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Concept of Operations: National Technology Test Bed Network for Water Resource Recovery

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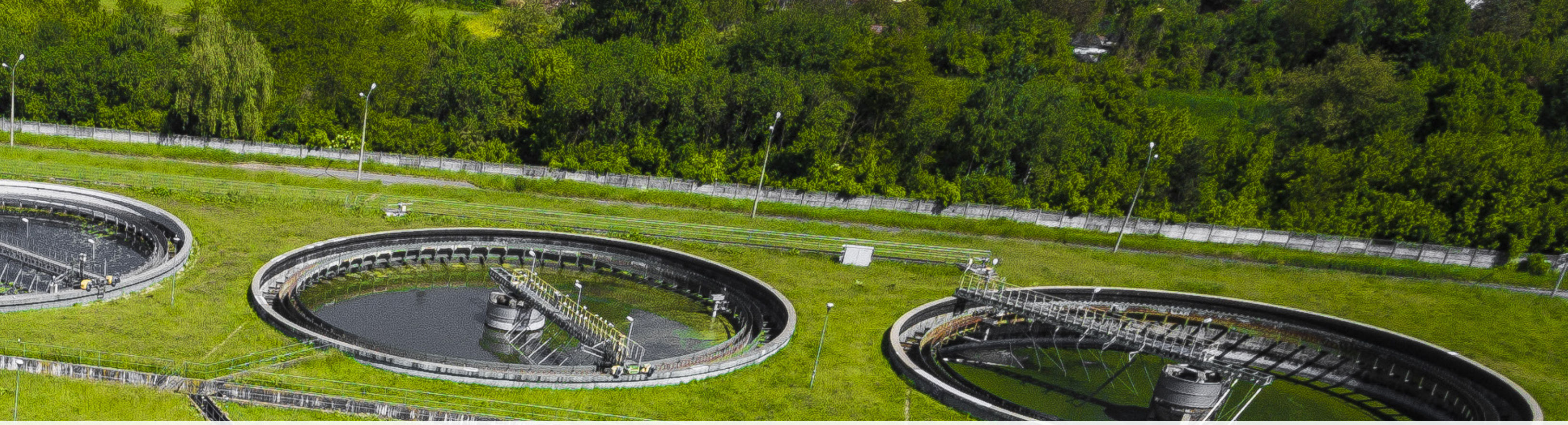

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U.S. DEPARTMENT OF ENERGY

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Executive Summary

There is an urgency to advancing wastewater technologies due to aging water infrastructure and emerging regulations. A crosscutting working group proposes a conceptual design for a test bed network to understand and evaluate wastewater technologies to drive acceptance and deployment of new technologies to enhance performance. The working group includes contributors from the U.S. Department of Energy, the U.S. Environmental Protection Agency, the U.S. National Science Foundation, and the Water Research Foundation (formerly known as the Water Environment & Reuse Foundation).

In "The Water-Energy Nexus: Challenges and Opportunities" (June 2014), the U.S. Department of Energy identified key issues with water-energy interdependencies and identified water resource recovery (broadly referred to as "wastewater management" or "sewage treatment") as a locus of opportunities to improve energy and water security. Traditional sewage treatment uses more than 30 billion kWh per year, almost one percent of our electricity supply (*EPRI 2013*), and energy use grew 74 percent from 1996 to 2011 (*Tarallo 2014*). Wastewater is a potential alternative source to address water scarcity. In addition, wastewater contains valuable energy, nutrient, and mineral resources. Traditional sewage treatment does not recover water or other resources. With improved technology and design, reclaimed wastewater could supplement existing water supplies and mitigate water stress. The energy (biogas and heat), nutrients (primarily nitrogen and phosphorus), and minerals in wastewater could displace fossil sources, reduce America's dependence on imported energy, and reduce greenhouse gas emissions. If fully implemented, resource recovery would reduce discharges to the environment and provide ecosystem services.

The primary role of both public and private wastewater facilities is to reduce risk to human health and the environment. The institutional driver is to meet regulatory requirements. Capital budgets and revenue from taxes and services are limited at wastewater utilities, reducing the ability to invest in innovation. Therefore, utilities are very risk averse and slow to adopt new technologies that go beyond their traditional historical mandate.

Upgrading today's aging wastewater treatment infrastructure to a new generation of water resource recovery facilities (WRRFs) requires the development and deployment of innovative technologies. The path to technology adoption depends on expensive, time consuming, and often repetitive cycles of testing and validation. Existing water resource recovery technology testing facilities (e.g., test beds) are underutilized and cannot, by themselves, broaden technology uptake. It has been proposed that technology adoption could be accelerated by a network linking these test facilities with innovators, manufacturers, utilities, regulators, policymakers, and educators. This document proposes a structure for a National Test bed Network (TBN) for water resource recovery. The concepts for its operation are explored herein.

There is already a substantial effort to build a TBN with the Leaders Innovation Forum for Technology (LIFT). Launched by the Water Research Foundation (WRF, formerly WE&RF) and Water Environment Foundation (WEF), LIFT provides a communications platform to link utilities with technology providers and developers in the water resource recovery industry. Additional capabilities that extend LIFT's impacts to regulators and policymakers

could further accelerate technology adoption. The network component of LIFT is Facilities Accelerating Science & Technology (FAST).

The goal of the TBN is to engage stakeholders to help make informed decisions, considering both regulatory frameworks and the state of technology. The role of the TBN is to inform stakeholders, and not to replace or circumvent the permitting and regulatory roles of states, counties, and tribal lands. The underlying mission of the TBN is to accelerate innovation at WRRFs.

This document identifies drivers to launch a TBN and critical needs for successful implementation of the network. An important driver to technology implementation at WRRFs is the relationship between local utilities and state regulators. The TBN could provide access to validated performance data and facilitate deployment. To link the stakeholders and accelerate deployment, the TBN will require standards for methods, data quality, data management, and data security. These standards will enable validation of performance and will expand the "toolbox" that utilities and regulators could consider. Design, set up, and launch of this toolbox is beyond the scope of operations of utilities and regulators and will likely require external support to achieve full operation. Herein, a pathway is proposed to achieve this full operation.

This document defines the function of a WRRF TBN. It also proposes a structure for the TBN to achieve its stated goals and mission. Finally, this document summarizes findings from several sources, including a series of workshops about the TBN concept, operators of test beds in ancillary industries, and discussions with regulators and permitting agencies. A description of this work was published in the peer-reviewed literature (Mihelcic 2017).

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The Need for a National Test Bed Network

Innovation is required in water resource recovery (WRR)

- **Reduce energy use:** The energy use in water resource recovery could be reduced significantly.
- **Meet water demand:** The imbalance between water demand and supply is growing, and recovered wastewater could help address the imbalance.
- **Enhance performance:** Tightening regulatory requirements and the need to improve infrastructure resilience drive the need to enhance performance.
- **Deploy innovative technologies:** The need to enhance performance with restricted capital budgets requires innovative technologies.

Pathways for innovation are challenging

- **Regulatory:** Changes in regulations require a strong margin of safety to mitigate health and environmental risks.
- **Permitting:** Issuing of permits requires clear verification that the innovation will always meet regulatory requirements under a wide range of performance and environmental conditions.
- **Lack of profit incentives:** Most WRR providers are public utilities or regulated private utilities that lack profit incentives and capital to invest in innovation.
- **Risk aversion:** Due to the tight regulatory climate and the limited returns on investment, the industry is extremely risk adverse, limiting innovation.

A well-designed test bed network linking innovators, manufacturers, regulators, policymakers, and other stakeholders to a technology testing and validation ecosystem can overcome these challenges.

Key Components: Processes, Products, and Outcomes

Successful implementation of a test bed network (TBN) requires that stakeholders derive measurable value from participation while working toward long-term goals. Design of the network should maximize productivity and minimize operational disruption by integrating existing organizational procedures and structures from across the stakeholder community into a harmonized suite of inter-institutional processes.

The TBN's *processes* are the activities undertaken by its members.

- **Communications:** Leverage existing channels for innovator dialogue and public outreach. Expand and facilitate critical inter-region and interstate exchange.
- **Technology Testing and Validation:** Incorporate best practices and lessons learned from EPA's Environmental Technology Verification (ETV) program and Water Research Foundation's FAST water network. Engage the full range of stakeholders navigating and utilizing test beds.
- **Test bed Certification:** Formal validation of technologies is more efficient when the test beds and protocols themselves have undergone a certification process.

The TBN's *products* are the valuable output that result from collaboration between stakeholders.

- **Data:** Develop, support, and maintain a curated and secure clearinghouse for validated test data and results, with an emphasis on accessibility by regulators and policymakers.
- **Metrics:** Publish common metrics for WRR and its impacts on overall system performance. Metrics need to be flexible to account for diverse scales and geographies.
- **Agreements:** Foster reciprocity agreements for inter-regional acceptance of technology, as well as regional-cooperation agreements to achieve common energy and environmental goals.
- **Intellectual Property:** Support the protection of intellectual property developed during testing and validation to incentivize innovation during test bed participation in the TBN.

The TBN's *outcomes* are long-term, high-level benefits to the industry and society.

- **Accelerating Innovation:** Facilitate rapid evaluation and validation of technologies that enhance the performance of water resource recovery facilities with increased water, energy, and nutrient recovery at reduced costs and energy use while maintaining or improving public-health outcomes.
- **Reducing Risk:** Protect innovators from reputation risk due to testing prototype technologies. The TBN should be a safe place to fail without long-term impacts on perception of new technologies.
- **Enhancing Water and Energy Security:** Accelerated deployment of innovative WRR technologies will lower energy consumption for utilities, reduce water treatment costs for ratepayers, and improve water security for society, while creating economic opportunities in manufacturing, construction, and operations.
- **Improve Water Quality:** Better WRR technology will result in cleaner watersheds and improved public health.

Initial external support is critical to the successful launch of the TBN. The program should transition to stakeholder support after it is launched.

Background

Several studies and projects led up to this study and are included in Appendix B.

- "The Water-Energy Nexus: Challenges and Opportunities" (June 2014), the U.S. Department of Energy (DOE).
- Leaders Innovation Forum for Technology (LIFT) (http://www.werf.org/lift) is an initiative managed by the Water Research Foundation (WRF) and the Water Environment Foundation (WEF) to help bring new technologies to the WRR field.
- The U.S. Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) (1995-2014) pioneered a national-scale program for water resource technology.
- Demand for a national technology testbed network TBN for water resource recovery was identified in a stakeholder workshop hosted by the National Science Foundation (NSF), EPA, and DOE. The Energy-Positive Water Resource Recovery Workshop (EPWRR) was a critical stakeholder meeting where the need for a TBN was identified (http://www.energy.gov/sites/prod/files/2016/01/f28/epwrr_workshop_report.pdf).
- A working group including representatives from DOE, EPA, NSF, the U.S. Department of Agriculture (USDA) and WRF conducted two workshops:
  - Workshop for Developing Evaluation Metrics to Advance a National Water Resource Recovery Facility Test Bed Network — National Science Foundation, U.S. Department of Energy, U.S. Environmental Protection Agency, U.S. Department of Agriculture, Water Environment and Reuse Foundation: Arlington, VA, 2016; http://www.werf.org/lift/docs/EPWRR_Metrics_Workshop/EPWRR_Metrics_Workshop.aspx
  - Workshop for Developing the Structure of a National Energy Positive Water Resource Recovery Facility Test Bed Network — National Science Foundation , DOE, EPA, U.S. Department of Agriculture, and the Water Environment and Reuse Foundation: Denver, CO, 2016; http://www.werf.org/lift/docs/EPWRR_Structure_Workshop/EPWRR_Structure_Workshop.aspx
- Test bed networks implemented in other industries.

Introduction

Wastewater management is essential for public health, environmental safety, quality of life, and the functioning of cities, towns, and communities. Wastewater management has served as a keystone public utility for society and our relationship with the environment. As the United States wrestles with increasing challenges with water that include scarcity in some regions and flooding in others, advancing water resource recovery (WRR) infrastructure is considered a core opportunity in both the public and private sector.

Furthermore, WRR infrastructure is typically among the oldest investments in municipalities. The current infrastructure was designed solely to treat wastewater and remove pollutants. Technological progress has resulted in new concepts that could transform legacy wastewater management systems from energy consumers to net energy producers; from single-purpose water management utilities to multi-purpose recyclers of water, food, energy and agricultural byproducts; and from ratepayer-funded disposal facilities to value-driven product and service providers.

Simultaneously, many regions are experiencing increased flooding due to a combination of aging infrastructure, population growth, urbanization, changes in land use, and climate change. Nonetheless, WRR infrastructure is usually only upgraded or replaced in response to major events such as significant population growth, major regulatory changes, damage from natural disasters, and mechanical/structural system failures. These actions demonstrate that disconnects between the innovation ecosystem, the investment drivers, and the operational realities of the wastewater management business. When infrastructure is replaced after catastrophic disasters or systems failures, there is little opportunity to evaluate, test, and approve innovative technology solutions that could enhance performance, decrease costs, and increase resilience.

New technologies can reduce the cost and energy inputs to wastewater management, recover the resources in wastewater, and improve the flexibility and resiliency of WRR systems. Many of these technologies have been proposed and are in development; more will certainly emerge as science and technology progress. However, the timeline for research and development to demonstration and widespread market adoption is extremely long in the WRR industry. Technologies may take decades to become widespread, limiting the ability of the sector to respond to challenges and changes. The slow process is attributable to multiple factors: WRR is a long-lived capital investment; access to testing at appropriate scale may be constrained; and the WRR industry is highly regulated and risk averse. A test bed network (TBN) will facilitate innovation in two ways: 1) create a set of standards for investors, regulators, permitters, and end users to evaluate technologies and 2) guide technology developers and investors to the performance gaps that require innovation.

Value of a Network

Efforts to accelerate the adoption of new WRR technology are already underway. Organizations at all levels of government, industry, and academia have recognized both the need to deploy a new generation of sustainable WRR technologies and the opportunity to re-imagine the nation's aging wastewater utilities.

There are ample funding opportunities for researchers to test novel separations, disinfection, and resource recovery technologies at the bench scale. Equipment manufacturers are actively marketing developed technologies to municipalities. There are examples of large wastewater utilities that have installed resource recovery equipment, and several others that have expressed a willingness to test and implement innovative new technology, transforming themselves into the wastewater resource recovery facilities (WRRFs) of the future. However, there is limited coordination between these entities and stakeholders who must work together to drive new technology from the bench scale to broad acceptance in the market. The WEF and WRF industry groups have created the LIFT program (http://www.werf.org/lift/) to address some of the known technology gaps. For example, LIFT operates FAST (Facilities Accelerating Science and Technology), a directory of facilities that are willing to host testing or demonstration of new WRR technology (http://www.werf.org/lift/FASTWaterNetwork).

Research has shown that an additional level of communication and coordination is necessary to accelerate technology development and adoption. Specifically, the deployment of new technology is hampered by the lack of stakeholders' confidence in the results of technology tests and demonstrations that have occurred outside of their immediate domains. These stakeholders include technology innovators, manufacturers, utilities, regulators, and policymakers at the local, state, and federal levels. A network that facilitates hands-on access to operating hardware, access to validated data, access to funding, and access to intellectual capital would reduce risks across the entire innovation pipeline and accelerate sustainable WRR technology.

Table 1 lists the WRR industry stakeholders and the value each would receive from enhancing their ability to collaborate on testing and demonstration of new technology. These are representative stakeholders (many of whom helped prepare this document) and this is not a comprehensive list. The table also describes the value each brings to the network, which is discussed further in the Network Processes section. More detail is given in Appendix A.

Table 1: The roles of selected network members and other stakeholders. This table summarizes both the value of the network to the participants, and the value that value that each brings to the network by fulfilling those roles. Core members (first six rows) share information and feedback to facilitate technology advancement and deployment. External affiliates (last two rows) are involved as the ultimate supporters and beneficiaries of advanced WRR technology. Government agencies that support innovation and regulation play an intermediate role.

	Stakeholder and Mission	Value of TBN to Stakeholder	Value Stakeholder brings to TBN
Members	**Test bed Operators** are often utilities, manufacturers, researchers, or government laboratories with flexible platforms and leadership roles in innovation.	Provides a stream of technology to be tested and a venue for publicizing capabilities and results. Provides assistance developing, testing, and validation protocols; may provide certification.	A diversity of test beds at academic, commercial, utility, and dedicated facilities guarantees appropriate testing conditions and measurement capability at the bench test, slipstream, pilot, and demonstration scales.
	Wastewater utilities operate facilities that collect and treat wastewater while managing costs for their ratepayers.	Provides low-cost access to knowledge of emerging technology that can meet regulations, improve performance, and lower costs.	Provides early input to steer laboratory research toward end-user needs. Participates in technology demonstration when technology is at slipstream or pilot scales. Partners with original equipment manufacturers on commercial demonstrations. Publicize project progress to ratepayers. Engage with regulators via existing channels.
	Equipment manufacturers and industrial technology providers design and build components and facilities for WRRFs.	Provides independent validation of equipment performance; improves utility knowledge of new products; accelerates regulatory review.	Provides early input to steer laboratory research toward commercially viable products. Collaborates on research grants and provide cost sharing. Partners with utilities on commercial demonstration. Archives and publishes performance data.
	Academic and commercial researchers develop, prototype, and test novel concepts for WRR at small scale.	Identifies channels to testing, demonstration, and commercialization; provides hands-on experience for emerging workforce.	Introduces innovative WRR technologies. Scans domestic and international research communities for latest research results. Collaborates on test protocols and metrics. Investigates the science and technologies that address challenges in WRR.
	Federal, state, local, and tribal regulators implement the rules that protect the environment and public health.	Identifies and broadcasts emerging regulatory needs to the technology community; introduces validated technologies with minimal overhead.	Provides early input to steer laboratory research to achieve regulatory goals. Communicates regulated standards and metrics. Review slipstream and pilot test data. Collaborates on development of validation protocols. Accepts validated test data and accelerates inter-regional technology approval.
	Technology validators rigorously test and report on the performance of new equipment.	Provides a steady stream of business to certify technologies and technology evaluation platforms; opens collaboration opportunities.	Provides early input to enable laboratory research that can be tested against accepted standards and metrics. Leads the development of validation protocols. Certifies test beds.

Government Agencies	The **DOE** promotes a safe, secure and clean energy system.	Promotes technology and policy innovations that can drive down energy consumption and increase energy production at WRR facilities.	Funds early stage research and development efficiency and WRR projects that are tested in-network. Balances cost-sharing requirements that incentivize early engagement with new technology against financial commitments that are a barrier to participation.
	The **EPA** implements federal legislation that protects human health and the environment.	Enables federal regulation to keep pace with evolving technology; accelerates inter-regional transfer of technology testing and experience.	Creates water-treatment regulations that drive WRR research and development needs. Convenes state-level regulators. Contribute expertise from prior technology-testing programs such as ETV.
	The **National Science Foundation** supports basic research and education and workforce development, including that related to water.	Enables bench-test scale researchers to pilot-test and scale-up new technologies; creates opportunities for education and workforce development.	Funds basic science and innovation on the nexus of food-energy and water systems. Contributes ideas for technologies to be tested across the network and provides student scientists to perform work.
	Other federal agencies including the **USDA, Bureau of Reclamation, Army Core of Engineers, National Oceanic and Atmospheric Administration,** and **Department of State**	Early access to new technologies that align with each agency's roles and responsibilities in water management. Provides platform for testing and scale-up of new technologies required to meet emerging agency missions.	Any agency that has a stake in water supply and water discharge is a potential supporter of technology that would be tested in-network. Federal agencies bring experience in management of facilities and data for the public good.
External	**Policymakers**	Informs policymakers of current and emerging capabilities to treat water. Inter-regional networking of policymakers in water management can be a crucible for sharing of best practices and a crucible for policy innovation.	Supports federal, state and local research and development funding. Leads educational tours and public demonstrations. Works with regulators to drive emerging technology uptake.
	Communities	Facilitate academic/municipal outreach and education. Facilitate K-12 education and tours.	Early identification of issues of public acceptance of new technology. Engagement with community members to encourage acceptance of new technology and steer development and deployment pathways that improve trust and acceptance.

The design of the TBN should enable stakeholders to capture value at all levels of participation and engagement. As indicated, the underlying structure should enable stakeholders to access information within the guidelines of their specific need (e.g., performance under a specific set of conditions or documented implementation). This document explores in detail a concept of operations and pathways to establish a network that benefits all stakeholders.

Processes, Products and Outcomes

For the TBN to be successful, stakeholders must derive value not only from the acceleration of new technology, but from their participation in the network as well. In that sense, there is a distinction between the network's *processes, products,* and *outcomes.*

The network's *processes* are the features of the network and the activities undertaken by the stakeholders as they interact with the network. For example, the network might help a small company identify a suitable utility at which a new technology could be demonstrated (the LIFT test bed directory can already accomplish this in some cases). Participation in network processes can provide an immediate return on investment for stakeholders and/or contribute towards the network's products and outcomes.

The network's *products* are the tangible outputs of collaboration between stakeholders. Such products might include peer-reviewed or informational data, protocols, and publications. The network's products may also provide a direct return to the participants who developed them (a publication may support a subsequent decision to install new technology), and/or they may help the industry advance towards the network's desired outcomes.

The overall *outcome* of the network will be to accelerate the adoption of new water technologies that can reduce costs, improve efficiency, and recover resources (i.e., water, energy, and nutrients), while maintaining or improving public health and reducing environmental risks. These goals will be accomplished by informing stakeholders of specific technology options to help guide capital investment while minimizing capital and technology risks. These are long-term outcomes that justify investing time and effort in the development and operation of the TBN, but they may be insufficient to drive stakeholder participation (and, by extension, acceleration of technology implementation).

The remainder of this document describes these processes, products, and outcomes in detail, and describes guidelines for implementing a successful WRR technology-development network. The components necessary for technology innovation in the WRR industry already exist; only that connectivity between those components is missing. The proposed structure can result in a self-sustaining network because it delivers value to its participants.

The network cannot be created instantaneously. Building the communications channels and developing the relationships that define the network will require some investment of resources. Furthermore, sustainable operation of the network will require both financial and institutional support. Many of those inputs are resources that would have otherwise been dedicated to independent research, design, and development (RD&D) efforts. By investing a small amount of time in coordination of those efforts, the return on RD&D investment can be increased substantially.

Network Processes

All aspects of operating the TBN will facilitate the transition of technologies from bench scale to demonstration. The TBN not only connects the technology developers to a set of facilities at an appropriate scale, it provides natural touch-points between developers, utilities, and regulators, as well as education and workforce training to future leaders in this sector. These touch-points can steer development efforts to meet utility needs and address regulatory concerns. They can also provide advance knowledge of emerging technology to operators and regulators, thus creating both business and regulatory pull, as well as unique educational experiences and materials to attract the future workforce. The three essential processes of communication, technology testing, and validation of results on certified test beds are explored in more detail in the following sections.

Facilitating Technology Testing

The ability of the TBN to push technology towards commercialization is based on rapidly connecting technology developers with local and appropriate test facilities where technology can be tested. The FAST Water (LIFT) test bed directory forms the backbone of this network function. Advertising the directory, both to raise awareness of it in the technology-development community and to increase the quantity and diversity of facilities, is the responsibility of the network's communications functions. It is envisioned that TBN-aware developers will be able to search and browse online for a facility that is local and is appropriate in scale, influent characteristics, and measurement capabilities.

The specific role that the TBN plays will depend on the Technology Readiness Level (TRL) of the solution being tested. TRLis a standard indicator of the maturity of the research. At low TRLs (levels 2 through 5), technology developers will use the network to connect with testing facilities and to work with potential customers (i.e., utilities) to refine technologies. The TBN can also help partners to co-fund development efforts using actual research dollars and/or in-kind access to facilities, technologies, intellectual property (IP), and personnel. Additionally, early engagement of multiple stakeholders can identify fit-for-purpose partnerships for value-chaining and multiple-use of technologies across the spectrum of resources in the wastewater stream. At mid-level TRLs (5 through 7), the TBN should help to provide a platform for pilot and demonstration experiments. At higher TRLs (7 through 9), the network can facilitate third-party validation, testing, or evaluation for regulatory approval. Table 1 lists these roles and the value that each member brings to advancing technologies throughout the TRL spectrum. This testing may also support investment decisions where performance can be weighed against capital and operating expenses of an existing technology. At all TRLs, the test bed operators, industry, utilities, and regulators will cooperate to define suitable and flexible metrics for testing (see the Products section, below).

Additionally, the TBN can advertise facility availability at specific test beds, or community demand for technologies that can meet defined criteria such as energy performance and/or treatment efficacy. The network should facilitate test data hand-off between test beds that serve higher TRL levels and/or support testing under different environmental conditions or water qualities.

Communications Channels

A network is defined by its connectivity, and in the case of the TBN, the communications between stakeholders in the wastewater enterprise is the key to achieving the essential functions listed above. Communications gaps have been identified as more of a barrier to technology advancement than a lack of testing facilities. Because not all stakeholders will be core network members, the TBN will require external communications channels as well as internal ones. The *internal* communications facilitate technology testing, results validation and collaboration, enabling the diverse membership to work as a team. The *external* communications expand the size and impact of the network, enticing new members to participate and creating market pull through educational, technical, and marketing campaigns.

- **Internal Communications**
    - Directory and Internal News: Communication between facilities about each other's activities and capabilities, as well as sharing of protocols to ensure that similar work is comparable where appropriate.
    - Test bed Access Requests: Arguably one of the most important functions in pushing technologies along the development pipeline is enabling technologists to connect to test beds with appropriately sized and scoped flows, slipstreams, necessary processes and process configurations, bench/pilot space, instrumentation, and staff. Similarly, optimum utilization of these capital-intensive laboratories and test beds requires a steady and manageable stream of innovative technologies at appropriate scales.
    - Collaboration: The TBN should enable enhanced collaboration among the community of technology developers and validators, users, and standard-setting bodies. Collaboration between industry and academic/government researchers is increasingly favored by R&D funding organizations, and the TBN will accelerate both partnering and access to current funding opportunities. The network may also provide a forum for technologists to research the capabilities of emerging technologies.
    - Access to Test Data and Demonstration Results: The TBN will create a data repository (see the Products section). Facilitating secure, reliable, and appropriate communication with this data repository is a process that enables it to realize value. In the wastewater treatment and resource recovery industry, technology pull is tightly linked to the policy and regulatory environment.
    - Guiding Policymakers and Regulators: System performance results can be shared with policymakers and regulators at the preliminary stages of project development. These internal communications provide early guidance to expected availability of new technologies and processes before they are fully validated. The data repository (including validated metrics and performance results) can be used by regulators to generate permits and by policymakers to update regulations.

- **External Communications**
    - Recruiting: The network should start with a small number of core members representing the various membership-eligible types of institutions such as test beds, utilities, manufacturers, and regulators. Broader impact will require continued growth, which depends on an effective strategy of outreach to potential members whose participation can rapidly create additional value. This recruiting may be accomplished through various channels such as email campaigns, professional online

networks, conference presentations, and a strong web presence providing valuable digital resources.

- Dissemination of Results: Technical communications will be a primary mechanism to attract new members to the TBN. The community of scientists, engineers, managers, and investors should be made aware of the TBN's activities and progress via technical publications, conference presentations, and/or hosting of TBN-focused webinars, meetings, and workshops. The TBN should organize technical session(s) at the annual Water Environment Federations Annual Technical Exhibition and Conference (WEFTEC, https://www.weftec.org/), and/or other similar conferences to recognize achievements, present findings, and coordinate activities.
- Public Outreach: The TBN can enhance the public's ability to understand emerging technologies and WRRFs by issuing timely press releases and enabling on-site reporting by the news media. These outreach materials should be developed by national organizations, and the network should lead local media and public interactions. Literature designed to enhance the public's understanding of emerging WRR technologies should be supported by a strong social-media presence that leverages its members' social media and other online assets.
- Training: The TBN should develop training materials as specific network processes become mature. As technologies are demonstrated within the network, network members can use that experience to develop training materials and manuals for emerging technologies. These may be made available online or delivered as instructor-led courses facilitated by the TBN.
- Education: (K-12 and undergraduate). The TBN should design educational materials for teacher use and general public review. These may include information that emphasizes (1) the importance of WWR to protect public health and the environment, and (2) the work that the TBN is doing to improve the industry's environmental performance while reducing costs and still protecting public health. The TBN should provide local coordination for a national effort to distribute these materials.

Validation and Certification

As discussed above, formal validation of technology is critical to its market acceptance. The existence of performance standards acts as a market signal to technology developers, creating a "market pull" for new technologies.

EPA's experience with ETV suggests that water treatment technology validation can be costly—approximately $100,000 per treatment technology. The timeline for technology validation is approximately18 months. Supporting technologies, such as on-line sensing, can be validated more quickly with less expenditure. Formal validation can be made more efficient when technology can be evaluated against agreed-upon metrics and tested under pre-defined protocols.

Furthermore, the test beds themselves should undergo some sort of certification to assure their customers (i.e., utilities, developers, and regulators) that the technology-validation results they are producing are accurate. The TBN can benefit the test beds by developing a framework under which test beds can be accredited or certified to test to specific standards.

Products

The TBN's products are the tangible outputs of collaboration between stakeholders. The network's products provide a direct return to the participants who developed them, and they may help the industry advance toward the network's desired outcomes. The TBN should produce and distribute publications and educational materials, standards, test data, IP, and inter-regional technology transfer.

The values of the TBN products are stakeholder dependent. The value comes from identifying relevant information to guide decisions, thus enabling stakeholders to make sound technology decisions and accelerating the decision-making process.

Repository of Test Data and Results

A core product of the TBN will be test data and results. The TBN will make that data accessible by network members in data repository. The data must be of sufficient quality and scope to serve as evidence of a technology's performance for the industry's regulators. Regulators and policymakers will be needed to specify the types of data that can be used to validate a technology's performance for further scale-up or acceptance. To the extent possible, test data and results should be third-party verified. The TBN itself may be a key participant in the process of certifying various entities to verify test data and results.

The process of designing a repository for test data will require significant effort and stakeholder input. Considerations for repository design include data variety (i.e., data that may be collected on various time and flowrate scales, as well as data that may not be time- or place-based), data quality, and user access controls. Data security will be extremely important to this effort, both generally, and specifically when and how data can be shared within and outside the network to simultaneously protect IP and drive regulatory uptake.

It will be necessary to convene working groups of stakeholders in the wastewater technology field to define requirements for the data repository. Technology developers and manufacturers will be needed to specify the types of data that can be collected in a test protocol. By developing metrics and standards for data collection and analysis, the TBN can ensure the quality of the test results.

Data scientists will be needed to help developers communicate with users and to normalize data. The network should expect to employ the expertise of a third party with experience in building data portals.

Metrics, Standards, and Protocols

A TBN can serve as a hub for the development of technology performance standards. The process of setting performance standards benefits from the experience of multiple stakeholders. Validation entities are the most fluent in the challenges of testing to a set of standards, while regulators can define the performance standards that technologies must meet. Technology developers benefit from early exposure to the standards they will strive to achieve, and utilities can contribute operational constraints.

The TBN can also facilitate efforts to benchmark existing facilities against existing and emerging standards. Published protocols for testing, measurement, data collection, and benchmarking are key products of the TBN. For example, an ASTM-like standard could be achievable over time (https://www.astm.org/Standard/standards-and-publications.html).

Inter-Regional Cooperation

The inability of policymakers, regulators, permit-writers, and utilities to accept the results of testing and demonstration of new technologies that occurs outside of their region has been identified as a major challenge to accelerating WRR technology adoption. The TBN will be designed to enable stakeholders from various regions to quickly adopt best practices, cooperate across regional boundaries, and encourage policy innovation that overcomes this barrier. Two specific forms of inter-regional cooperation have been shown to be effective in isolated prior examples. The TBN will replicate these successes by developing data- and information-sharing protocols and practicing early stakeholder engagement. Examples of inter-regional cooperation include the Great Lakes region with the 10 States Standards (http://10statesstandards.com/) and the Chesapeake Bay Program (https://www.chesapeakebay.net/who/how_we_are_organized).

- **Reciprocity Agreements** can be useful between regions with similar environmental conditions and constraints. Reciprocity agreements enable regulators in one region to accept certifications and permitting procedures developed in a different region. Reciprocity agreements could even be developed internationally. The key advantage of reciprocity is to broaden the scope of technology solutions considered within a limited budget. Reciprocity agreements provide value to technology developers (larger potential markets), utilities (a broad set of potential solutions), and permitters (access to a large dataset of performance information). An example of reciprocity is TARP - The Technology Acceptance and Reciprocity Partnership. Set up by 8 states, it focuses on "New technologies often face unnecessary and financially burdensome regulatory and permit hurdles that slow down or prevent their use". Reciprocity can be summarized with ISO 14034 (https://www.iso.org/standard/43256.html) as "*verify once and accept everywhere*".
- **Regional Cooperation** occurs when stakeholders from multiple jurisdictions agree to collaborate towards a specific WRR goal. An example is the recent agreement on nutrient loading in the Chesapeake Bay (https://chesapeake.usgs.gov/nutrientandsediment.html). In the Chesapeake Bay, regional data sharing on performance testing of onsite systems for use in technology approval is another example of cooperation that is a step short of reciprocity which may be more difficult to attain. At a higher level, broad, regionally-appropriate publications such as the 10 State Standard demonstrate that regional cooperation is possible over very large areas (http://10statesstandards.com/). Wastewater standards were updated in 2014 and are reported in: Recommended Standards for Wastewater Facilities (http://10statesstandards.com/wastewaterstandards.pdf)

Intellectual Property

IP (e.g., patents, trade secrets, and unpublished methods) will be developed by member organizations working at testing facilities within the TBN. Thus, the TBN facilitates the development of IP, and if resources are available, the TBN may be able to support some of the administrative burden of protecting IP. However, the governance of the TBN should be such that the IP's developer will retain control of it.

IP may be used as an incentive, even while it is protected for the benefit of the inventor. There are many examples of research collaborations that are mutually beneficial because access to IP (e.g., a limited-time royalty-free license) can be negotiated in lieu of fees or other up-front costs.

Publications

Some of the TBN's most visible products will be publications. Publications may take various forms, and the network's role in producing them will vary.

Peer-reviewed scientific papers are a primary output of academic and national laboratory researchers. These researchers will be enabled by the network and they may forge new collaborations for publication through the TBN. Annual conference presentations (see Communications Channels, above) will provide a consistent venue for publication of network results.

The network will also create and publish templates for performance reports, targeted brochures, whitepapers, news articles, and educational materials (K-12) that translate technology success stories for non-technical audiences such as policymakers and the general public.

Outcomes

The TBN's outcomes are measured as contributions to the high-level goals of the its participants. These outcomes are largely long-term, and while they contribute to the justification for investing time and effort in the TBN's development and operation, they are insufficient to drive participation (and hence technology acceleration). Nonetheless, as the network is designed and begins operation, it is important not to lose sight of the intended high-level outcomes.

For each stakeholder, the primary outcome will be informed and accelerated decisions about technology and processes. That outcome could include further research, investment, permitting, or updating of regulations.

Accelerating Innovation and Technology Adoption

The most proximate outcome of the TBN is to accelerate technology adoption at WRRFs, which underpins most of the remaining outcomes of environmental protection, energy and water security, lower costs, and greater economic opportunity. However, "acceleration", much like "innovation", is hard to measure. This difficulty is acknowledged while defining acceleration as the primary desired network outcome. It is of the utmost importance to all stakeholders, provided that accelerated adoption of new technology does not conflict with other goals or create an unacceptable level of risk. LIFT is already working its utility members to track the goal (http://www.werf.org/lift/visualizationtool). The LIFT survey will be reissued periodically to track progress.

Mitigate Risk

The WRR industry, because of its role as a municipal service and its ultimate mission to protect public health and the environment, is risk averse. The TBN products (i.e., publications, standards, data, and results) can help to mitigate following three types of risk:

1. **Technical risk** that a test or a new technology may fail can be spread across the network instead of repeated over multiple demonstrations. This risk is spread in two ways: 1) additional tests could be performed at other facilities if one facility only has capacity for limited number of tests; and 2) multiple technologies could be tested in parallel to increase the chance that a successful solution is identified.
2. **Investment risk** in developing new technologies is decreased by giving those technologies a shorter path to market (or to demonstration of non-marketability). Capital risk of constructing new technologies is lowered by their successful demonstration.
3. **Risk of loss of public trust** is reduced through education and communication of a project's progress and success stories.

Improve Energy Security

WRRFs are currently a major consumer of energy in many municipalities, and at the same time, the water they treat contains significant quantities of available energy. Because most WRRFs have significant water storage capacity (both in terms of inflow and outflow), the timing of energy consumption and production can often be adjusted at these facilities. WRRFs can contribute to energy security by consuming less, producing more, and integrating into regional energy grids in a manner that reduces congestion and/or alleviates instabilities and price-shocks associated with "peak" and "trough" demand periods. However, WRRFs can only deliver these services with a new generation of flexible and reliable WRR technology. With the rapid changes occurring in fuel and electricity markets, it is critical to accelerate new WRR technology into the marketplace.

Reduce Costs

Advanced WRR technology can reduce the cost of water management to ratepayers by decreasing the resources demanded by the WRR process. There will be up-front capital costs to deploying advanced WRR technology. The TBN can help to reduce these costs by sharing early experiences and best practices across the stakeholder community.

Create Jobs and Train a Future Workforce

The replacement of aging water infrastructure across the country will create trillion-dollar economic opportunities for the manufacturing and construction industries. The technology-accelerating results of a TBN can help retain the development and manufacturing jobs associated with new WRR infrastructure in the United States. The TBN can also facilitate hands-on opportunities for students and those already in the workforce to gain experience in the WRR industry that relates to innovation, acceleration, and implementation of new technologies. As with many heavy industries, the current workforce is aging, and training the next generation will be crucial for industry-wide stability.

Fostering Economic Development

With increasing water scarcity, access to water resources can inhibit economic development. Many industries have a strong need for water resources. These industries include chemicals manufacturing, metals processing, mining, agriculture, energy production, power production, food processing, high-performance computing, data centers, and recreation. Industrial water demand can be addressed by recovering, treating, and using wastewater. To control capital and operating costs, and minimize energy use and environmental impact, water should be treated with the "fit-for-purpose" concept in mind. Fit-for-purpose means that the end-use quality is considered when treating the water. Critical water-quality factors include salinity, pH, dissolved gases, turbidity, bacterial and viral loads, and biological and chemical oxygen demand. Water processed using WRR technology could support industrial and manufacturing activity in water-intensive industries if suitable technologies receive regulatory approval and are cost effective. A TBN designed with the fit-for-purpose concept in mind could accelerate innovation and enable industrial water reuse to foster economic development.

Protect Public Health and Improve Water Quality and the Environment

The WRR industry exists to protect the environment. Local, state, and federal (e.g., EPA) regulatory stakeholders all have an interest in technologies that improve the sustainability of wastewater management. As they improve energy performance, they should improve public health and reduce environmental risk (or at a minimum, not increase that risk).

Implementation Guidelines

In order to meet the demands described above, the TBN should be designed (see Figure 1) to catalyze technology push and market pull (as identified in the LIFT framework, http://www.werf.org/lift/About_Lift/What_is_LIFT_/lift/What_Is_LIFT.aspx?hkey=e4f8cc87-73e3-4cb1-bb34-caf66cb21912) while reducing barriers to deployment. This conceptual design is structured to extend the reach of individual test beds into a coordinated network where stakeholders generate and access validated data to accelerate the decision-making process. The TBN's membership roles and operational structure should be designed to achieve the outcomes listed above using the following mechanisms:

- **Technology Push:** Improve access to opportunities that accelerate Research, Development, Demonstration, and Deployment (RDD&D) of WRR innovations.
- **Engagement and Feedback:** Increase connectivity and communication between technologists, manufacturers, utilities, regulators, educators, students, and the public.
- **Market Pull:** The market pull comes from the need for improved performance at the WRRF. Improved performance includes reducing net energy use, reducing costs, and meeting new regulatory requirements. By informing the regulation and policy landscape, the TBN helps shape demand in the wastewater treatment sector

The TBN should not attempt to replace regulators and permitters. This action could reduce participation in the network. Rather, the engagement and feedback between regulators, permitters, innovators and industry should be designed to give the regulators and permitters data and tools to more effectively perform their duties.

The TBN must be appropriately structured so that each of these objectives are met using maximum support for technologies throughout the development and deployment pipeline. Components of the TBN's structure include the test beds themselves, and the organization, membership, and staff of the TBN.

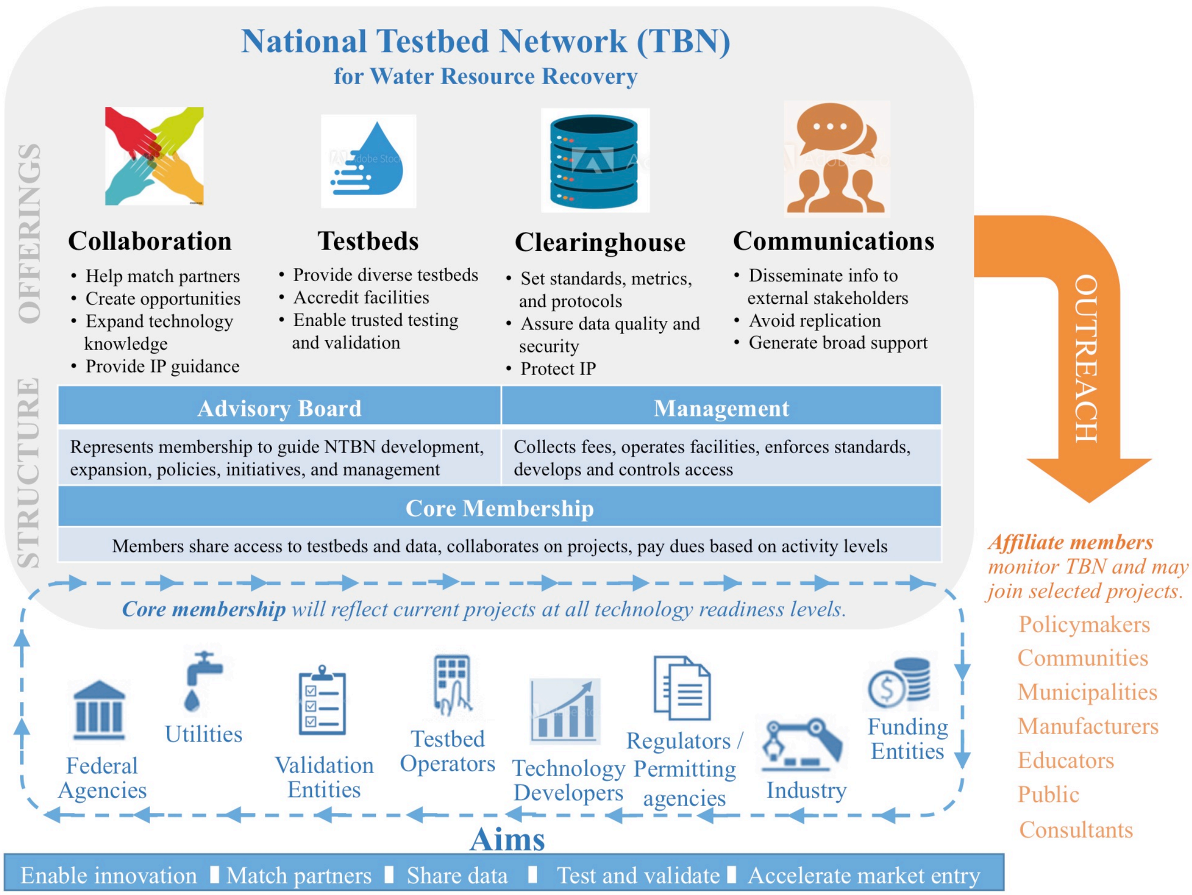

Figure 1: The structure of the national testbed network (TBN) is designed to enhance communication among members (regarding test bed access, collaboration, and data archiving/publication) as well as with the broader community of non-member stakeholders such as policymakers and the general public. Educational outreach to university, high schools and middle schools, though not specifically depicted, is a key part of the communication between the TBN and community members.

TBN Membership

At least two levels of membership should be considered for inclusion in the TBN. The financial responsibilities of network members will depend on the amount of research that the TBN is able to support.

In order to keep the network focused on accelerating technology deployment, *core membership* in the network will be limited to committed participants (i.e., stakeholders who have an active and technical role in research, development, deployment, and regulation). These stakeholders include the test bed facilities themselves, technology developers (academics, small businesses and OEMs), technology vendors (OEMs and construction companies), utilities, regulators, third party validators, and RDD&D funding entities. The core members will do the work of developing and implementing the processes of the network, and guiding the activities towards useful products and successful outcomes. Their roles and responsibilities are as follows:

- **Test beds and Test bed Operators:** Test beds are facilities (see below) that host evaluation of wastewater technologies. Test beds can be operated by public or private entities such as utilities, universities, government laboratories, and industrial facilities. Test beds can range from bench-scale experiments to full-scale demonstration. The network may accredit facilities, enabling them to provide trusted testing and validation services. Test bed *operators* provide facility access to network members. Test bed operators manage assets and ensure that test data is collected and deposited in the data clearinghouse. Test bed operators maintain standards, metrics protocols, and methods, and provide test reports as required. Test bed operators ensure that intellectual property is managed according to the network's requirements.
- **Federal Agencies:** Federal agencies include those with regulatory authority such as the EPA and Bureau of Reclamation, as well as those with science, technology, and resource missions, including the DOE, the NSF), the USDA, the State Department, the Army Corps of Engineers, and the Department of Defense.
- **Utilities:** Utilities provide wastewater services to communities and can be public or private and range in size from serving small communities of hundreds of homes, to major metropolitan areas of 10 million people. Utilities are responsible for securing permits and meeting or exceeding regulatory requirements. Utilities are funded from several sources, including ratepayers, federal and state appropriations, and bonds. Utilities are typically the end users for the technologies evaluated in the TBN.
- **Validation Entities:** Validation entities review performance data. They ensure that regulators and permitting agencies have the required information to evaluate wastewater technologies and make decisions about regulatory standards and permit approval.
- **Technology Developers:** Technology developers generate new research ideas, technologies, and intellectual property to meet wastewater treatment requirements. They include universities, research institutes, government laboratories, and private companies. In the TBN, the goal of technology developers is to deploy the technology with end users.
- **Regulators and Permitting Agencies:** The primary role of regulators and permitting agencies is to ensure that public health and the environment are protected from harm. Federal regulators such as EPA set standards that must be met nationally without specifying the mechanism to achieve the standard. States or regions may also have regulatory functions within their own jurisdictions. Permitting agencies review the performance data of proposed technologies or solutions to ensure compliance with regulatory standards. Permitting agencies function at the state or regional level. The TBN enables regulators to set appropriate standards using validated performance data. The TBN enables permitting agencies to evaluate technologies and issue permits based on validated performance data considering the environmental conditions, technology performance, and regulatory requirements in the permit application.
- **Industry:** Industry is the primary vendor or aggregator of the technologies for utilities and other end users. Industry may internal develop, externally license, or acquire the technology from a technology developer. Industry uses the TBN to provide independent and validated information to share with potential customers and permitting agencies.

Industry also may use the network to make decisions regarding technology acquisitions from developers. Industry may also be an end user of the technologies.

- **Funding Entities:** Funding entities support development of technologies. They include both public and private organizations, federal agencies such as DOE or NSF, state or regional agencies, investors, or industry. Funding entities may also directly support the TBN by including development of standards and metrics, ensuring reliable operation of test bed facilities, or providing secure platform data dissemination. Public funding entities use the TBN to meet public goals in terms of technology performance and deployment while meeting regulatory requirements. Private funding entities use the TBN to increase risk-based returns on investments.

In order to facilitate a broad range of benefits, *affiliate membership* in the TBN should be made available to policymakers, educators, municipal representatives, and the interested public. Affiliate membership will never carry a financial cost, and will enable stakeholders to access to non-proprietary publications and educational materials. It will also institutionalize two-way communication between the technical and non-technical communities.

Governance

The amount of attention that must be paid to the development and maintenance of the TBN will depend on the its size, growth rate, and maturity. Depending on the demands of the community, the network may need to become its own corporate entity (most likely a non-profit agency), become a part of an existing entity or trade association, or exist solely as an online entity. The operation of such an entity will be provided by member-stakeholders. Under any of these scenarios, TBN staff will perform the following functions:

- **Management**: Prioritize work based on strategic goals, resources, and emerging opportunities. Make day-to-day decisions about staffing, funding, budgeting, communications, etc.
- **Communications**: Develop a strategic approach to communications. Operate internal communications channels and prepare external releases.
- **Supporting Functions**: Provide administrative support. Advise management on national, regional, and local technical matters such as data systems, legal issues, safety, quality, and emerging issues.
- **TBN Advisory Board/Steering Committee**: Define mission and strategic goals, approve management decisions, ensure representation by all stakeholders (technologists, utilities, manufacturers, regulators, policymakers, etc.), and oversee growth and/or evolution of the network.

Facilities

The core components of the TBN are the test beds themselves. A large number of test bed facilities exist and many have self-identified as potential participants through the FAST Water Network component of the LIFT program's test bed directory (see Figure 2). This network is building from LIFT with the goal of organizing the facilities into a functioning network. Test beds are categorized into various levels as follows:

- **Level 1 (Bench Scale)**: A university or research lab that can assist with bench-scale work, but is not dedicated to piloting new technologies.
- **Level 2 (Recovery Facility that is a Willing Host)**: A WWRF that is interested in innovation and willing to host a project, but does not have a dedicated test facility.
- **Level 3 (Recovery Facility with Dedicated Space)**: A WWRF or research lab with a dedicated physical space available for piloting innovative water technology.
- **Level 4 (Facility Dedicated to Technology Testing)**: A staffed facility dedicated solely to R&D/piloting of new technologies (can be housed at a functioning WRRF).

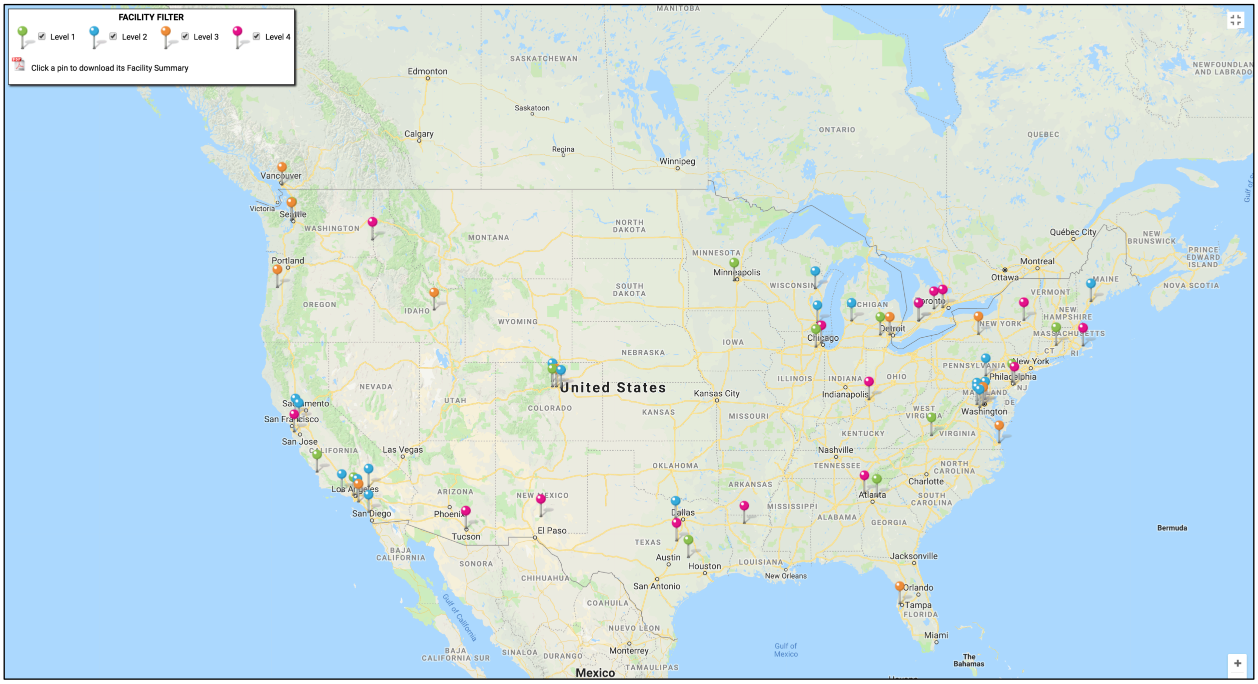

Figure 2: A map of the LIFT facilities captured on December 10, 2017 (source: http://www.werf.org/lift/LIFT_Test_Bed_Network.aspx).

The TBN is a partnering system wherein promising technologies could be evaluated at a sister facility for evaluation under different conditions or water systems. These facilities not only form the core (and most capital-intensive) aspect of the TBN, they already employ technologists, operators, and managers who could help to staff the network (see below). Beyond self-identification through LIFT, an ongoing effort of the TBN will be to increase the quantity and diversity of facilities that participate to include a wide range of sizes, operating climates, influent characteristics, and outfall constraints, as well as the types of technologies that can be tested (e.g., water reuse, digestion, energy, heat recovery, collection system, and carbon diversion).

Specific efforts to increase the breadth of participating facilities within the TBN may include public outreach and targeted requests inside the network to identify new members. Based on the experience of Networking and Information Technology Research and Development (NITRD, https://www.nitrd.gov/) wireless technology test bed portal (a near-perfect analog to LIFT's Test Bed Directory), and the outgrowth of that project into the National Advanced Spectrum and Communications Test Network (NASCTN) program, it is expected that this effort to build a TBN has a high potential for success.

Conclusions

There are national and international needs for a secure clean water supply. Wastewater recovery provides a unique opportunity to meet these demands. Due to potential health and environmental risk, as well as limited access to capital, existing WRRFs are extremely risk adverse and resist implementation of new technologies. In addition, current wastewater management is a large and growing energy consumer. New technologies could improve water recovery and net energy use simultaneously. To achieve these goals, stakeholders from technology developers and investors, to utilities, permitting agencies, and policymakers require access to performance information using defined metrics and validation methods. A water resource recovery TBN could provide the required resources for stakeholders to make informed decisions and accelerate innovation. Success will result in improved water and energy resource management.

Appendix A: Stakeholder Value Narratives

For the TBN to accelerate implementation of technologies in WRRFs, the key stakeholders must be identified. The value proposition for each stakeholder must be articulated to ensure that the network is worth the investment and participation.

The network will thrive when the benefits of participation outweigh the financial and administrative costs of membership. The chief benefit of participation is accelerating technology deployment. This benefit will almost certainly take time to accrue after launching the network. Additional benefits may include a wider network of collaborators and partners in applications for R&D grants, direct R&D funding, increased communication with regulators and policymakers, opportunities for workforce training and development, and technology-transfer assistance.

For example, the network could accelerate dissemination of best practices and innovative technologies that support emerging regulatory drivers. The National Research Council has recommended that *sustainability* be integrated as a key driver by regulatory agencies such as the EPA (NRC, 2011). By enabling advances in wastewater treatment and resource recovery, the TBN would support efforts to achieve environmental sustainability (NRC, 2011) focused on a problem of broad national interest (Anastas, 2012).

Utilities (WRRFs)

Wastewater utilities exist primarily to protect the environment. The TBN's primary goal of accelerating technology development supports better quality wastewater treatment solutions. These reduce costs (through wise infrastructure investment and operating costs) such as fewer pipe inspections, which meets the utilities' secondary goal of keeping costs down for ratepayers. The existence of the network also helps to mitigate the capital risk associated with new technology. This benefits utilities, which are traditionally risk-averse.

Virtually all utilities are cognizant of both the performance of their facilities and of their specific regulatory environment. Depending on the size and the nature of leadership, many utilities have little knowledge of the state of technology and emerging solutions that could meet their regulatory obligations while reducing taxpayer costs. With small or less-advanced utilities, the TBN could function as the research and discovery arm with a wide range of sophistication. The TBN could serve as a utility's "in-house Ph.D." and provide a resource on the role of technology in its capital and infrastructure investments. Participation in the TBN effectively reduces fixed costs in comparison to hiring an in-house technical staff or retaining paid consultants.

Published metrics, standards, and guidelines increase utilities' confidence that technology will work as designed. Accepted test results and regional agreements that are derived from validated testing lower the cost of doing business by avoiding lengthy pilots. Early stakeholder engagement of regulators accelerates technology into service, thereby lowering costs for ratepayers by getting higher performing technology into operation sooner. Access to a testing data repository, in combination with quality assurance of test beds within the network, help to manage capital risk when a utility considers deploying emerging technology.

Examples of utilities that could participate in the network include the East Bay Municipal Utility District (EBMUD) in California, the Municipal Water Reclamation District (MWRD) in Chicago, and DC Water in Washington, DC.

Academic Researchers and Technology Developers

University researchers are at the front end of the innovation pipeline. They are chiefly concerned with seeing their technologies accelerated into the marketplace. The TBN matches researchers to a facility at the appropriate scale to test, iterate, and fail quickly, thereby guiding resources to the most successful pathways to deployment. Testing through the TBN also prepares the engineering workforce by giving them hands-on opportunities to experience technologies in the field. Communicating through the network can reduce the cost of doing research by enabling connections for better grant teaming. Deployment of new technology creates engineering jobs for graduates.

Researchers and Investors have two areas where the TBN provides a value proposition.

- Researchers frequently select project directions by reviewing the peer-reviewed literature. Researchers have little guidance as to important questions that require novel solutions. The TBN connects researchers to practitioners with real challenges. Access to the industry, utility, and society challenges enables researchers to focus their work on developing viable solutions to important opportunities.
- Researchers develop innovative technologies but have limited time or resources to demonstrate their value. The TBN provides the channel to testing, demonstration, and commercialization of new technologies. Access to these channels enable investors to introduce products to market and achieve targeted performance.

The TBN features help to guide research toward successful outcomes quickly by facilitating test bed access, matchmaking, test-bed handoff, and early contact with regulators. Educational materials development and facilitation of peer-reviewed publications support workforce development and progress towards graduation. Collaboration platforms, test-bed handoff, quality analysis (QA) of test-bed performance, and intellectual property (IP) management can make the business of research easier and less financially daunting.

Examples of academic and other research institutions with vibrant programs in WRR technology include University of Colorado Boulder, University of South Florida, Stanford University, Argonne National Laboratory, Southern Research Institute, EPRI, Columbia University, and Research Triangle Institute.

Technology Providers and Manufacturers

For technology developers, time-to-market is critical to their financial sustainability. The TBN's ability to accelerate technology development (i.e., to get to scale and then to shorten acceptance time) could enable many innovations to succeed where others have failed. This acceleration is innately tied to risk reduction. First, shorter time-to-market mitigates investment risk. Second, better and independent testing reduces technical risk, which, in turn, shortens time-to-market. The TBN can also reduce the cost of doing business by enabling access to facilities (both real and virtual) that would otherwise have to be built or rented by the company. Finally, when it is successful in accelerating innovation, the TBN creates financial opportunity to grow the size of a new business, thereby creating jobs.

These parties have good knowledge of the performance, regulatory environment, and challenges in utilities. Technology providers lack access to innovative technologies developed by researchers. The TBN provides a matchmaking forum to expose technology providers to new options. In addition, the performance can be evaluated in a format of relevance for technology providers to consider.

Development of metrics, standards, and guidance accelerates testing and piloting by broadcasting best practices and avoiding duplication of effort. Matchmaking and hand-off services help to speed up testing. The data repository, regulatory engagement, and regional partnerships help scale outward by reducing risk for both innovators and manufacturers.

Examples of companies in this space include Cambrian, Evoqua, and Veolia. A comprehensive list of industry players in the WRR space is beyond the scope of this document.

Regulators and Policymakers

Regulators make the rules that protect the environment. They are the key authority between the policymakers who set high-level goals and permitting agencies who enforce rules on a case-by-case basis. Regulators are fundamentally risk averse and must maintain legislated standards of environmental protection even when considering novel technologies with broader sustainability benefits. Regulators can use information from the TBN to justify regulations that improve environmental protections, particularly when those can be achieved with technology that has a cost-benefit advantage. The network can also serve as a crucible for policy innovation that reduces many aspects of technical and economic risks.

The TBN's support for manufacturer-independent technology validation is the highest value to regulators. This is closely matched to the TBN's data repository, which makes the results of validation tests accessible to a broad range of stakeholders. It is also tied to the development of metrics and standards. Regulators will have early access to (and influence on) these standards by participating in the TBN.

Policymakers are public servants whose goals are to improve the quality of life for private citizens. They must balance environmental protection and energy security with economic growth and ratepayer costs. The availability of higher-performing wastewater technology gives policymakers more options to incentivize investments in cleaner and lower-cost treatment and resource recovery options.

Communications and outreach efforts can educate policymakers and communities. This function is tied to the data repository and provides quantitative backing for the advantages of new technology. It is also tied to early stakeholder engagement, providing critical touchpoints between innovators, regulators, policymakers, and communities who must balance competing priorities and who thrive on personal interaction.

Ultimately, policy makers and regulators must work together to meet environmental and health missions with a significant safety margin to greatly reduce risk. At the same time, they chart a pathway to continuous improvement while controlling or reducing costs of operations.

The TBN provides the following benefits across the regulatory process.

- Researchers and investors foster new technologies. Policy makers and regulators can observe these stakeholders and inform them of emerging needs that require solutions. The TBN enables multiple parties to develop solutions to challenges
- Technology providers and utilities seek cost-saving technologies to meet new regulations. The TBN introduces them to technologies that have been validated in the appropriate regulatory environment.
- The TBN enables policy makers to create informed regulations based on validated performance results.
- The TBN enables regulators to introduce utilities to solutions without requiring utilities to support a large technical staff.

Taken together, the TBN enables policy makers and regulators to more effectively make, inform, and enforce solutions that meet societal needs.

Department of Energy

The DOE's mission is to ensure a safe, secure, and clean energy supply while fostering economic growth. Water resources and technologies are a core component of the mission. Wastewater management consumes about one percent of the power supply; therefore, it warrants investment from DOE (Badruzzaman 2015). The TBN enables DOE to address the energy mission while enabling EPA to address its mission.

The TBN provides the following critical value propositions:

- Identify, invest in, and deploy technologies that meet EPA mission requirements while reducing energy consumption. The TBN provides a matchmaking opportunity to move DOE technologies into the marketplace.
- Engage and inform stakeholders (including researchers, utilities, and policy makers) of the opportunities to save energy while meeting the health and environmental quality requirements.
- Enables DOE to develop models of energy performance based on implementation of new technologies.

Environmental Protection Agency

The EPA's primary task is to protect human health and the environment. Unregulated, untreated wastewater discharge can degrade entire ecosystems, while thoughtful management of wastewater can ensure the health of lakes, rivers, oceans, and groundwater for drinking, recreation, and habitat while recovering valuable resources. Technologies advanced by the TBN can reduce the cost of environmental protection and can mitigate the risk to the environment of deploying the new technology.

In response to population and energy stressors and global climate change, wastewater facilities are at risk and impact the EPA's mission. The TBN enables EPA to monitor technology and develop and enforce policies based on validated technologies. The TBN also provides a forum for EPA to enable small utilities to access environmental data in a validated format without requiring a large technical staff.

Features that accelerate the adoption of technologies that protect the environment are the highest value to EPA. Outcomes such as regional agreements and rapid uptake by regulators are enabled by validated data and publications. Technology development, which leads to these outcomes, is facilitated by the TBN's matchmaking and collaboration platforms

National Science Foundation

The NSF supports basic research and people to create knowledge. The TBN creates high-quality workforce training and research opportunities in the field of water resource recovery.

Matchmaking and facilitating access between university researchers and utilities creates opportunities for students to learn and advance. Communications and outreach activities prepare the workforce from the earliest stages through post-graduate studies. Matchmaking also accelerates technology development which drives more inquiry into basic sciences. Collaboration platforms allow more diverse institutions to work on funded opportunities.

The NSF could use the TBN to link to research centers that they support including Engineering Research Centers, (https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5502) and Industry/University Collaborative Research Centers https://www.nsf.gov/eng/iip/iucrc/home.jsp). The NSF can also use the TBN to connect academic technology developers to pilot and commercialization opportunities through its SBIR programs.

Other Federal Agencies

Other federal agencies are stakeholders in water innovation but were not active participants in the working group that produced this document. The Department of Agriculture is charged with providing a secure water supply for agricultural activity and ensuring a safe water supply for rural communities. The Army Corp of Engineers ensures the integrity of water infrastructure to protect health, the environment, and commerce. The Bureau of Reclamation is responsible for inland waterways that receive discharged wastewater and are the sources for input water. The NOAA is responsible for the impact on the ocean and coastlines, the ultimate receiver of wastewater.

Appendix B: Background Studies

In "The Water-Energy Nexus: Challenges and Opportunities" (June 2014), the U.S. Department of Energy identified key issues with water-energy interdependencies and increasing water scarcity and variability. Water stress arises from a range of factors including population growth, regional migration, energy use, and climate change. Wastewater is one of the largest components in the water-energy nexus. Wastewater management (especially sewage treatment) is a large consumer of energy in many communities. At the same time, wastewater contains valuable resources that are of potential benefit to society. Appropriately treated wastewater can yield clean water for industrial and municipal use, low-carbon energy, and nutrients.

Since public wastewater facilities have historically served the critical but narrow role of reducing risk to human health and the environment, they are very risk averse and slow to adopt new technologies that go beyond their traditional historical mandate. Utilities work with consulting civil engineers (in many cases because they are legally required to do so) to design changes to their facilities. These engineers (who are conservative by training) produce conservative designs that must be approved by regulators, who add an additional layer of conservatism.

Risk aversion could itself stymie the realization of improved wastewater management outcomes. Significant investments in wastewater infrastructure are required. Several studies of the investment requirements for water management over the next 20 years estimate costs ranging from $0.6-3.6 trillion for the U.S. to $23 trillion globally (Booz Allen Hamilton, 2007). These investments will impact both developing and mature economies. The EPA Clean Watersheds Needs Survey indicates that wastewater treatment facilities alone require and investment of $271 billion over the next 20 years (EPA 2012).

The following sections include descriptions of prior and ongoing programs and initiatives that meet some of the demand for collaboration that advances sustainable wastewater-management technologies. There is precedent both within and beyond the wastewater management industry for such collaboration to be impactful.

Leaders Innovation Forum for Technologies (LIFT)

LIFT (http://www.werf.org/lift/) is an initiative managed by WRF and WEF to help bring new water technologies to the field. LIFT's strategy is based on the hypothesis that innovation is derived from both needs and solutions (technology demand and supply). LIFT currently encompasses the following activities:

- **FAST Water Network Directory**: Dozens of facilities nationwide have self-identified in a publicly available, online test bed directory. Facilities include information about themselves including their capabilities and areas of technology concentration.
- **Technology Scans:** LIFT identifies and evaluates innovative technologies to inform utility end-users, funders, and advisors and to expedite early adoption of technologies. Technology scans represent the power of technology supply.
- **Focus Groups:** LIFT convenes and facilitates working groups of utilities interested in collectively addressing specific common challenges such as shortcut nitrogen removal and water reuse. Focus groups represent the power of market demand.
- **LIFT Link:** LIFT Link is an online platform that enables collaboration between utilities and technology providers.

- **SEE IT Scholarships:** LIFT provides funds to utilities to get a first-hand look at new technologies by visiting peer facilities. Seeing these technologies in action allows visiting representatives to learn about them and their implementation in the real world.

Genifuel Project

In 2014, the LIFT technology scan effort identified the Hydrothermal Processing (HTP) concept under development at Genifuel Corporation as technology of interest to WRF members. HTP has been under development at the Department of Energy's Pacific Northwest National Laboratory (PNNL) for over 30 years. HTP converts wet biological wastes to bio-crude oil, biogas and clean water.

Between 2014 and 2016, WRF, Genifuel, PNNL and Leidos collaborated to perform a bench-scale technology evaluation of the HTP concept. In 2017, the process will be tested at pilot scale in the field by a consortium including WRF, Genifuel, SoCal Gas, Tesoro Refinery, and several municipal and industrial partners.

ETV and Cluster Programs

The EPA's Environmental Technology Verification (ETV) Program (December 10, 2017 1995-2014) pioneered a national-scale program for water resource management technology. By 2014, it had tested 500 technologies, developed 100 test protocols with over 200 active stakeholders and received global recognition. Although EPA's ETV program ended due to a lack of funding in 2015, an international consortium worked to bring elements of the program to a new ISO standard (ISO 14034) in 2016. Several water-testing organizations are considering adopting the standard for their operations.

A white paper developed by the Water Environment Federation's (WEF) National Stormwater Testing and Evaluation of Products and Practices (STEPP) working group proposed a national program to help the sector achieve inexpensive and consistently high-performance products and practices that can be used in a variety of regions and settings. Other Europe-based cluster evaluation programs are designed to address region-specific water needs. Facilities in The Netherlands and Sweden are listed as part of LIFT.

Water technology innovation developed in an industry cluster organization or network could help stimulate technology RD&D, improve cost effectiveness, and potentially streamline the regulatory approval process. Taken together, technology development in a cluster or network could help address water resource management challenges.

A number of cluster programs (a group that integrates stakeholders along the supply chain in a specific field) have been developed at federal and state levels since the 1990s. The EPA supports a clean water cluster program coordinated from the Cincinnati Research Facility (https://www.epa.gov/clusters-program). Recently, the New England states rolled out a roadmap for the New England Water Innovation Network (NEWIN), an industry cluster leveraging the region's expertise and addressing the needs of the regional water-sector (Figure 3).

Figure 3: New England Water Innovation Network (NEWIN)'s framework describes a spectrum of technology developers and the services a test bed network could provide.

NEWIN's framework for the innovation ecosystem is a useful starting point, demonstrating that a network can improve connectivity across scales and technology-readiness levels. However, the diagram does not include connectivity to the broader set of stakeholders required to accelerate technology in the wastewater sector, including regulators, validators, and utility customers.

Stakeholders from across the WRR community should seek ways to engage existing regional clusters and build upon their experience to create a national network that can accelerate technology adoption and inter-region translation of results.

Energy-Positive Water Resource Recovery Workshop Report

Demand for a national technology TBN for WRR was identified in a stakeholder workshop hosted by the NSF, EPA, and DOE. The Energy-Positive Water Resource Recovery Workshop (EPWRR) was a critical stakeholder meeting where the need for a TBN was identified.

In 2015, DOE, EPA, and NSF released the Energy-Positive Water Resource Recovery Workshop Report (https://www.energy.gov/eere/bioenergy/energy-positive-water-resource-recovery-workshop-presentations). The key findings are summarized in Box A1. WRRFs could transition from net energy consumers to renewable energy producers. Workshop participants identified key short- and long-term research priorities that could catalyze innovation in the sector. In addition, workshop participants identified challenges with regulatory, technical, social, and financial barriers.

- While compliance with water treatment standards will remain the core mission of future facilities, this long-standing priority has promoted a risk-averse culture. As a result, many facilities today are disinclined to deploy and validate advanced resource recovery technologies that could generate economic value. Pioneering facilities are needed to scale up promising technologies, validate them, and help set the standards for safely integrating resource recovery into existing and future WRRFs.

- Financing poses a perpetual challenge for the RDD&D of water resource recovery technology. Many WRRFs operate as regulated utilities in structures that leave little revenue for research and innovation. Without capital-improvement budgets, these facilities necessarily focus on maintaining existing services instead of building for the future.

The TBN could address following two critical challenges to technology deployment and validation at WRRFs. They are core drivers for implementing the TBN.

- **Lack of Standards**: Facility managers considering the purchase of new equipment or implementation of new technologies and practices need access to reliable, validated data from the field. Successful technology demonstrations build confidence that innovative approaches that are compatible with current systems and operating environments. Currently, the lack of rigorous testing protocols and test parameters impede the development of field data to support purchasing decisions and accelerate market adoption.
- **Need for Pioneering Facilities**: In a regulated utility environment, there is little benefit for being the first to implement an innovative technology or practice. Historically, each WRRF has been motivated to deliver a basic level of service with well-known technologies. However, technologies only become well known with a number of implementations at facilities of varying needs and sizes. With few, if any, facilities willing to be the first to use new and innovative technologies and practices, market acceptance can be significantly delayed. A facility (or multiple facilities) dedicated to piloting new technology would overcome this barrier and promote market acceptance.

EPWRR Workshop: Envisioning the Utility of the Future
Key Findings

April 2015

The WRRF of the future should assign top priority to wastewater treatment for the protection of human health and the environment. It should also expand its list of services and products in support of healthy, economically vibrant communities. For example, the future WRRF could effectively manage more diverse waste streams, generate fuel, produce water and fertilizer, and help communities recover other valuable resources. To achieve this vision, the ideal WRRF of the future should use and recover resources efficiently, coordinate with utilities and other community services, engage customers and the public in new ways, and deploy a range of smart technology and systems.

- **Resource Efficiency and Recovery**: Beyond merely treating wastewater, WRRFs of the future should emphasize the recovery of diverse resources, including water, nutrients, and energy. WRRF systems should effectively and economically safeguard public health and the environment while producing water, power, and other products to meet community needs and standards.
- **Integration with Other Utilities**: To meet the growing demand for clean water, WRRFs should continue to treat variable wastewater streams to high standards. In addition, WRRFs could produce electricity, lesser water grades, and saleable products that efficiently and economically serve a mix of shifting local priorities.
- **Engaged and Informed Communities**: To shift current community perceptions of wastewater treatment toward positive associations with resource recovery, WRRFs should actively engage with their customers, elected officials, industry, and the public. Initial outreach efforts should expand public understanding of sustainable water resources and awareness of WRRF goals. Ultimately, effective customer engagement could improve public infrastructure and increase local support for net-zero-water buildings and other integrated solutions to water, energy, and food supply challenges.
- **Smart Systems**: Future WRRFs could use a host of sensors, software, and innovative equipment to track performance and inform plant operations. Smart systems would enable facilities to actively monitor the volume and content of incoming waste streams, supervise plant operations, and verify the safety or quality of outputs to enable real-time adjustments in processing parameters.

The EPWRR Workshop identified the following near-, mid-, and long-term technology solutions that are under consideration and whose development and deployment could be enabled by a TBN:

- Near Term (5 – 10 years)
    - Shortcut Nitrogen Removal
    - Improved Solids Deconstruction
    - Water Reuse (fit-for-purpose)

    - Biogas use in CNG/LNG vehicles
    - Data-intensive biosciences (genomics, proteomics, etc.)
    - Constructed Wetlands
- Mid-Term (both Near-Term and Long-Term)
    - Real-time control, process monitoring, systems integration
    - Membrane bioreactors (anaerobic and fluidized bed)
    - Algae-based systems
    - Hydrothermal processes
    - Heat Recovery
- Long-Term (10+ years)
    - Modular Integrated Systems
    - Methanogens
    - Forward Osmosis
    - Microbial electrochemical fuel cells
    - Source Separation and Decentralization.

Additionally, the following technologies (not explicitly covered in the EPWRR Workshop Report) are known to be under active development in the WRR community (as reported in interviews of facility operators):

- UV disinfection
- Ultrafiltration
- Desalination
- Recovery of other products and resources
- Digestion enhancements
- Flow cell batteries power to allow gensets to rapidly spin up and avoid power disruptions.

Workshop for Developing Evaluation Metrics to Advance a National Water Resource Recovery Facility TBN

NSF, DOE, EPA, USDA, Water Environment and Reuse Foundation: Arlington, VA, **2016**; http://www.werf.org/lift/docs/EPWRR_Metrics_Workshop/EPWRR_Metrics_Workshop.aspx.

The workshop focused on the following technical areas:

- Developing Common Metrics for All Technologies
- Developing a Framework for New Metrics as new Innovations Emerge
- Storing the Data Generated During Testing
- Sharing Information After the Pilot is Completed.

The findings were prepared by J. Mihelcic (USF) and are summarized in Table 2.

Table 2: Specific metrics and indicators identified by the four breakout groups in the Metrics workshop

Metrics	Breakout Group 1	Breakout Group 2	Breakout Group 3	Breakout Group 4
Mass Balance (material and energy)	-Specific Rates (intensification): -Mass Balance for COD, N, P (mass removed/gallon/d) -Energy balance (O_2/kg mass removed; kWh/mass removed/d)	-Energy (kWh/kg-recovered *or* kWh/m^3-recovered *or* kWh/ft *or* EEO – electrical energy per order, kVAR) -Products Recovered (kg, m^3, kWh-product/kg-recovered or removed *or* kg, m^3, kWh-product/m3-treated and % recover of resource) -Chemicals Used and Biomass produced (kg/kg or m^3-recovered or m^3-t) -Operation Factors (temp., location, weather, flows, loads)	-Mass Balance for C, N, P (Generic inventory data, which are needed to conduct mass balances for specific analyses of nutrient recovery, GHG emissions) -Energy balances (Inventory data needed to conduct energy balance including a quantification of the potential for energy recovery and capacitance in treatment technologies and their peak power demands)	-Mass Balance and stoichiometry (COD, BOD_5/COD) -Energy Balacne for Power and energy consumption (kWh/m^3-whole plant vs. unit process) -Products Recovered (kg valuable product recovered/m^3 treated water)
Economic	-O&M costs ($/mass removed/d) -Live Cycle Costs -Avoided costs from Resource Recover -Other costs (labor, training, expertise, remote control) Physical Footprint (land)	-O&M Costs (OPEX($/m^3-treated) and Capital Costs , CAPEX ($/m^3-treated) Cost to Recover Resource ($/kg or m^3-recoverd or kWh-produced)		-Life Cycle Cost; O&M Costs (OPEX) and Capital Costs (CAPEX) -Cost to Remove Resource ($/kg removed or detected) -Other costs (Technology development) -Physical Footprint (land)
Risk	-Process Risks -Scalability -Resiliencey (time to startup, time to recover) -Ease of integration in existing infrastructure -Degree of automation	-Variability over 24-hour cycles (diurnal; discreet vs. composite; seasonal (e.g. wet weather conditions) -Cost uncertainty -Operationa availability (actual running time vs. down time)		
O&M		-Staffing requirements (FTE), training, education, skill level of operators, certifications, labor categories	-Ability to meet specific operational goals (e.g., 100% operational over two-week period)	-Level of education/certification required -Personnel hours
Environment	-Included in mass balance (material and energy) category -Carbon footprint -Water quality	-Included in mass balance (material and energy) category	-Included in mass balance (material and energy) category	-Boundary conditions -Carbon footprint -Water quality (performance based on end use (i.e., irrigation, industrial, potable, etc.))
Regulatory		-Statistics based effluent concentrations -Emerging contaminant removal, cost, feasibility, etc.	-Constituent concentrations will determine ability of process to meet NPDES permit specifications or requirements for direct or indirect re-use -Toxicity assays	

Workshop for Developing the Structure of a National Energy Positive Water Resource Recovery Facility Test Bed Network

NSF, DOE, EPA, USDA, Water Environment and Reuse Foundation: Denver, CO, **2016**; http://www.werf.org/lift/docs/EPWRR_Structure_Workshop/EPWRR_Structure_Workshop.aspx

Goals of the workshop were:

- Identify the stakeholders and their needs for the test bed network
- Develop network pathways, functions, and structures to meet the needs and objectives
- Develop plans for the formation, operation, and assessment of the test bed network.

The workshop was charged with considering both the structure and function of the TBN. In the breakout sessions, the attendees compared TBN from other industries and did not identify a unique structure needed for WRRFs. The output focused more on the function of the TBN. The findings are summarized in the box below.

Functions Identified By the Breakout Groups

TBN Central Function: Accelerating market adoption of new technologies

Specific major functions identified:

1. **Matchmaking/Registry/Ombudsman/Concierge:**
    - Connect the stakeholders
    - Provide internal/external communication channels
    - Sharing knowledge and information
    - Align regulations and policies to streamline approval,
2. **Test bed accrediting and risk reduction:**
    - Ensure the test beds provide data confidence
    - Provide standardized evaluation metrics and QA/QC protocols
    - Provide technology performance testing without endorsement
    - Serve as a safe place to innovate
    - Provide testing depository to assist in avoiding repetitive mistakes and reducing risks.
3. **Data management, archiving, and reduction of administrative burden:**
    - Provide different levels of data sharing and management service
    - Serve as a technology clearing house
    - Provide guidelines and documents for generating IP agreements, CREDO agreements, testing and evaluation protocols .
4. **Information dissemination, education, and public outreach:**
    - Communicate and engage general public on the topic
    - Disseminate information via website, conferences, publications, and social media
    - Provide internship and field-education opportunities for workforce (re)training.
5. **Flexible and robust service to different technology needs:**
    - Disruptive, modular, mobile technologies preferred
    - Technologies focusing on energy and resource recovery
    - Technologies fitting for specific needs (regulatory, regional, centralized/distributed, etc.).
6. **Platform for competition, collaboration and other opportunities:**
    - Organize competitions, prizes, and other opportunities to promote innovation, collaboration, and technology validation and translation to market place.

Other functions:

- Communicate the regulatory landscape that a tech provider will encounter; provide a place for regulator involvement on technology innovation; upfront to streamline regulatory approval.
- Connect to funding opportunities, assistance on preparing proposals, provide a break between the funder and funded.

Test Bed Networks in Other Industries

There is ample and recent precedent to support the value proposition for a technology TBN. The National Advanced Spectrum and Communications Test Network (NASCTN) is a newly-formed example of the type of organization that is envisioned here. Although the wireless technology industry faces challenges that are vastly different from those faced by the wastewater industry, many of the fundamental drivers for the existence of test beds and the sharing of protocols and data are similar. Both industries must operate in a variety of environments (e.g., urban and rural) and both have a variety of stakeholders (i.e., industry, academic, governmental, and regulator). NASTCN is operated by the National Institutes of Standards and Technology (NIST) and exists to accelerate the development and deployment of spectrum-sharing technologies.

Multiple test beds for the evaluation of wireless communications technologies were active before NASTCN was formed. The Networking and Information Technology Research and Development Program (NITRD, https://www.nitrd.gov/), an 18-agency funding organization coordinated by the NSF, identified as an R&D gap the lack of communication and standardization among test beds and test protocols. NITRD built a web-based portal where wireless technology test-beds could self-identify and publicize their capabilities in a national directory. After a few years of this portal's operation and growth, NIST, the National Telecommunications and Information Administration (NTIA) and the Department of Defense (DoD) determined that there would be additional value in supporting a network of these test beds to accomplish specific shared goals. These goals include the development and publication of test protocols, matchmaking between technology developers and test beds, development of test plans that span multiple test beds, and the publication of reports and results.

Appendix C: List of Existing Test Beds and Analogous Networks

Existing Water Technology Test beds and Networks

- Primary cluster network resources
  - LIFT http://www.werf.org/_ad/Test_Bed_Facility_Summary_Table.aspx
  - EPA Cluster https://www.epa.gov/clusters-program/resources-clusters
- U.S.-based networks
  - ReNUWIt (NSF – Colorado School of Mines, New Mexico State, Stanford, Berkeley: Urban Water Infrastructure)
  - C2RC (Stanford - Wastewater Treatment)
  - Stormwater Testing and Evaluation for Products and Practices (STEPP) Initiative
  - Water Technology Innovation Clusters
    - Massachusetts Clean Energy Center
    - NEWIN (Boston)
    - The Water Council (Milwaukee)
    - Accelerate H2O (Texas)
    - Confluence
    - Current (Chicago)
  - Water Security Test Bed (EPA/INL - Security of municipal water supply)
  - Santa Fe Waters Test Bed (NSF - Water flow and nitrate flux in a basin)
  - University of South Florida, National Center for Reinventing Aging Infrastructure and Nutrient Management (http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/outlinks.centers/center/216)
  - Water Research Foundation (WRF)'s National Center for Resource Recovery and Nutrient Management (http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/outlinks.centers/center/221)
- International networks
  - Litmus/Nimbus (Cork, Ireland - Gives technology developers site access to facilities across the full water value chain)
  - Sembcorp (Singapore - Utility operator provides access to wastewater treatment and waste to energy facilities for technology development)
  - Safe Global Water Institute (University of Illinois - Case studies of rural water supplies in Mexico and Africa)
  - European Union Wastewater Technology Validation Program
  - Canada Wastewater Technology Validation Program (inspired by EPA-ETV)
  - Southern Ontario Water Consortium
  - WaterTAP – Ontario's water technology project
  - Korean R&D Center for Advanced Technology of Wastewater Treatment and Reuse (www.bwtoptech.or.kr)
  - Hammarby Sjostadsverk, Sweden (http://sjostad.ivl.se/Sjostadsverket/english/hammarby-sjostadsverk/about-sjostadsverket.html)

- R3 Water (Sweden, Spain, Belgium: http://r3water.eu/activities/)
- WATEC Israel – Water Technology & Environment Control Professional Conference
- Nanjing International Water Hub
- Water Research Commission-South Africa (WADER Program)

Non-Water Technology Test Beds and Networks

- NCCC - CO_2 Capture Technologies (CCTCN - International Network): The National Carbon Capture Center, a technology test bed operated by Southern Company and supported by the Department of Energy, is a principal member of the international Carbon Capture Technology Network. This network grew organically from the interaction of the independently-funded and operated test beds (mostly in the U.S. and E.U.) at international conferences. This technology is still dependent on governmental funding (there is not yet a mature market for CO_2 capture besides enhanced oil recovery the way there is for wastewater treatment), and the international nature of the interactions, the network itself takes a "light touch" approach to technology development. The group has agreed to attack specific problems of common interest. It has provided value to its members in developing test and measurement protocols for previously hard-to-quantify performance parameters.
- ATP3 - Algal bioenergy
- RAFT - Algae-Derived Fuels: RAFT is essentially a multi-institute project, and does not operate as a user-facility-style TBN. RAFT is capable of testing various strains of fuel-producing algae under the varied environmental conditions across its geographically distributed test beds.
- Automated Home Energy Management (AHEM) – Home energy management system (National Renewable Energy Laboratory)
- ESCI - KSP - Energy Smart Communities Knowledge Sharing Platform
- Sematech - Semiconductor Manufacturing Technology (International)
- NSTB - SCADA Network Security
- GENI - Computer Networking Technologies (NSF-supported)
- DETER - Cybersecurity Technologies (DHS-supported)

Appendix D: Funding Mechanisms for the TBN

Funding mechanisms are beyond the scope of this document. WRF is proposing funding structure and mechanism (WRF 2017). EPA's experience with the ETV Program shows that base federal funding is important to an effort that seeks to evaluate new technologies throughout the Technology Readiness Level (TRL) pipeline.

Over the time period where ETV's funding declined, the mix of technologies that were examined by ETV went from 65/35 (with 65 percent coming from small companies) to 35/65. The ETV model proved unsustainable without federal support because the cost of technology validation was too high, and the requirement that the government put its "seal of approval" on the validation was too important.

Ultimately, a TBN should be self-sustaining with appropriate support from all of its stakeholders, including the following:

- Federal (Technology Push)
    - Research grants (DOE, EPA, NSF, USDA, NIST, USGS, etc.)
    - Small Business Innovation Research Program Grants (SBIR)
    - Educational fellowships and grants
- State (CEC, NYSERDA, etc.)
- Direct Industrial (Demand Pull)
- Original Equipment Manufacturers (OEMs)
- Membership fees (test beds, validators)
- Non-profit (environmental, economic development).

Appendix E: Relevant Publications

Reports from the Workshops

Energy-Positive Water Resource Recovery Workshop Report; National Science Foundation, U.S. Department of Energy, U.S. Environmental Protection Agency: Arlington, VA, 2016. http://www.energy.gov/sites/prod/files/2016/01/f28/epwrr_workshop_report.pdf.

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