discussion among invited speakers relevant to the objective of each panel. During the discussion, speakers engaged in an active and collegial exchange with members of the Energy Research Committee, members of the Workshop Special Panel, and other participants about current and future research into produced water and its challenges and opportunities.

Panel 1. Dr. Hornberger facilitated a panel discussion on produced water quality and treatment. The panelists were selected given their expertise and experience characterizing produced water quality, designing and assessing treatment systems for produced water, and analyzing its toxicity. Members of the panel included:

- Ryan Hall, NGL Energy Partners, Director, Technical Operations
- Dr. Aaron Jubb, Research Chemist with the USGS Geology, Energy & Minerals (GEM) Science Center in Reston, Virginia.
- Dr. Holly Puglis, Research Ecologist with the Columbia Environmental Research Center at USGS
- Dr. James Rosenblum, CO School of Mines, Assistant Research Professor, WE2ST Water Technology Hub

[1] A basin is a "depression in the crust of the Earth, caused by plate tectonic activity and subsidence, in which sediments accumulate…If rich hydrocarbon source rocks occur in combination with appropriate depth and duration of burial, then a petroleum system can develop within the basin. Most basins contain some amount of shale, thus providing opportunities for shale gas exploration and production." Source: https://glossary.slb.com/terms/b/basin.

Panelists discussed the processes and complications around collecting, preserving, and analyzing a representative sample of produced water. They also discussed current approaches being studied to treat produced water, considering various end uses, as well as the methods required to assess the toxicological hazards of untreated and treated produced water. The panelists noted that treatment, characterization, toxicological assessment, and research needs would vary by basin and region.

Panel 2. Dr. Warner facilitated a panel discussion with the executive and research directors of the state Produced Water Consortia. This panel discussed the ongoing efforts by three western states to leverage produced water to offset their freshwater needs.

The New Mexico Produced Water Research Consortium (NMPWC) was initiated in 2019 under a Memorandum of Understanding between the New Mexico Environment Department and New Mexico State University. The Consortium's stated mission is to "to advance scientific research and technology development required to guide future statewide produced water reuse policy."

Texas Produced Water Consortium (TxPWC) was established in 2021 through Senate Bill 601, with Texas Tech University providing administrative oversight along with the Government Agency Advisory Council and the Stakeholder Advisory Council.

The Colorado Produced Water Consortium (CPWC) was established in 2023 in the Department of Natural Resources under House Bill 1242. The role of the CWPC is to make recommendations to state agencies regarding the recycling and use of produced water, to develop guidance documents to promote best practices for in-field recycling and use of produced water, and to make recommendations to reduce the consumption of freshwater within oil and gas operations.

The members of the panel were:

- Hope Dalton, Director, Colorado Produced Water Consortium
- Rusty Smith, Executive Director, Texas Produced Water Consortium
- Dr. Pei Xu, Professor, NMSU, research director of the New Mexico Produced Water Research Consortium

Panelists discussed each state consortia's approach to produced water use. Topics included each consortia's process for assessing possible uses of produced water and the concerns about each use, the definition of "treated" produced water, and the best methods for the public to engage with each consortium. These approaches are informed by the regulations in each state. Texas, for example, is actively reviewing surface water and land-use discharge permits; the consortium is considering other produced water uses, so long as they are safe for human and ecological health and economically viable. New Mexico has prohibited the discharge of produced water to the environment, so its consortium is conducting bench scale research and closed-loop pilot studies, which involve characterizing toxicity and water quality of treated produced water. The New Mexico consortium, in partnership with the Texas consortium, is also conducting pilot studies on irrigation. Colorado is focused on increasing recycling within oilfields and developing data on produced water volumes by location. These state consortia are also designing efforts for community engagement and outreach. The panelists cited public perspectives on produced water quality as being a barrier to its use outside the oilfield and noted that research efforts are underway to be able to demonstrate that treatment is effective at removing harmful constituents of produced water.

Panel 3. Dr. Hornberger facilitated a panel discussion on lessons learned from case studies on produced water discharged to the environment intentionally or through spills and leaks. These panelists were selected given their expertise and experience in the fate and transport of organic and inorganic materials in the environment. Members of the panel included:

- Dr. Thomas Borch, Professor in the Department of Soil and Crop Sciences at Colorado State University, with joint appointments in the Department of Civil and Environmental Engineering, and Department of Chemistry
- Dr. Isabelle Cozzarelli, Research Hydrologist with the USGS Geology, Energy & Minerals (GEM) Science Center in Reston, VA
- Dr. Nathaniel Warner, Associate Professor, Civil and Environmental Engineering, The Pennsylvania State University

Panelists discussed studies that explored how current management practices can affect the environment and how these studies might inform future produced water management practices, as well as the need for more attention towards various types of management practices. The panelists discussed the need for treatment to be based both on the location (i.e., basin or region of hydrocarbon development) and on the intended end use of the treated water. It was noted that any additional transportation of produced water—either for treatment or for disposal—could increase the risk of potential human exposure through spills or leaks. Finally, the panel discussed how different sectors (industry, government, research, and community) have different perceptions and even definitions of risk, which may need to be considered when engaging across sectors as part of future produced water projects.

5. KEY THEMES DISCUSSED AT THE WORKSHOP

This section briefly summarizes major themes that emerged over the course of the day during the facilitated panel discussions, question and answer sessions, and the breakout discussions and report-back, all of which the Energy Research Committee will take into consideration as it begins its work. The themes are intended to provide a summary of the workshop discussion and do not necessarily reflect the views of workshop participants or their organizations.

5.1 VARIABILITY AND COMPLEXITY OF PRODUCED WATER

There was recurring discussion about what is known regarding the composition of produced water. Participants stated that there is more knowledge about the inorganic constituents in produced water but reported that there is still much to learn about organic constituents, particularly with respect to their hazard and treatability. Complicating matters further, the volume and chemical composition of produced water varies as a function of local geology and how the well is being operated and maintained (i.e., the types of chemicals used to develop and maintain a well). Participants noted that produced water is often a complex mixture of organics and inorganics, with varying levels of salinity, and requires multiple laboratory techniques to identify and quantify its individual chemical constituents. Participants discussed how the variability of produced water characteristics across basins can be greater than within a single basin, but that within-basin variability can span a wide range.

Participants discussed available options for treating and characterizing produced water, noting that the variable nature of its composition presents challenges for designing treatment systems, which will require a multi-step process (also known as a “treatment-train”). Nevertheless, a panelist noted that there are technologies that can ensure relatively homogenous produced water quality flow to a central treatment system, explaining that pulses of produced water of highly variable composition, such as those from

recent workover events,[2] can be diverted out of the treatment system for separate disposal (e.g., deep-well injection). The drawback, however, is that these technologies are expensive.

Furthermore, the available analytical methods to characterize produced water are expensive. One participant reported a price tag of $15,000 to collect, transport, store, and analyze produced water collected from one sample event. Another participant noted that results from chemical analyses depend on what part of a produced water storage system is sampled and on when the sample is taken because the quality of produced water can change significantly during operations and subsequent on-site storage. Furthermore, one panelist noted the challenge of obtaining reproducible analytical results among labs, indicating a need for geochemical reference materials to guide laboratories in developing consistent analytical methods.

The cost of analyzing produced water samples to demonstrate treatment efficacy, even at a demonstration or pilot scale, contributed to a broader conversational theme about whether the cost of produced water treatment and analysis outweighed any benefit from its use.

Further discussion of treated produced water centered around the ability to assess its potential adverse effects on ecological and human health and the complicating factor of mixed chemical effects. While toxicity assessment methods exist, they are not necessarily sufficient to understand the possible effects of exposure to produced water that might arise from its various envisioned uses. Participants talked about the need for toxicity assessments that can be applied to site-specific combinations of treated produced water and its intended use outside the oil field.

Participants discussed a range of needs to assess the composition and toxicity of untreated and treated produced water and generally agreed that method development for treated produced water should be prioritized over untreated produced water. Several outstanding research needs were identified:

- Uniform understanding of what constitutes a "representative" sample of produced water, based on geographic regions, considering that sample collection and storage may be difficult or conducted under extreme environmental conditions.
- The development of a protocol for storing and preserving representative produced water samples prior to analysis that accounts for the reactivity of produced water constituents and the physical changes that can occur (e.g., precipitation due to cooling a sample).
- The development of basin-specific geochemical reference materials to characterize produced water composition.
- Whole effluent toxicity assessment of treated produced water, recognizing that even after a "comprehensive" laboratory analysis of individual chemical constituents, questions remain about the toxicity of the chemical mixture.
- A standard protocol for deciding when treated produced water can be used safely outside the oil field.

5.2 Management and Fate in the Environment

Participants also discussed management practices for treated produced water and how they might influence its fate in the environment. They noted that regional variability in produced water quantity and quality necessitates regional management strategies. For example, some regions produce high quantities

[2] Workover events refer to "the repair or stimulation of an existing production well for the purpose of restoring, prolonging or enhancing the production of hydrocarbons." Source: https://glossary.slb.com/en/terms/w/workover.

of produced water that may be transported elsewhere for treatment or use. This transport introduces the risk of accidental spills and leaks of produced water, as well as noise, dust, and vehicle exhaust from increased truck traffic. Participants discussed the importance of considering such factors when developing management strategies. They suggest that management methods for other degraded waters, such as reuse of domestic wastewater for irrigation or even municipal systems, might be leveraged to inform produced water management strategies.

Participants cited the importance of produced water management strategies accounting for the fate and transport of residual chemicals in treated produced water following release to the environment. Participants mentioned the potential for chemical bioaccumulation, persistence, and toxicity. Participants generally agreed that limited data are currently available to support decisions about expanded produced water use outside of the oilfield and that regulators and policymakers lack the information needed to establish requirements for protecting human and ecological health. Thus, participants recommended the following steps to support the development of produced water management practices:

- Prioritize enhanced chemical characterization of produced water in regions where oil and gas development yields the highest volumes of produced water and disposal challenges (e.g., induced seismicity) are greatest.
- Conduct research to understand the fate and transport of produced water chemicals in the environment, and by extension, how people and ecological receptors might be exposed to them. This information is essential for developing risk-based exposure criteria or guidelines, which are lacking for many constituents known to be in produced water.
- Evaluate options for whole effluent toxicity assessments, considering the need to account for the variable composition of produced water.
- Focus on the environmental changes and exposures associated with each possible use of produced water. For example, water soluble chemicals are of primary concern for plant uptake, but other chemicals may be more likely to affect soil or air quality (e.g., VOC emissions from wastewater storage functioning as ozone precursors).
- Conduct longitudinal studies with repeated environmental monitoring to understand the environmental changes and exposures associated with various uses of produced water, such as land application, surface water discharge, and aquifer storage and recharge.
- Study produced water's fate and transport in the environment in regions where produced water is already being discharged to surface water (e.g., there are currently over 400 current National Pollutant Discharge Elimination System permits for produced water in US EPA Region 8, which consists of Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming and 28 Tribal Nations). Locations where known discharges are occurring proximate to drinking water sources should be prioritized for study.
- Conduct research on the management of solids resulting from produced water treatment, considering their potential utility (e.g., recovery of lithium or other rare earth elements or critical minerals) and potential human or ecological exposures (e.g., to radioactivity and heavy metals concentrated in the solids).
- Define potential environmental hazards and human exposures associated with produced water management strategies (e.g., increased truck traffic, ozone precursors from wastewater storage, and exposure to hazardous air pollutants).

Participants noted that in addition to these scientific and technological considerations, produced water management decisions will also need to consider the cost and degree of community acceptance associated with various uses.

5.3 Multisector Engagement

Participants discussed the need for engagement across sectors (e.g., government, industry, communities, and researchers) about the proposed uses of produced water. Much of this discussion concerned the governance of these uses. For instance, participants discussed whether regulators had the necessary information to write protective permits. They discussed whether Clean Water Act framework of criteria and guidelines could be adapted to govern produced water uses. Any adaptation would need to account for the variable composition of produced water.

Participants discussed questions related to multisector engagement in the governance of produced water uses:

- What kinds of disclosures are required of industry in current permitting procedures (e.g., the types and quantities of chemicals used to complete, maintain, or restore a well)?
- How do regulatory processes across states and regions differ, and how might these differences influence the location and type of produced water treatment and use and associated engagement requirements?
- How do water or mineral rights vary across regions?
- Who has oversight of each produced water use and what are the associated requirements for engagements (e.g., oil and gas commissions versus state environmental agencies)?
- What are effective communication strategies for engaging with communities proximate to its use, storage, and transportation about associated risks?

Questions concerning risk brought about discussion of risk comparisons. Participants mentioned two possible comparisons: (1) compare risks from produced water use with risks from potable reuse of domestic wastewater, and (2) compare results for treated produced water and other industrial wastewaters from toxicity assays used to make decisions about surface water discharge. Participants discussed the challenges of comparing risks, citing studies that describe how these comparisons do not necessarily assuage concerns about being exposed to potential hazards. Participants also discussed the use of produced water during times of necessity, such as wildland fire management, and the need for measures to protect human and ecological health even such times of crisis when risk aversion can be lower.

Participants concluded with a general discussion about the challenges of multisector engagement, notable among them being a lack of trust among sectors. They agreed that this engagement is important for many reasons. For example, multisector engagement can help to ensure access to produced water for the purpose of studying its composition and other characteristics. This information, in turn, can be used by policy makers charged with governing produced water management and use. Citing the lack of trust among community members in particular, participants discussed the value of involving an impartial arbiter and early and honest engagement to build trust and share knowledge across all sectors.

6. Next Steps

HEI Energy appreciates the knowledge and questions shared during the workshop and is committed to sharing the information gathered at the workshop, so this report and all workshop materials can be accessed on our website (https://www.heienergy.org/events#planning-workshops). The Energy Research Committee will consider findings from the workshop in finalizing its strategic research planning for 2025-2030.

7. References and Other Resources

ALL Consulting. *US Produced Water Volumes & Management Practices in 2021 | Groundwater Protection Council*. November 2022: https://www.gwpc.org/wp-content/uploads/2021/09/2021_Produced_Water_Volumes.pdf.

[Database] CompTox Chemicals Dashboard v2.4.1. US Environmental Protection Agency. Chemicals in Produced Water. https://comptox.epa.gov/dashboard/chemical-lists/PRODWATER. List of chemicals identified as being present in produced water. The chemicals were reported in the paper by Danforth et al. (2020) entitled "An integrative method for identification and prioritization of constituents of concern in produced water from onshore oil and gas extraction."

Groundwater Protection Council (GWPC). *Produced Water Report: Regulations, Current Practices, and Research Needs.* June 2019: https://www.gwpc.org/wp-content/uploads/2019/06/Produced_Water_Full_Report___Digital_Use.pdf

Groundwater Protection Council (GWPC). *Produced Water Report Update*. May 2023: https://www.gwpc.org/wp-content/uploads/2023/06/2023-Produced-Water-Report-Update-FINAL-REPORT.pdf

[Database] HEI Energy Literature Hub and Spatial Bibliography: https://www.heienergy.org/literature-hub

HEI Energy. *Potential Human Exposures to Produced Water from Onshore Oil and Gas Production.* December 2023: https://www.heienergy.org/system/files/hei-energy-brief-5-produced-water.pdf

Railroad Commission of Texas. *Produced Water Beneficial Reuse: Framework for Pilot Study Authorization*. January 2024: https://www.rrc.texas.gov/media/nznn2wsj/240108-produced-water-framework-final.pdf.

U.S. Environmental Protection Agency. *Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States (Final Report)*. December 2016: https://cfpub.epa.gov/ncea/hfstudy/recordisplay.cfm?deid=332990

U.S. Environmental Protection Agency. *Detailed Study of the Centralized Waste Treatment Point Source Category for Facilities Managing Oil and Gas Extraction Wastes.* May 2018: https://www.epa.gov/sites/default/files/2018-05/documents/cwt-study_may-2018.pdf

U.S. Environmental Protection Agency. *Draft Water Reuse Action Plan*. September 2019: https://www.epa.gov/sites/default/files/2019-09/documents/water-reuse-action-plan-draft-2019.pdf

U.S. Environmental Protection Agency. *Summary of Input on Oil and Gas Extraction Wastewater Management Practices Under the Clean Water Act.* May 2020: https://www.epa.gov/sites/default/files/2020-05/documents/oil-gas-final-report-2020.pdf

[Database] U.S. Geological Survey. *Produced Water Geochemical Database*. December 2023: https://www.usgs.gov/tools/us-geological-survey-national-produced-waters-geochemical-database-ver-30-december-2023

APPENDIX A: WORKSHOP AGENDA

Time	Activity
9:00-9:30	Registration
9:30-10:00	**Introductions and Workshop Overview** • Why a research planning workshop about produced water now?
PANEL 1 10:00-10:45 **Q&A** 10:45-11:00	**What is in produced water? *Facilitated by G. Hornberger*** • Ryan Hall, NGL Energy Partners, Director, Technical Operations • Aaron Jubb, Research Chemist with the USGS Geology, Energy & Minerals (GEM) Science Center in Reston, Virginia • Holly Puglis, Research Ecologist with the Columbia Environmental Research Center at USGS • James Rosenblum, CO School of Mines, Assistant Research Prof, WE2ST Water Technology Hub
11:00-11:30	Breakout group discussion of Panel 1 charge questions
11:30-12:00	Report back on Panel 1 discussion
12:00-1:00	*Lunch*
PANEL 2 1:00-1:45 **Q&A** 1:45-2:00	**What produced water uses are being contemplated outside of the oil field? *Facilitated by N. Warner*** • Hope Dalton, Director, Colorado Produced Water Consortium • Rusty Smith, Executive Director, Texas Produced Water Consortium • Pei Xu, Professor, NMSU, research director of the New Mexico Produced Water Research Consortium
2:00-2:30	Breakout group discussion of Panel 2 charge questions
2:30-2:45	*Break, coffee*
2:45-3:15	Breakout groups report back on Panel 2 discussion
PANEL 3 3:15-4:00 **Q&A** 4:00-4:15	**What do we know about the fate and transport of produced water following release to the environment? *Facilitated by G. Hornberger*** • Thomas Borch, Professor in the Department of Soil and Crop Sciences, at Colorado State University with joint appointments in the Department of Civil and Environmental Engineering, and Department of Chemistry • Isabelle Cozzarelli, Research Hydrologist with the USGS Geology, Energy & Minerals (GEM) Science Center in Reston, VA • Nat Warner, Associate Professor, Civil and Environmental Engineering, Pennsylvania State University
4:15-4:40	Breakout groups discussion of Panel 3 charge questions
4:45-5:15	Report back on Panel 3 discussion
5:15-5:30	Wrap up, review plan for next steps

APPENDIX B: BIOGRAPHIES FOR THE WORKSHOP SPECIAL PANEL

Alfred (Bill) Eustes, Co-Chair, HEI Energy Research Committee, Colorado School of Mines

Dr. Alfred William (Bill) Eustes III is an associate professor emeritus in the Petroleum Engineering Department at the Colorado School of Mines. Prior to that, he was an ARCO Oil and Gas field drilling engineer. His recent drilling research work has involved NASA robotic drills for the Moon and Mars, NSF Antarctic deep ice drilling and coring, lost circulation studies, and other drilling projects. He is a DOE National Renewable Energy Lab Joint Appointee developing geothermal drilling improvements. Dr. Eustes has a BSME (78) from Louisiana Tech, MSME (89) from the University of Colorado, Boulder, and a PhD-PE (96) from the Colorado School of Mines.

George Hornberger, Co-Chair, HEI Energy Research Committee (Chair), Vanderbilt University

Dr. Hornberger is Distinguished Professor Emeritus, Vanderbilt University, Nashville, Tennessee. From August 2008 to June 2021 he was the Director of the Vanderbilt Institute for Energy and the Environment with a shared appointment as the Craig E. Philip Professor of Engineering and as Professor of Earth and Environmental Sciences. He previously was a professor at the University of Virginia where he held the Ernest H. Ern Chair of Environmental Sciences. He has been a visiting scholar at the Australian National University, Lancaster University, Stanford University, the United States Geological Survey (USGS), the University of Colorado at Boulder, and the University of California at Berkeley. Dr. Hornberger's current work focuses on coupled natural-human systems and aims to understand how climate, groundwater, surface water, energy production, food production, and human abstraction of water interact in complex ways. Recent research projects have included work in Sri Lanka on adaptation to drought, in Bangladesh on the controls on freshwater availability, and in the United States on how cities evolve water conservation practices. He has published extensively, with numerous scientific papers, book chapters, and books.

Dr. Hornberger has served on numerous boards and committees of the National Academies, most recently as co-chair of the Committee on "Advancing a Systems Approach to Studying the Earth." In 2015, he completed service as the chair of the Health Effects Institute Special Scientific Committee on Unconventional Oil and Gas Development. Before that in 2013, he chaired a related National Research Council Committee on Development of Unconventional Hydrocarbon Resources in the Appalachian Basin. He previously served as an editor on several highly regarded journals. Dr. Hornberger won the Robert E. Horton Award (Hydrology Section) from the American Geophysical Union in 1993. In 1995, he received the John Wesley Powell Award from the U.S. Geological Survey. In 1999, he was presented with the Excellence in Geophysical Education Award by the American Geophysical Union and in 2007 he was selected Virginia Outstanding Scientist. Professor Hornberger was elected to the U.S. National Academy of Engineering in 1996. He was also elected a Fellow of the American Geophysical Union in 1994, the Association for Women in Science in 1996, and the Geological Society of America in 2005, received the William Kaula Award from the American Geophysical Union in 2010, the Harvie Branscomb Distinguished Professor Award from Vanderbilt University in 2017, and the Margaret Cuninggim Women's Center Mentoring Award from Vanderbilt University in 2022.

Dr. Hornberger holds a B.S.C.E. in Civil Engineering and an M.S.C.E. in Hydrology from Drexel University and a Ph.D. in Hydrology from Stanford University.

Isabelle Cozzarelli, HEI Energy Review Committee (Chair), USGS Geology, Energy & Minerals Science Center

Dr. Cozzarelli is a Research Hydrologist in the USGS Geology, Energy & Minerals Science Center in Reston, VA. She specializes in interdisciplinary long-term research on the fate and effects of organic contaminants in surface and subsurface environments. Her research focuses on coupled hydrogeological, microbiological, and geochemical processes controlling reactions in hydrogeologic systems and fundamental understanding of biodegradation and contaminant biogeochemical cycles in order to protect water quality and ecosystem health.

She has served as Adjunct faculty in Virginia Tech's Department of Geosciences and on a number of scientific journal editorial boards. She received the USGS Meritorious Service Award in 2017 and, in 2023, she received the "Friend of Water-Rock Interaction & Applied Isotope Geochemistry Award" from the International Association of Geochemistry.

Dr. Cozzarelli was a member of International Advisory Board for the Danish GEOCON (Advancing GEOlogical, geophysical and CONtaminant monitoring technologies) multi-institution study for the period 2014-2018. Dr. Cozzarelli is an elected Fellow of the Geological Society of America and currently Chairs the HEI Energy Review Committee. She holds a B.S. in Geomechanics from the University of Rochester, and a M.S. and PhD. in Environmental Sciences-Geochemistry from the University of Virginia.

Nathaniel Warner, Pennsylvania State University

Dr. Warner is an Associate Professor at Penn State. Dr. Warner's research group established research methods that helped trace environmental impacts, including radioactivity, from management of oil and gas produced water. His work on the impact of energy development to water resources over the past fourteen years has included evaluation of produced water as a dust suppressant, discharges of treated produced water to supplement surface water, and novel treatment for reuse. Prior to Penn State Dr. Warner worked as a professional geologist for six years.

APPENDIX C: BIOGRAPHIES FOR WORKSHOP SPEAKERS

PANEL 1

Ryan Hall, NGL Energy Partners, Director, Technical Operations

Ryan is the director of technical operations for NGL Energy Partners. NGL is the nation's largest water midstream managing over 2.7MM BBL of produced water per day. He holds a BS in Environmental Engineering from Pennsylvania State University and a Masters in Environmental Management from Duquesne University. He leads NGL's efforts to advance the beneficial use of treated produced water.

Aaron Jubb, Research Chemist, USGS Geology, Energy & Minerals (GEM) Science Center, Reston, Virginia.

Following his graduate studies, Dr. Jubb completed post-doctoral work at the National Oceanic and Atmospheric Administration's (NOAA) Chemical Science Division in Boulder, Colorado focusing on the atmospheric chemistry of CFC replacements and at Oak Ridge National Laboratory in Oak Ridge, Tennessee with an emphasis on the development and application of surface enhanced Raman scattering sensors. Dr. Jubb joined the USGS in 2017 where his principle areas of study involve: composition of oil and gas-associated wastewaters; molecular characterization of sedimentary organic matter; and in situ characterization of rock wettability.

Holly Puglis, Research Ecologist, Columbia Environmental Research Center at USGS

Dr. Holly Puglis is an ecotoxicologist with the USGS with nearly 15 years of experience studying the effects of contaminants in aquatic systems. Holly co-leads an interdisciplinary team of scientists within the Survey to understand the impacts of energy development on environmental health. Her work within the team has focused on the impact of produced water contamination on native amphibian populations, potential toxicity of drill waste materials to aquatic biota, and the effects of produced water on seed germination.

James Rosenblum, Research Assistant Professor, Civil & Environmental Engineering, Colorado School of Mines

Dr. James Rosenblum is a research assistant professor at Colorado School of Mines, leading their Water Technology Hub. His research focuses on water reuse of municipal and industrial sources using biological to membrane-based processes, and their assessment through chemical characterization to in-vitro bioassays. Dr. Rosenblum's research also involves data science to evaluate the chemical risks and hazards associated with drinking water. He earned his PhD in Environmental Health Science at Ohio State Universities College of Public Health and has worked as a consultant to being the founder of an industrial water treatment company.

PANEL 2

Hope Dalton, Director, Colorado Produced Water Consortium

Hope Dalton is the first Director of the Colorado Produced Water Consortium. The Consortium was established in 2023 in the Colorado Department of Natural Resources by House Bill 23-1242 Water Conservation in Oil and Gas Operations to help reduce the use of freshwater within oil and gas operations. The Consortium's responsibilities also include making recommendations towards developing an informed path for reuse and recycling of produced water inside and potentially outside of oil and gas operations within the state, measures to address barriers associated with the utilization of produced water and research to evaluate analytical and toxicological methods employed during produced water treatment.

Hope has over 20 years' experience working in local, state, and federal government, including service at the Colorado Department of Public Safety, South Platte Renew, Metro Water Recovery, and Tri-County Health Department. Hope has experience in research, policy development, land use, and leading diverse stakeholder groups.

Rusty Smith, Executive Director, Texas Produced Water Consortium

A native of West Texas, Rusty Smith brings a unique blend of experience in both the private and public sectors to the direction of the Consortium. Rusty comes to Texas Tech from the Lubbock Economic Development Alliance where he previously served as a project manager, focusing on recruiting new businesses and fostering innovation in the Lubbock region.

Prior to moving back to Lubbock, Rusty spent several years in Austin working in public policy in both the Texas House of Representatives and the Texas Senate, primarily focusing on natural resources, agriculture, and energy. Most notably, Rusty served as the Committee Director for the Texas Senate Committee on Agriculture, Water and Rural Affairs during the 85th Texas Legislature for Chairman Charles Perry. During that time, he oversaw all legislation under the jurisdiction of the committee, including issues impacting water resources across the state. After the 85th session Rusty was hired to serve as the Director of Government & Regulatory Affairs for the Texas Independent Producers & Royalty Owners Association, a statewide oil & gas trade association serving nearly 3,000 individual and corporate members. Rusty received a BS from Texas A&M University and an MBA from Texas Tech.

Pei Xu, Professor, NMSU, Research Director of the New Mexico Produced Water Research Consortium

Dr. Pei Xu is a professor in the Department of Civil Engineering at the New Mexico State University, and the research director of the New Mexico Produced Water Research Consortium. Her research focuses on water reuse, desalination, membrane processes, nanomaterials, produced water treatment and reuse, resources recovery and brine valorization. The goal of her research is to address critical water shortage challenges in arid and semi-arid regions. She was selected by the American Association for the Advancement of Science as a Leshner Fellow on Food and Water Security, and C. Herb Ward Family Endowed Interdisciplinary Chair and PESCO Endowed Professor at NMSU.

PANEL 3

Thomas Borch, Professor in the Department of Soil and Crop Sciences at Colorado State University, with joint appointments in the Department of Civil and Environmental Engineering, and Department of Chemistry.

Thomas Borch is a Professor in the Department of Soil and Crop Sciences at Colorado State University (CSU), and he holds a joint position in the Department of Chemistry. Dr. Borch is internationally recognized as an authority on soil and water processes that affect the fate and transport of emerging contaminants, metals, and soil organic matter (SOM). He currently studies the effects of permafrost thaw and wildfires on the molecular chemistry of soil carbon and water quality. Dr. Borch's research group, in collaboration with sociologists, economists, engineers, chemists, microbiologists, and toxicologists, have also been pioneering research related to characterization, treatment and reuse of industrial water such as oil and gas produced water for crop irrigation. Dr. Borch's research has resulted in 130 peer-review publications and nearly 200 invited talks nationally and internationally. Dr. Borch has received the Faculty Early Career Development (CAREER) Award from the National Science Foundation (NSF) in 2009, the 2015 (Mid-Career) SSSA Marion L. and Chrystie M. Jackson Soil Science Award by the Soil Science Society of America for outstanding contributions in the areas of soil chemistry and mineralogy and was elected Fellow of the Soil Science Society of America in 2022.

Isabelle Cozzarelli, Research Hydrologist, USGS Geology, Energy & Minerals (GEM) Science Center, Reston, VA.

See biography in Appendix C

Nathaniel Warner, Associate Professor, Civil and Environmental Engineering, Pennsylvania State University

See biography in Appendix C

APPENDIX D: WORKSHOP PARTICIPANTS

This summary does not necessarily represent the views of workshop participants or their organizations.

Scott	Anderson	Occidental Petroleum
Irene	Andress	Colorado Produced Water Consortium
Erik	Anglund	Occidental Petroleum
Treasure	Bailley	US Environmental Protection Agency
Jennifer	Baka	Penn State University
Alex	Betts	ExxonMobil
Justin	Birdwell	USGS
Uni	Blake	American Petroleum Institute
Thomas	Borch	Colorado State University
Tom	Champoux	Health Effects Institute
Isabelle	Cozzarelli	USGS, Geology, Energy & Minerals Science Center
Hope	Dalton	Colorado Produced Water Consortium
Cloelle	Danforth	Health Effects Institute
Gabriela	Daza	Health Effects Institute
Greg	Deranleau	Colorado Energy & Carbon Management Commission
Ryan	Hall	NGL Energy Partners
Ashley	Harper	US Environmental Protection Agency
Jason	Herman	New Mexico Environmental Department
George	Hornberger	Vanderbilt University
Michael	Jahne	US Environmental Protection Agency
Colleen	Jones	Utah State University
Aaron	Jubb	USGS, Geology, Energy & Minerals Science Center
Cresten	Mansfeldt	University of Colorado
Wyre	Mauldin	Texas Produced Water Consortium
Amy	Maybach	US Environmental Protection Agency
Rick	McCurdy	Select Water Solutions
Christopher	Paciorek	University of California, Berkeley
Tricia	Pfeiffer	US Environmental Protection Agency
Holly	Puglis	USGS, Columbia Environmental Research Center
Aaron	Redman	ExxonMobil Biomedical Sciences
James	Rosenblum	Colorado School of Mines
Ted	Russell	Georgia Institute of Technology
Erin	Sedlacko	Colorado Produced Water Consortium
Robert	Shavers	Health Effects Institute
Rusty	Smith	Texas Produced Water Consortium
Sean	Thimons	US Environmental Protection Agency
Peter	Thorne	University of Iowa
Rebecca	Tisherman	RAND Corporation
Suzanne	VanDrunick	US Environmental Protection Agency
Fred	Verner	Chevron
Donna	Vorhees	Health Effects Institute
Claire	Wadler	Colorado School of Mines
Nathaniel	Warner	Penn State University
David	Wyker	Chevron
Pei	Xu	New Mexico State University

APPENDIX E: BREAKOUT GROUP QUESTIONS AND COMMENTS FROM WORKSHOP PARTICIPANTS

Following each workshop panel discussion, workshop participants joined multisector breakout groups to discuss the charge questions associated with each panel topic. After reconvening, a representative from each breakout group briefly described discussions that took place in their groups. Below is an anonymized list of these remarks.

Panel 1, Breakout Session

Breakout Session Questions	Comments from Workshop Participants
What do we already understand well about produced water composition?	• Understand inorganic composition (brines, salt, minerals), but do not understand temporal or spatial composition, or how these may affect treatment byproducts. • Produced Water has variable composition even within a state; however, there is more likely to be consistency within basins or fields. • Basin to basin differences in produced water composition are more pronounced.
What research is needed to better characterize produced water?	• Further development of analytical methods to characterize produced water constituents is needed, with an emphasis on emerging contaminants of concern (microplastics, PFAS, transformation byproducts, chemical additives); which may be through developing non-targeted analysis to help understand "unknowns" (i.e., unidentified chemical constituents in produced water). • Development and demonstration of methods for high saline brines • While understanding individual constituents is important, there is also a need to develop methods that consider chemical groups (VOCs, aromatics, etc.) • Currently, the analytical list to understand what is in produced water is very long; it is a costly analysis. • Need for methods that can be run quickly and accurately. • Create a tiered approach to understand indicators. • Inter-laboratory comparisons to demonstrate consistency and reproducibility of methods would be aided by geochemical reference materials. • Variability between flowback and formation when you change from flowback to produced water after a well begins producing hydrocarbons. • Research needed to understand what is needed to understand composition over a well's lifetime. • Composition of well inputs (stimulation, maintenance, workover fluids) • Transport and degradation of organics • Methods are needed for more labs to do whole effluent toxicity testing of treated effluent. • Need to develop acute and chronic toxicology studies for aquatic life and human beings. • Toxicological linkages (i.e., which chemicals are hazardous).
Do these research needs differ by location (e.g., state and basin)? Do they differ by anticipated use?	• Research will be different for different basins and dictated by end users. • Representative samples from basins are needed. • Geochemical reference standards for different basins.
Is research needed on treatment options?	• Treatment processes need to be fit-for-purpose; research is needed to understand and define treatment trains by end-use. • Demonstrating treatment effectiveness is important. • For treatment success, there needs to be homogeneity within treatment trains and process streams. More research is needed to understand potential produced water variability that occurs during storage when managing through processes and treatment trains. • Brine management is important after treatment, either through blended waste or brine valuation; how are any radioactive (NORM) wastes being managed? • Long-term monitoring of discharge locations and area receptors (human or ecological). • Treatment versus human health versus economic cost. Are there economical, treatment-based solutions in the future? • Standards, criteria, or guidelines for treated produced water that is being discharged, currently and in the future.

Panel 2, Breakout Session

Breakout Session Questions	Comments from Workshop Participants
How might people be exposed to produced water based on anticipated uses and management?	• Spills and leaks can happen at any time, pre- or post-treatment. • Any intentional or unintentional release of raw, or partially treated produced water. • Exposure due to use/reuse scenarios, land applications, surface discharge, groundwater discharge can cause occupational exposure or exposure to the general public. • Unintended full immersion, inhalation from cultural uses need to be considered. • Agriculture, irrigation, dust suppression: you can mobilize contaminants into surface water or groundwater. • Air exposures and cooling towers, ozone precursors from storage. • We have chemical testing to characterize the water, we need to think about the end user.
Is research needed to better characterize the fate and transport of produced water treated for a given use in the environment?	• Create longitudinal soil studies (i.e., long term studies with repeat sampling) for any type of land application or modeling for these locations; further, need to understand fate and transport of chemicals of concern from cradle to grave, as it is difficult to know exactly where things are going; need to understand unintended as well as intended receptors. • Include ecological samples during any longitudinal studies. • Discharge to surface water and mixing with existing/background water quality issues. • Consider potential environmental justice considerations/studies when identifying use scenarios. • Further research is needed on exposure risk, risk management, risk perception, risk acceptance. • Tradeoff or acceptance of risk for emergency use of produced water (i.e., wildfire suppression). • Can treat water sufficiently; however, targets and criteria are lacking. Also need to be able to demonstrate treatment efficacy with toxicity tests. • With respect to standards setting, cannot rely on drinking water or existing standards because produced water is a different thing. • Economics is also something to consider; water pricing is variable depending on the availability of water.
Do these research needs differ by location (e.g., state and basin)? Do they differ by anticipated use?	• Research needs will depend on application type, location, and treatment. • Considerations for location may include risk “ownership” and risk transfer. • Need to consider trans basin diversions
If research proceeds on produced water exposure, how might the community (e.g., ranchers, farmers, and Indigenous communities) be engaged?	• Want to engage public in two ways, both to share out research results, and also to hear feedback from communities. • Gaining trust through an honest broker and strong communication. • Use a variety of ways to communicate, including social media and other types of creative efforts (not just reports).

Panel 3, Breakout Session

Breakout Session Questions	Comments from Workshop Participants
Do you think any of the exposures merit research, and if so, why?	• There are plugged, abandoned, and orphan wells that not only release methane and carbon dioxide, but other wastes, potentially even produced water from orphan and plugged wells that were abandoned approximately 50 years ago. How prevalent are surface releases from plugged and abandoned or orphaned wells that experience infrastructure failure (e.g., casing or content)? • Studying downstream environment from known discharge points, whether from federal or state discharge systems. It can include monitoring for bioaccumulation, being mindful of how to track all other potential dischargers/sources. Particularly important and challenging because some produced water releases have been occurring for decades at this point. • Characterize ecology and establish baseline ahead of any releases. • Leverage the research that continues for other water sources, as all the same research that is considered for other water sources should be considered for this water, too. Produced water is not special; it can be treated like other wastewater. • Identify and understand the most expensive compounds to remove. • Establish and define benchmarks (regional, end use). • Identify the disincentives to knowing what is in produced water or treated produced water. • What are representative or baseline samples, methods, and constituents of concern for produced water? • Can we develop reference materials/standards?

Considering the entirety of the day, what else do you think we need to consider?	• What do regulators need to do their jobs better (recognizing that, for example, the Safe Drinking Water Act is inappropriate for produced water)? What information and how much of it do regulators need to establish a standard for treated produced water? Or what toxicological assays need to be applied to establish treatment criteria?
	• What are the toxicological assays that need to be applied to establish treatment criteria?
	• Can we establish a link between produced water and environmental justice analysis and leverage federal research money (Justice40). Disadvantaged communities identified through environmental justice analysis and to identify federal money related to energy communities.
	• Identify and understand risk tolerance in times of crisis. Examples of crises and how to arm risk managers ahead of time, includes produced water use for:
	  ○ Municipal fire suppression.
	  ○ Wildfire suppression.
	  ○ Irrigation or agriculture during chronic water scarcity or depletion scenarios.
	  ○ Supplement water sources after an upset event (e.g., harmful algal blooms can disrupt water systems).
	• Can we consider produced water for beverage manufacturing (or other treated water needs)?
	• How can we understand the potential benefits of produced water use when compared to the risks?
	• Establishing consistent methods and constituents of concern.