Final Report on Workshop for Developing Evaluation Metrics to Advance a National Water Resource Resource Recovery Facility Test Bed Network

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1. Introduction

The Workshop for Developing Evaluation Metrics to Advance a National Water Resource Recovery Facility Test Bed Network was held at the National Science Foundation (NSF) Headquarters (Arlington, VA) on May 16-17, 2016 (http://events.energetics.com/metrics/). This workshop was sponsored by NSF and developed in collaboration with the Department of Energy (DOE), Environmental Protection Agency (EPA), United States Department of Agriculture (USDA), and Water Environment and Reuse Foundation (WERF). Approximately 59 stakeholders participated in the workshop from geographically diverse regions representing academia (research and teaching), municipalities, technology vendors, federal government, and nongovernmental organizations. Several stakeholders were also managers of existing or planned testbeds.

The ***workshop's primary objective*** was to: define several key metrics that every new resource recovery technology (or process) evaluated at the national test bed network should measure and report. The workshop focused on four technical areas: 1) Developing Common Metrics for All Technologies, 2) Developing a Framework for New Metrics as New Innovations Emerge, 3) Storing the Data Generated During Testing, and 4) Sharing Information After the Pilot is Complete.

A follow-up workshop (Workshop for Developing the Energy Positive Water Resource Recovery Facility Test Bed Network Structure) on June 20-21, 2016 focused on envisioning the structure of the national test bed network and specific action plans. Specifically, that workshop sought to: 1) Identify the stakeholders and their needs for the test bed network, 2) Develop network pathways, functions, and structures to meet the needs and objectives, and 3) Develop action plans for the formation, operation, and assessment of the testbed network. A separate report was developed for the Structure Workshop.

The names and affiliations of the organizing committee are provided in Appendix A. A list of workshop attendees is provided in Appendix C.

In the opening talk, the workshop participants were informed that in the report "Sustainability and the U.S. EPA" (National Research Council, 2011) *metric* is defined as the unit of measurement or how the indicator is being measured. In contrast, an indicator is defined in that report as a summary measure that provides information on the state of, or change in, a system, that is, what is being measured. Effective metrics are also known to have the follow characteristics: 1) relevant, 2) easy to understand by all stakeholders, 3) reliable, 4) quantifiable, and 5) based on accessible data (Mihelcic and Zimmerman, 2014).

2. Previous Workshops

Prior to the workshop, all participants were provided background reading that included reports from three previous workshops (discussed below) and Draft 3 of the "Concept of Operations for a Wastewater Technology Testbed Network" paper (dated May 10, 2016).

A workshop on Hydrogen, Hydrocarbons, and Bioproduct Precursors from Wastewaters (March 17-18, 2015, Washington, D.C.) was organized by the DOE's Bioenergy and Fuel Cell Technologies Offices. It gathered experts to share information and identify the current status and research, development and demonstration possibilities for production of hydrogen and higher hydrocarbons (containing four or more carbon molecules) from wastewaters using biological, biochemical, and other techniques. In particular, the workshop focused on microbial fuel cell-based technologies and anaerobic membrane bioreactors. One outcome of this workshop was the acknowledgement of the need for real-world demonstrations, at relevant scales and using real wastewaters.

The Energy Positive Water Resource Recovery Workshop (April 28-29, 2015, Arlington, VA) was organized by the NSF, EPA, and DOE. It's purpose was to gain insights and identify specific technical and non-technical barriers that hinder development and deployment of the water resource recovery facilities of the future. Workshop participants provided information to federal stakeholders on ongoing efforts in academia and practice to help realize a vision of the water resource recovery facilities of the future. The workshop report (NSF, DOE, EPA, 2015) prioritized sixteen areas of research likely to result in significant progress. The workshop participants also identified deployment challenges. A key deployment challenge identified was the long standing priority of complying with water treatment standards that resulted in a risk-adverse culture in practice. This has resulted in many facilities not being inclined to deploy or validate resource recovery technologies that could generate economic value while also supporting social and environmental sustainability (NSF, DOE, EPA, 2015).

The Intensification of Resource Recovery (IR^2) Forum (August 9-11, 2015, Manhattan College, NY) sought to foster meaningful networking opportunities, discussions, and collaborations from representatives of leading municipal and industrial water resource recovery facilities participating in the LIFT program, their advisors/consulting firms, universities, financial firms, and others. Created through a LIFT technology scan, the forum was broken down into topical sessions featuring technology provider presentations, followed by working sessions where participants had the opportunity to develop connections and collaborate on ideas and projects to advance the technologies more rapidly into practice. Related to the metrics workshop, the (IR^2) Forum did endorse the need for a national test bed network.

Subsequently, 45 entities notified the Water Environment & Reuse Foundation (WERF) that they would be interested in being part of a national test bed (Figure 1). As part of notifying WERF of their interest, entities also indicated if they should be listed as a Tier 1-4 testbed (Table 1).

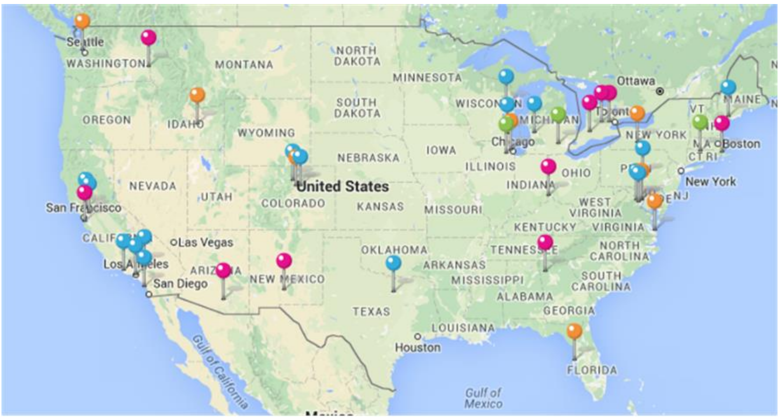

Figure 1. Location of 45 Test Facilities (as of May 16, 2016) that had notified WERF they are interested in being part of a national test bed facility (www.werf.org/testbeddirectory) (figure courtesy of Water Environment & Reuse Foundation).

Table 1. Description of level number associated with a testbed facility (information from the Water Environment & Reuse Foundation).

Level No.	Description
1	A university or research lab that can assist with bench-scale work but is not dedicated to piloting new technologies
2	A water resource recovery facility that is interested in innovation and willing to host a project, but does not have a dedicated test facility
3	A water resource recovery facility or research lab with a dedicated physical space available for piloting innovative water technology
4	A staffed facility dedicated solely to R&D/piloting of new technologies

3. Summary of Workshop and Charge Questions

A detailed workshop agenda is provided in Appendix B. Table 2 summarizes how time was allocated at the workshop. Each of the five charge questions were addressed by four individual breakout groups (10-15 individuals) who were assigned an organizing committee member(s), professional facilitator, notetaker(s), and rapporteur. Output from each breakout group was presented and discussed with the larger workshop group.

Table 2. Summary of how time was spent at workshop.

Monday Morning	Three keynote talks provided perspective of appropriate metrics from a utility perspective, considerations for small to large facilities, and how to integrate energy and a sustainability framework into metric selection. The three keynote talks were following by a six-person panel that provided both local utility and federal perspectives on what would be appropriate metrics for assessing treatment and resource recovery technologies.
Monday Afternoon	**Breakout Sessions: Defining Appropriate Metrics**

	Charge Question #1: a) What will we be able to achieve with a common set of metrics, b) what is an appropriate set of common metrics that should be measured across a national test bed network and reported for all technologies that impact the performance of a wastewater resource recovery and treatment technologies, c) what standard procedures exist to measure these metrics? **Breakout Session Two**: *Developing a Framework for New Metrics* **Charge Question #2:** a) How might metrics change across different levels of testbeds and b) what is the proper framework that would allow new metrics to be included in the future?
Tuesday Morning	Each of the four rapporteurs reported out to whole group that was followed by a discussion of Day 1 breakout sessions.
Tuesday Late Morning and Afternoon	**Breakout Session Three:** Storing the Data Generated During Validation & Sharing Information After the Pilot Is Over (breakout sessions for three final charge questions and time for groups to report out to larger groups and have discussion with larger group). **Charge Question #3:** What is most effective method to store data generated during testing. **Charge Question #4:** a) Who needs to have access to the data, b) what is the most effective way to share information after a pilot is over to ensure wide dissemination and public access? **Charge Question 5:** Are there any issues you would like added to the structure workshop that will follow in June?

In the opening sessions some key points that were addressed are summarized in the remainder of this section. First, from a utility perspective, there is interest in metrics that measure how well a new technology or process minimizes: 1) energy, 2) chemicals, 3) labor (operations and maintenance), and 4) construction materials and physical footprint. There was a comment by a keynote speaker that new technology is also implemented when regulations serve as the driver, the business case is clear, and technology maturity is reasonable. It was also discussed during the opening session that the metric of carbon output rate (kgCO2/kWh) depends on the power distribution portfolio of the specific provider and time of day. Therefore, metrics such as kg CO2/m3 of wastewater processed may penalize a technology tested in a location that has a more carbon intensive energy provider. Therefore, one participant suggested that kWh/m^3 of wastewater processed or chemical usage/m^3 of wastewater processed are better metrics.

Figure 2 provides a framework discussed in the opening sessions to organize thinking about sustainability that would inform the evaluation of activities or technologies. This framework is flexible and includes environmental, societal, economic, managerial, and technological metrics. The societal metrics identified in this figure can be obtained by use of survey of plant operators. It was pointed out during the discussion that environmental impact offsets can also be used as one indicator of resource recovery (e.g., Mo and Zhang, 2013). Finally, during the panel discussion, some additional comments on appropriate metrics included: 1) metrics should consider the feedstock characteristics of a particular technology, 2) there needs to be a process where data are independently verified, 3) quality outputs should be shared with everyone, 4) process performance is important to consider when evaluating a technology (e.g., running time, downtime, maintenance requirements, how easy can it be scaled up, what are operators skills in terms of training, what is cost of training or retraining operators, how does technology respond to temperature or wet weather changes, 5) mass and energy balances need to be determined, 6) the system boundary needs to be defined when evaluating environmental impacts such as greenhouse gas emissions, and, 7) it is important to determine if a technology or process consistently meets permit levels. There was also a comment made by the panel that most existing testbeds don't currently consider feedstock characteristics and mass and energy balances.

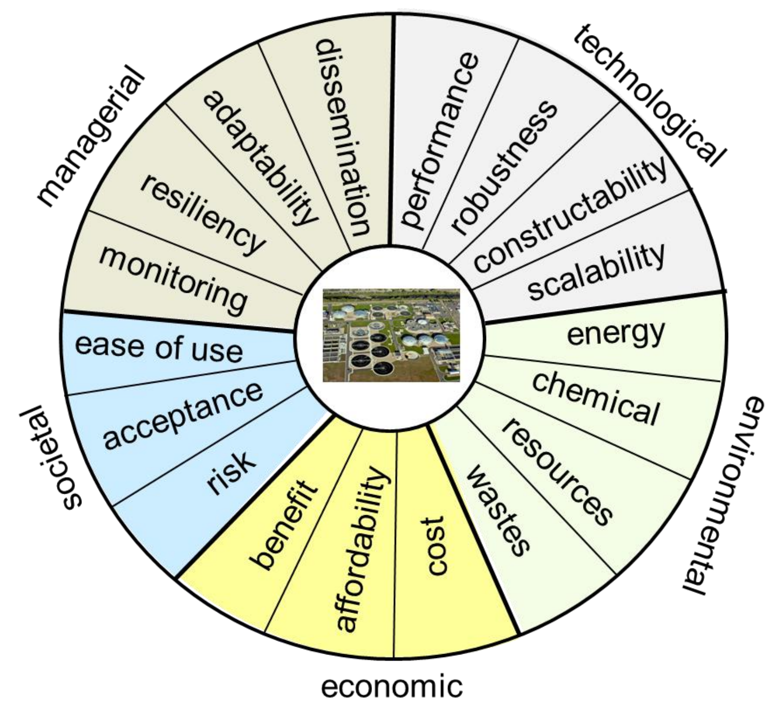

Figure 2. A sustainability framework discussed during first morning of the workshop (with permission from "Integrating a Sustainability Framework with Assessment of Treatment and Resource Recovery Technologies," (presentation by Professor Qiong (Jane) Zhang, Civil & Environmental Engineering, University of South Florida)

4. Results

The results are organized by the individual charge questions in this section.

4.1. Charge Question #1: a) What will we be able to achieve with a common set of metrics, b) what is an appropriate set of common metrics that should be measured across a national test bed network and reported for all technologies that impact the performance of a wastewater resource recovery and treatment technologies, c) what standard procedures exist to measure these metrics?

Charge Question 1a: What will we be able to achieve with a common set of metrics?

The four breakout groups determined that a common set of metrics would: 1) facilitate dissemination of information, 2) simplify interpretation of data, and 3) enable transparent comparison of technologies and process through standardized measurements, and 4) establish the legitimacy of test data.

Developing a common set of metrics was recognized to assist efforts to measure progress toward achieving the primary goal of resource recovery through wastewater treatment technology innovation. Overall the workshop participants agreed the testbed network would accelerate adoption of new technology and processes, provide reproducible and consistent quality data, enhance the state of knowledge that would guide technology design, policies and strategies, and serve to educate the next generations of scientists and engineers in this area. The network would also serve to connect innovators and researchers with facilities and technology adopters.

Charge Question 1b: what is an appropriate set of common metrics that should be measured across a national test bed network and reported for all technologies that impact the performance of a wastewater resource recovery and treatment technologies

Most of the breakout groups first brainstormed a large list of possible metrics (for two examples, see Figure 3) and then attempted to categorize or prioritize them. Table 3 shows that the four breakout groups independently saw value in developing metrics that covered similar categories of: 1) mass balance (material and energy), 2) economic, 3) risk, and 4) operation and management (O&M). One group mentioned having a category of metrics that would specifically cover regulatory issues and products produced by new technologies, and another group consideredd environmental impacts to be important.

There was a general consensus at the workshop that if information was uniformly obtained on important inputs to a system (referred to as Inventory in this Figure 4) and then outputs (referred to as Impact in Figure 4), then appropriate metrics could be easily derived from this information. Table 4 provides a shortened list of specific metrics identified by each of the four break out groups organized around the categories identified by the breakout groups.

Table 3. The four breakout groups organized their metrics into the following categories. Bolded items indicate categories that two or more breakout groups had in common. ( ) refers to language used by the individual breakout group.

	Breakout Group 1	**Breakout Group 2**	**Breakout Group 3**	**Breakout Group 4**
Major Categories for l Metrics Identified by Breakout Groups	**Economics** (Costs) **Mass Balance** (Performance/mass balance) **Risk** (Process Risk)	**Economics** (Costs) **Energy** (Energy Demand) **Risk** Products **Operation and Maintenance** Regulatory	**Economics** (Life Cycle Cost Data) **Energy** (Quantification of energy recovery and capacitance in treatment technology and their peak power demands) **Mass Balance** (Process specific and whole system metrics that allow one to conduct mass balances)	**Economics** **Mass Balance** (Stoichiometry and Mass Balance) **Operation and Maintenance** (Managerial) Environmental

Figure 3. Examples of initial process of two breakout groups developing a broad list of metrics that impact the performance of a wastewater resource recovery and treatment technologies.

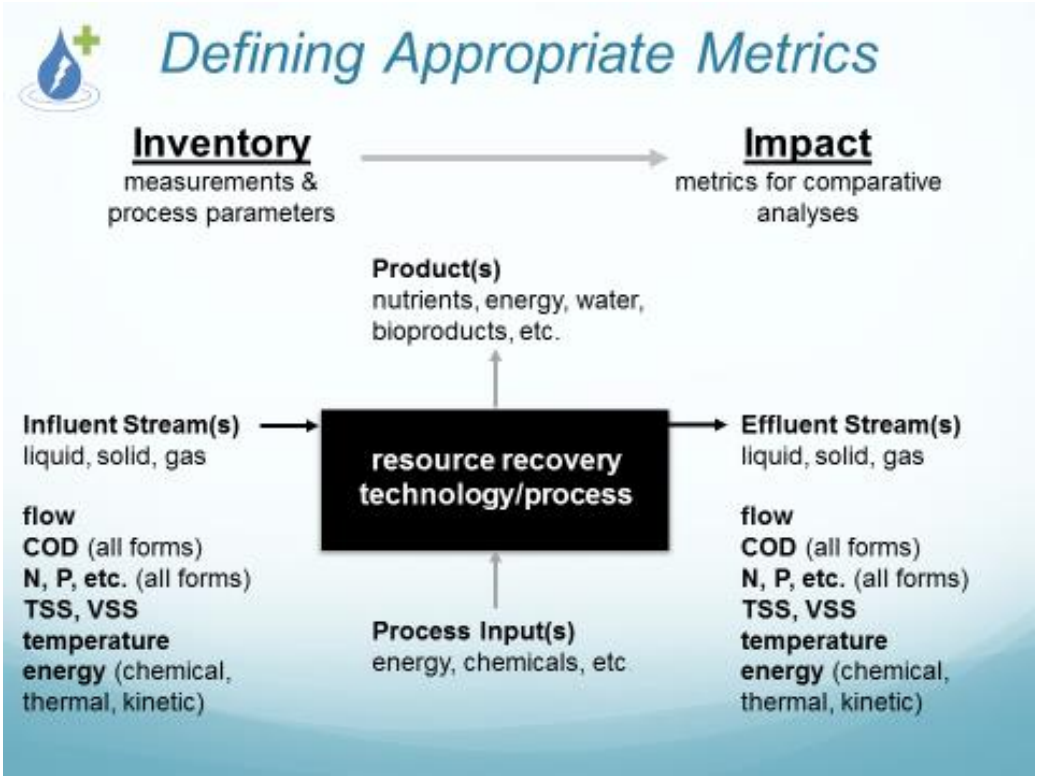

Figure 4. Defining appropriate metrics that impacts the operations of a water resource recovery facility. There was consensus at the workshop if we uniformly obtained information on mass and energy inputs to a system (referred to as Inventory in this figure) and then outputs (referred to as Impact in this figure), then appropriate metrics could be easily derived from this information (figure developed by Jeremy Guest, Department of Civil & Environmental Engineering, University of Illinois).

Table 4. Specific metrics and indicators identified by the four breakout groups.

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/m^3-treated *or* kWh/ft *or* -EEO – electrical energy per order, kVAR) -Products Recovered (kg, m3, kWh-product/kg-recovered or removed *or* kg, m3, kWh-product/m3-treated and % recovery of resource) -Chemicals Used and Biomass produced (kg/kg or m^3-recovered or m^3-t) -Operational 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 Balance for Power and energy consumption (kWh/m3- whole plant vs. unit process) -Products Recovered (kg valuable product recovered / m^3 treated water)
Economic	-O&M costs (($/mass removed/d) -Life Cycle Costs -Avoided costs from Resource Recovery -Other costs (labor, training, expertise, remote control) -Physical Footprint (land)	-O&M Costs, OPEX ($/$m^3$-treated) and Capital Costs, CAPEX ($/$m^3$-treated) -Cost to Recover Resource ($/kg or m^3-recovered 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 -Resiliency (time to startup, time to recover) -Ease of integration in existing infrastructure -Degree of automation	-Variability over 24-hour cycles (diurnal; discrete vs. composite; seasonal (e.g., wet weather conditions)) -Cost uncertainty -Operational 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	

Charge Question 1c: what standard procedures exist to measure these metrics?

It was recognized by all groups that standard methods generally exist for all the measurements noted to perform mass balances on C/N/P, conduct energy balances, quantify life cycle costs, and characterize effluent quality (although standardization is needed for non-regulated endpoints). It was pointed out that standard procedures do not exist for measuring reliability and are client driven. They can be specified however.

4.2. Charge Question #2: a) How might metrics change across different levels of testbeds and b) what is the proper framework that would allow new metrics to be included in the future?

Charge Question 2a: How might metrics change across different levels of testbeds?

Breakout groups recognized that metrics may change across different geographical locations of testbeds and scale of technology (e.g., lab, pilot, and full scale). For example, there will be variability of environmental and operating conditions between test beds regionally that may influence resource recovery performance. These differences could include: climate, size, type of test beds (i.e., testbed tier), differences in wastewater characteristics, wastewater temperature, seasonal variabilities in water quality and quantity, presence (and potential impact) of industrial contribution, and types of pollutants found in wastewater?

One breakout group noted that metrics obtained at one testbed tier level may not be translatable to other tier levels (definition of tier levels was provided in Table 1). Figure 4 was developed in one breakout group and suggested the scale of testing (across different tier testbeds) might influence the difficulty in obtaining data that supports metrics across different levels of testbeds, especially metrics that support impact. There may also be differences in the quality and quantity of collected data at different testbed tiers. For example, at a smaller scale (e.g., bench scale) there might be proof of concepts and one could measure more and make use stoichiometry. At the smaller scale one can also measure energy but workshop participants commented that the energy usage may change as a technology or process is scaled to larger size. It was also brought up that it will be easier to obtain economic or socio-economic metrics at the larger scale tier testbeds. Furthermore, one breakout group observed that evaluation of some managerial and societal measures of feasibility and sustainability may be subjective and will reflect existing plant design and operating philosophy.

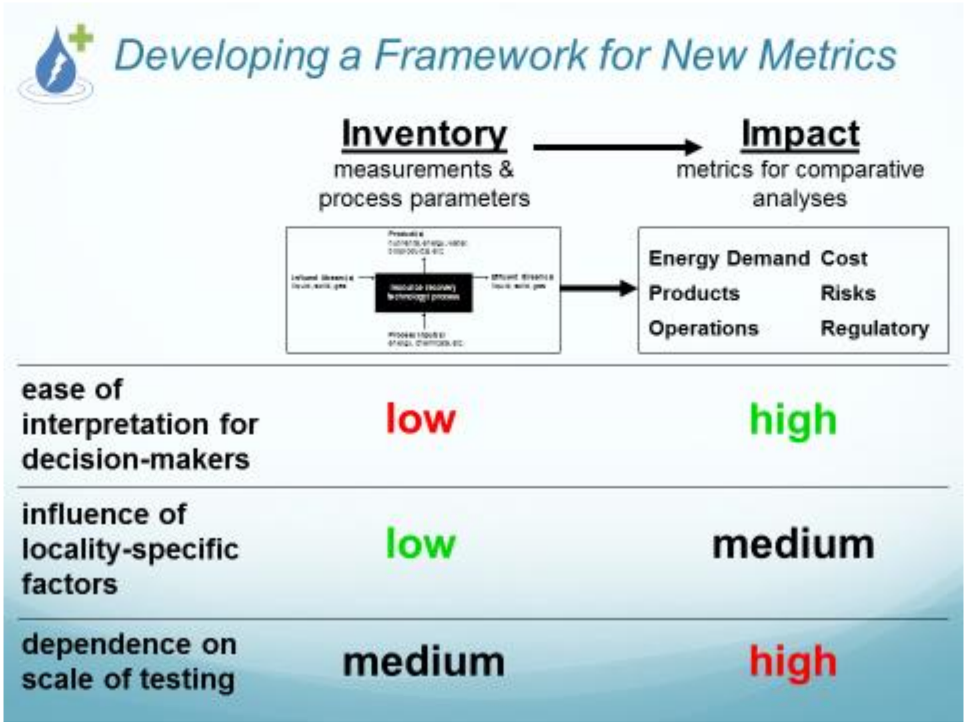

Figure 4. Figure showing how the scale of testing impacts degree of collecting data on measurements and process parameters and associated metrics (i.e. impact) by be greater.

Charge Question 2 b: what is the proper framework that would allow new metrics to be included in the future?

Analysis of materials provided by notetakers and rapporteurs suggested this charge question was not discussed in depth by any of the four breakout groups. It was noted in one breakout group that this is a policy question that should be considered in the structures workshop. Additionally, there seemed to be a general consensus that flexibility is important to the framework to allow for new metrics to be included in the future.

4.3. Charge Question #3: What is most effective method to store data generated during testing.

It was emphasized that requiring a standard data management plan that addresses how data is stored would be effective. Some of the usable formats identified in the breakout sessions that data should be stored were raw data, metadata and synthesized data. Data should also be able to be easily combined with other data for comparative analysis and be able to be independently analyzed. During this discussion of this charge question, it was also mentioned that providing data only as pdf files was less desirable, but fact sheets on different technologies would be useful. It was also noted that data could be more than numerical metrics and could include videos, links to videos, and other data visualization tools. Data security was also recognized as important to prevent an outside party from entering the data storage system and manipulating existing data. The need to develop a plan to share data from test failures as well as test successes was also discussed. Stored data should also neglect context and prior expert interpretation.

Some data management questions to be considered include: 1) should there be a central repository of data versus a central repository to links to data (that are perhaps managed by individual testbeds), how long should data be stored, and should data only be stored until the new technology becomes established? Again, the issue of intellectual property was raised in several breakout groups and how that might impact data availability. In addition, data may only show performance of the technology, but may not provide information on how a particular technology or process works in the field. There was also a discussion on whether a third party evaluation of data would be needed and if there are any state legal issues that may require public disclosure of data in all cases.

4.4. Charge Question #4: a) Who needs to have access to the data, b) what is the most effective way to share information after a pilot is over to ensure wide dissemination and public access?

Charge Question 4a: Who needs to have access to the data?

A large list of end users were identified: the public, research community, government agencies, funding organizations that include technology vendors and developers, venture capitalists, consultants, regulators, educators, professional organizations (e.g., WEF, WERF), utilities and their operators, and other testbeds in the network. A large part of discussion related to this question focused on what might cause restrictions in access to data; for example, whether access to data would be linked to financial support of a testbed or particular test, how would intellectual property considerations impact data access, and whether users of the data should pay to have access to the data. One breakout group recognized that data should be available to smaller utilities who may not have financial resources to pay for data. Another breakout session thought that a data management plan would have to make this clear and might have to customize data availability issues based on the source of external funding.

One breakout group noted there were differences of opinion expressed regarding the overall role of test bed evaluations in informing the stakeholder decision-making process. For example, a test could be used to describe the ease of operation of a technology and/or define the duration of the start-up learning curve associated with adoption of a new process. However, potential risks include: 1) labels of performance are likely to have long-term impacts on perceptions of a particular technology or process, and 2) as our understanding of technologies evolves, our ability to optimize and control them will also mature and improve. In addition, information on capital costs/risks is critical for decision makers but less certain and relevant at the bench-scale and more quantifiable for pilot- and full-scale test bed studies. However, capital costs/risks may not be scalable and generally have not been optimized at the experimental assessment stage. Therefore, at best, test bed evaluations may only provide information on relative capital costs of different technologies at a given tier level of testing.

Charge Question 4b: what is the most effective way to share information after a pilot is over to ensure wide dissemination and public access?

Data management plans were again reported to be an effective way to share information to ensure wide dissemination and public access. It was also recognized by one breakout group that it may be important to separate public (open) data and private data, which may be more secure.

One breakout group provided the following list of ways to share information: 1) user-friendly clearing house with a searchable/filterable database, 2) multi-access portal, cloud storage, 3) development of common data fields, and 4) leveraging social networking platforms. It was recommended also that there are examples on data share to learn from; for example, the stormwater BMP database, NID database, two-page act sheets developed for other technology evaluations, and easy to follow pictures/diagrams.

Other questions raised in the breakout groups included: 1) what is a reasonable expectation of data-sharing if a technology supplier is utilizing a testbed and benefiting from the claim of testbed validation?; 2) how might intellectual property considerations impact data access?; and 3) is it possible to have standardized agreements by testbed tiers because universities and utilities have different requirements for academic freedom / public information? There was also a question raised in one group that perhaps the WERF LIFT program has addressed some issues related to data sharing and intellectual property. It was also noted that there may be a conflict with a goal that testbeds would provide a safe place to fail, but how this would integrate with a requirement that all data must be shared.

4.5. Charge Question 5: Are there any issues you would like added to the structure workshop that will follow in June?

The following thirty issues were identified at the metrics workshop and shared with the Denver structure workshop conference organizers. They can be grouped into six categories: 1) operating the testbed, 2) operating and coordinating the network, 3) funding the testbed, 4) access to the testbed, 5) controlling/leading the testbed and network, and 6) testbed output and value creation.

1. Document what has already been done with other testbeds (e.g., NYC)
2. What happens after program goals are met?
3. How to address upstream and downstream effects of plant/testbed design and obtained results?
4. How do we ensure financial stability of the testbeds (business models)?
5. Technology providers may or may not be able to fund network
6. What is the required personnel and workforce to run testbed? Who will do the work?
7. What is role of colleges/universities in testbed involvement and training?
8. What are regulatory issues of personnel handling pilot (training)?
9. Utilities may want control over how or what technologies are allowed to test
10. Testbed networks are especially useful for smaller technology providers or vendors, so how do we ensure their participation?
11. How does the network standardize testbed influent characterization?
12. Utility Master Plans need to incorporate funds to support network
13. What are rate payer models to support customer needs and test bed technology vendor needs?
14. How is flexibility integrated with the testbed design?
15. Should there only be three tier levels of testbed instead of four?
16. Who are operators of technology at a testbed? (students, staff, technology vendors)
17. Who manages the testbed network and how do we ensure there is no conflict of interest?
18. What is the role of testbeds in network administration?
19. Should there be a performance challenge for different testbeds? (i.e., a big prize)
20. How to meet all stakeholder needs?
21. How to address level of maturity of different technologies?
22. How does network vet and prioritize the technologies to evaluate?
23. How is geographical locations and other conditions of a testbed facility integrated into use of network?
24. Is there a technology advisory group to the network?
25. What is an appropriate template that would be developed to standardize data collection/reporting?

26. Data storage – who?/how?/where?
27. We need a clear objective statement for the testbed, which need to be vetted, and this needs to be the constant guide during discussions.
28. For the four levels of testbeds, what is a hypothetical business plan?
29. Are there case studies from LIFT and start-up companies that provide insight on successes and barriers?
30. How is risk shared between stakeholders and testbed network?

5. References

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Acknowledgement

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Appendix A. Organizers of Workshop for Developing Evaluation Metrics to Advance a National Water Resource Resource Recovery Facility Test Bed Network

James Mihelcic (*metrics workshop chair)* Department of Civil & Environmental Engineering University of South Florida
Aaron Fisher Technology and Innovation Manager, Water Environment Research Foundation (WERF)
Adriane Koenig Oak Ridge Institute for Science and Education Research Participant, assigned to Environmental Protection Agency Office of Science and Technology
Jeff Moeller Director of Water Technologies at the Water Environment Research Foundation (WERF)
Mark Philbrick Waste-to-Energy Coordinator, Bioenergy Technologies Office, Department of Energy
Jason Ren (*structures workshop chair*), Environmental Engineering, University of Colorado Boulder
Bob Rose Policy Analyst for EPA Office of Water, Water Policy Staff
Brandi L. Schottel Science Analyst for Innovations at the Nexus of Food, Energy, and Water Systems (INFEWS), Chemical, Bioengineering, Environmental, and Transport Systems Division, National Science Foundation
A.J. Simon Energy Systems Scientist, Lawrence Livermore National Laboratory
Seth Snyder Water Initiative Leader, Argonne National Laboratory
Jason Turgeon Physical Scientist, Energy and Climate Unit, Environmental Protection Agency, Region 1

Appendix B. Metrics Workshop Agenda

Workshop for Developing Evaluation Metrics to Advance a National Water Resource Resource Recovery Facility Test Bed Network: May 16-17, 2016

National Science Foundation Headquarters, NSF Stafford I, Room 375, 4201 Wilson Blvd., Arlington, VA
http://events.energetics.com/metrics/

The ***workshop's primary objective*** is to: define several key metrics that every new technology evaluated at the national test bed network that impacts the operations of a water resource recovery facility should measure and report. The workshop will focus on four technical areas 1) Developing Common Metrics for All Technologies, 2) Developing a Framework for New Metrics as new Innovations Emerge, 3) Storing the Data Generated During Testing, and 4) Sharing Information After the Pilot is Completed

Day One – Monday, May 16, 2016 (375 Stafford 1 at NSF, 4201 Wilson Blvd., Arlington, VA 2223)

Time	Agenda Topic
7:30-8:15	Coffee provided
8:15 - 8:40	Welcome James Mihelcic, University of South Florida (workshop chair), Molly Mayo, Facilitator, Meridian Institute • Pramod Khargonekar, Assistant Director, Engrg. Directorate, NSF • Diana Bauer, Office of Policy and International Affairs, DOE • Mike Shapiro, Deputy Assistant Administrator, Office of Water, EPA • James Dobrowolski, National Program Leader, Division of Environ. Systems, USDA • Amit Pramanik, Director of Research, WERF
8:40-9:00	James Mihelcic, University of South Florida (workshop chair) *Introduction to a National Test Bed Network* (how workshop came to be, background on current and planned efforts related to the development of a national test bed network and directory, objectives of a national test bed, plan for a follow up structures workshop in Denver in June*)*
9:00 – 9:30 (20 min talk & 10 min Q+A)	**Keynote 1:** *Utility Perspective: Assessing the Performance of Innovative Technologies for Treatment and Resource Recovery* (Charles Bott, Hampton Roads Sanitation District)
9:30 – 10:00 (20 min talk & 10 min Q+A)	**Keynote 2:** *Choosing the Appropriate Metric from Small to Large Facilities* (Diego Rosso, University of California-Irvine)
10:00 – 10:30	Discussion Break - *Coffee and Snacks*
10:30-11:00 (20 min talk & 10 min Q+A)	**Keynote 3:** *Integrating a Sustainability Framework with Assessment of Treatment and Resource Recovery Technologies* (Qiong Zhang, University of South Florida)
11:00– 12:10 (≤5 min perspective of moderator and	Keynote Panel Discussion: Local to Federal Perspectives on Appropriate Metrics for Assessing Treatment and Resource Recovery Technologies (Moderator: Sudhir Murthy, DC Water) • Dan Murray, EPA, on detail to Metropolitan Sewer District of Greater Cincinnati

each panelist followed by 25 mins of discussion)	• Tania Ullah, National Institute of Standards and Technology (NIST) • Luke Mulford, Public Utilities, Hillsborough County, FL • Jeanette Brown, Manhattan College • Ken Williamson, Clean Water Services, Hillsboro, OR • Kristen Jenkins, Water Research Center
12:10–12:15	Afternoon Breakout Sessions Summary and Charge *Molly Mayo, Meridian Institute, Facilitator*
12:15 – 1:30	Lunch - *Participants on their own for lunch*
1:30 – 3:30	**Breakout Session One**: *Defining Appropriate Metrics* **Charge Question #1:** a) What will we be able to achieve with a common set of metrics, b) what is an appropriate set of common metrics that should be measured across a national test bed network and reported for all technologies that impact the performance of a wastewater resource recovery and treatment technologies, c) what standard procedures exist to measure these metrics?
3:30 – 4:00	Discussion Break- *Coffee and snacks provided*
4:00 –5:00	**Breakout Session Two**: *Developing a Framework for New Metrics* **Charge Question #2:** a) How might metrics change across different levels of testbeds and b) what is the proper framework that would allow new metrics to be included in the future?
5:00	Informal Gathering at nearby location

Day Two – Tuesday, May 17, 2016 (375 Stafford 1 at NSF, 4201 Wilson Blvd., Arlington, VA 2223)

Time	Subject
7:30-8:30	Coffee provided
8:30 – 8:40	Welcome Back *Molly Mayo, Facilitator*
8.40-9:20	Breakout Presentations from Day One (Charge Questions #1 and #2) ≤ 10 min Presentations from Breakout Rapporteurs. • Group 1: Rapporteur: Haydee de Clippeleir, DC Water • Group 2: Rapporteur: Jeremy Guest, University of Illinois • Group 3: Rapporteur: Jennifer Becker, Michigan Technological University • Group 4: Rapporteur: Daniel Yeh, University of South Florida
9:20 – 10:10	Discussion by all workshop participants of Breakout Group summaries to Charge Questions #1 and #2
10:10 – 10:40	Discussion Break- *Coffee and snacks provided*
10:40 – 10:50	Third set of Breakout Sessions Summary and Charge *Molly Mayo, Meridian Institute, Facilitator*
10:50 –12:05	**Breakout Session Three:** *Storing the Data Generated During Validation & Sharing Information After the Pilot Is Over* **Charge Question #3:** What is most effective method to store data generated during testing. **Charge Question #4:** a) Who needs to have access to the data, b) what is the most effective way to share information after a pilot is over to ensure wide dissemination and public access? **Charge Question 5:** Are there any issues you would like added to the structure workshop that will follow in June?
12:05-12:15	Reassemble and afternoon plan, Molly Mayo, Meridan Institute, Facilitator
12:15 – 1:30	Lunch - *Participants on their own for lunch*

1:30 – 2:10	Breakout Presentations from Day Two (Charge Question #3 & #4) ≤ 10 minute Presentations from Breakout Rapporteurs. • Group 1 Rapporteur: Krishna Pagilla, University of Nevada-Reno • Group 2 Rapporteur: Kartik Chandran, Columbia University • Group 3 Rapporteur: Weiwei Mo, University of New Hampshire • Group 4 Rapporteur: Belinda Sturm, Kansas University
2:10-2:45	Open Ended Discussion
2:45 – 3:00	Closing and Next Steps *Molly Mayo, facilitator; Jason Ren (structures workshop chair) James Mihelcic (metrics workshop chair)*
3:00	Workshop Adjourned

Appendix C. Metrics Workshop Attendees

First Name	Last Name	Affiliation
Beate	**Wright**	Water Research Foundation
Tania	**Ullah**	NIST
Jim	**Dobrowolski**	USDA
Kartik	**Chandran**	Columbia
Adriane	**Koenig**	EPA
Albert	**Cho**	Xylem Inc.
Amit	**Kaldate**	Infilco Degremnot
Ana	**Pena-Tijerina**	Village Creek Water Reclamation Facility
Belinda	**Sturm**	University of Kansas
Caitlyn	**Butler**	UMass Amherst
Charles	**Miller**	Utah State University
Dan	**Murray**	EPA
Daniel	**Yeh**	University of South Florida
Derick	**Brown**	Lehigh University
Diego	**Rosso**	Urban Water Research Center
Domenico	**Santoro**	Trojan Water Technologies
Glen	**Daigger**	University of Michigan
Haydee	**de Clippeleir**	DC Water
Jeanette	**Brown**	Manhattan College
Jeff	**Yang**	EPA
Jennifer	**Becker**	Michigan Technological University
Jim	**Oyler**	Genifuel
Ken	**Williamson**	Clean Water Services
Krishna	**Pigilla**	University of Nevada, Reno
Kristen	**Jenkins**	Southern Research
Luke	**Mulford**	Hillsborough County Public Utilities Department
Matt	**Ries**	WEF
Qiong	**Zhang**	University of South Florida
Shane	**Snyder**	University of Arizona
Temple	**Ballard**	SUEZ
Terry	**Wright**	ClearCove
Weiwei	**Mo**	University of New Hampshire
Aaron	**Fisher**	WERF
Ariela	**Zycherman**	AAAS Science and Technology Policy Fellow
Bill	**Cooper**	NSF
Bob	**Rose**	EPA
Brandi	**Schottel**	NSF
Craig	**Criddle**	Stanford University
Erik	**Coats**	University of Idaho Advanced WRRF
Jason	**Ren**	University of Colorado Boulder
Jason	**Turgeon**	EPA

Jeff	**Moeller**	WERF
Jim	**Mihelcic**	University of South Florida
Joe	**Cresko**	AMO, DOE
Marcus	**Gay**	Novus Technical Services
Mark	**Philbrick**	DOE
Molly	**Mayo**	Meridian
Nick	**Adams**	GE Water
Pablo	**Cornejo**	University of Colorado Boulder
Seth	**Snyder**	ANL
Sudhir	**Murthy**	DC Water
Tyler	**Huggins**	University of Colorado Boulder
Charles	**Bott**	HRSD
Jeremy	**Guest**	Illinois-CU
Sebastian	**Tilmans**	ReNuwit
Rabia	**Chaudhry**	Millennium Challenge Corporation
Eric	**Keys**	NSF
Veronica	**Aponte**	University of South Florida
Gerhard	**Forstner**	CNP - Technology Water and Biosolids Corp.
Bryan	**Brooks**	Baylor University
Teresa	**Harten**	US EPA
Julius	**Enriquez**	US EPA
Bryan	**Pai**	CSRA
Rebecca	**Weissman**	CSRA
Rachel	**Tardiff**	CSRA
Mary	**Apostolico**	SRA International
Thomas	**Pokorsky**	XPV/NEXOM
Zachary	**Scott**	Trojan Technologies
Craig	**Turchi**	National Renewable Energy Lab
Jeremiah	**Wilson**	Department of Energy
Theresa	**Stone**	Metro Wastewater Reclamation District
Malcolm	**Fabiyi**	Hydromantis USA
Michael	**Bolan**	Urbanalta Corp
Jonathan	**Rogers**	Energetics Incorporated
Ling	**Tao**	NREL