ESTCP

IMPLEMENTATION GUIDE

Improving ESTCP Demonstration Outcomes & Tech Transfer via Integration of Standardized Third-Party Technology Verification using ISO 14034

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14. ABSTRACT
Under ESTCP Project EW20-5333, the feasibility and potential impact of integration of the ISO ETV Standard into the ESTCP demonstration process was examined. The primary objective of the project was to demonstrate how integration of ISO standards into the ESTCP process can enable more rapid technology demonstration and tech transfer, and ultimately technology deployment.

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Acronyms

Acronym	Definition
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
DoD	United States Department of Defense
ESTCP	U.S. Department of Defense Environmental Security Technology Certification Program
EPA	Environmental Protection Agency
ESPC	Energy Savings Performance Contract
ETV	Environmental Technology Verification
ICC	International Code Council
IECC	International Energy Conservation Code
IEEE	Institute of Electrical and Electronics Engineers
IMC	International Mechanical Code
IPC	International Plumbing Code
ISO	International Standards Organization
LEED	Leadership in Energy and Environmental Design
NIST	National Institute of Standards and Technology
QA/QC	Quality Assurance / Quality Control
QMS	Quality Management Systems
SERDP	Strategic Environmental Research and Development Program
UESC	Utility Energy Service Contract

1.0 INTRODUCTION

DoD's Environmental Security Technology Certification Program (ESTCP) was established to promote the transfer of innovative technologies that have successfully established proof of concept to field or production use [1]. ESTCP demonstrations collect cost and performance data to overcome the barriers to employ an innovative technology because of concerns regarding technical or programmatic risk, the so-called "Valley of Death". The Program's goal is to identify and demonstrate the most promising innovative and cost-effective technologies and methods that address DoD's high-priority requirements.

Projects conduct formal demonstrations at DoD facilities and sites in operational settings to document and validate improved performance and cost savings. To ensure the demonstrated technologies have a real impact, ESTCP collaborates with end-users and regulators throughout the development and execution of each demonstration. Transition challenges are overcome with rigorous and well-documented demonstrations that provide the information needed by all stakeholders for acceptance of the technology. However, the transfer of technologies and market uptake is still limited, and challenges remain.

One approach to reducing barriers to entry and reducing risk associated with implementation of innovative technologies is to provide improved credibility, consistency, and high-quality data that directly addresses stakeholder information needs. An approach to technology demonstration and validation which addresses these objectives has been standardized via ISO Standard 14034: Environmental Technology Verification (ETV) [2] – establishing a scalable, unified framework for technology validation and incorporating qualified independent verifiers as well as data quality assurance requirements for test and calibration labs and data providers.

Under ESTCP Project EW20-5333, the feasibility and potential impact of integration of the ISO ETV Standard into the ESTCP demonstration process was examined. The primary objective of the project was to demonstrate how integration of ISO standards into the ESTCP process can enable more rapid technology demonstration and tech transfer, and ultimately technology deployment. Implementation of ISO standards can provide programmatic benefits including:

- Identification of potential unified consensus testing and demonstration approaches for specific technology categories;
- Determination of stakeholder needs and input in the overall ESTCP program to ensure needed data and information is obtained during demonstrations;
- Implementation of third-party verification of demonstration data and information to ensure high data quality, credibility, and consistency across demonstration programs;
- Potentially more rapid acceptance of technologies due to the inclusion of interested party's needs, standard protocols and improved data quality;
- Development of outreach materials and guideline documents to train users and enable implementation of ISO 14034.

This ISO 14034 Implementation Guide has been developed to detail the elements of applying ISO 14034 verification to technologies demonstrated within the SERDP/ESTCP program. If implemented by the ESTCP Program, it provides a process for demonstration performers to apply to a demonstration project to have it more widely and rapidly adopted into the DoD system. The implementation guide outlines the steps of verification as it applies to ESTCP specifically including: summary of relevant standards, roles of program participants, principles of the ISO Standard, and programmatic and implementation processes. Inherent to the ISO Standard, it is expected that third-party verification bodies would support and assist ESTCP Demonstration PIs in full implementation of the guidance presented within the document.

This ESTCP / ISO 14034 Implementation Guide is a product of the EW20-5333 project. Specific activities completed under the project that form the basis of the Implementation Guidance included the following tasks:

- Gap Analysis for ESTCP processes vs. ISO 14034 Standard - Compared ESTCP existing project guidance and requirements against the requirements of the ISO 14034 Standard to identify gaps and develop modified guidance and requirements.
- Established connection of tech developers to stakeholders to ensure data needs are met – Established stakeholder groups and processes to obtain input on stakeholder information needs.
- Establish relevant verification metrics - Utilized stakeholder approach to identify metrics for two specific and relevant technology types demonstrated under the ESTCP Program (an HVAC air filtration technology and an advanced high-efficiency air conditioning system).
- Completed technology verifications - Worked with demonstration project teams to ensure consistent verification approach was followed and completed independent verification of results in accordance with ISO 14034.
- Completed case studies for the two technology verifications - Evaluated impacts of verification on technology adoption in market – identified additional barriers to implementation and tech transfer.

These tasks produced a series of ESTCP deliverables that form the basis of this Implementation Guide:

- ESTCP Project #EW20-5333, Demonstration Plan "Improving ESTCP Demonstration Outcomes & Tech Transfer via Integration of Standardized Third-Party Technology Verification using ISO 14034, Version 3.1 [3]
- ESTCP / ISO 14034 Gap Analysis Report v 2.0 [4]
- ISO 14034 Verification Report & ISO 14034 Implementation Gap Analysis and Case Study Report for Nanofiber-Based Low Energy Consuming HVAC Air Filters [5]
- ISO 14034 Verification Report & ISO 14034 Implementation Gap Analysis and Case Study Report for Next Generation Advanced High-Efficiency DX Air Conditioner [6].

2.0 RELEVANT STANDARDS

Although the ESTCP program has significant existing processes in place and requirements for demonstration-validation programs, the development of standardized, consensus, technology-specific Verification Protocols for ESTCP projects is an important consideration to increase the effectiveness of ESTCP demonstrations. Use of standardized metrics and parameters can facilitate consistent evaluation approaches and data quality for technology categories important to DoD. Identification of technology category performance requirements and test methods should include:

- Standardized performance objectives for technology categories;
- Integration of ISO standards into the ESTCP process;
- Reference to other applicable testing standards (i.e. ASTM, ASHRAE, etc.)
- Integration of stakeholder needs and input in the protocols to ensure needed data and information is obtained during demonstrations for each specific technology type.

The standardized verification approach provided by ***ISO 14034*** can be applied to relevant ESTCP demonstrations (*the standard is not applicable to demonstrations based on modeling or other qualitative analyses or approaches, nor demonstrations falling under the Technology Transfer project category*). The standard includes requirements that ensure that, if implemented properly and accepted by the DoD community, interested parties have information they need to encourage more rapid acceptance, appropriate technology transfer, and broader implementation of validated technologies. The ISO 14034 ETV process includes:

- Implementation of standardized, consistent approaches to technology evaluation which can be adopted by ESTCP;
- Requirement for verification of technology performance data by a qualified independent third party – including selection and procurement of qualified third-party verification and test bodies (see Section 7.1);
- Requirements for quality of data provided by test labs and other performers and data providers;
- Mechanisms for stakeholder input at planning and verification stages to ensure those in the future deployment decision chain get information they need;
- Potential use of existing performance data that conforms to the requirements of the standard;
- Broad applicability to a variety of technology types, applications, and interested party needs.

Implementation of the ISO 14034 standard to ESTCP sponsored demonstration will follow the procedures of ETV – Guidance to Implement ISO 14034 guidance document [7]. This Implementation Guide provides information to support the process of ETV in accordance with ISO 14034 and is a companion document to the published ISO 14034 standard. It explains the responsibilities of applicants, verifiers and test bodies. It describes each step of the ETV procedure, including application, pre-verification, verification, reporting and post-verification. Additional details regarding the process of implementation of ISO 14034 to the demonstration are provided in this Implementation Guide.

Note that ISO 14034 integrates with two additional important standards that would be applied to ESTCP field demonstrations in an ISO 14034 compliant program:

- ***ISO 17020: Conformity assessment -- Requirements for the operation of various types of bodies performing inspection*** [8], which establishes qualifications for independent entities to perform verification work.

- ***ISO 17025: General Requirements for the Competence of Testing and Calibration Laboratories*** [9], to ensure data used in evaluation of new technologies meets consistent standards and is provided by qualified entities.

Full copies of the ISO standards are available for purchase at the ISO website: https://www.iso.org/standard/43256.html

ETV is particularly applicable to those technologies whose innovative features or performance cannot be fully assessed using existing standards. When applying the ISO ETV Standard, it is required to identify existing or anticipated regulations, Executive Orders, DoD directives, industry standards or other drivers that the technology proposed for demonstration and verification addresses. Possible drivers and other relevant standards may include:

- Executive Orders: EO 13423, EO 13514
- Legislative Mandates: Energy Policy Act of 2005, Energy Independence and Security Act of 2007
- Federal Policy: Federal Leadership in High Performance and Sustainable Buildings MOU 2006
- Service Policies: Army, Navy, Air Force
- Regulations: Air Force Instructions
- Guides: Whole Building Design Guide (http://www.wbdg.org/)
- Specifications or Standard Test Methods and Procedures: ASHRAE, ASTM, EPA, LEED, IEEE, ICC Codes (IMC, IPC, IECC, etc.)

With respect to other standards, codes, or methods, the ETV Standard also requires consideration of the following:

- relevant legal requirements, or standards related to the technology and its use;
- a statement that the technology adheres to applicable regulatory requirements;
- conformance to existing verification plans and relevant technical references including standard test methods, preferably international standards.

3.0 PROGRAM PARTICIPANTS – ROLES AND REQUIREMENTS

ESTCP demonstrations are completed through a collaboration of several programmatic participants. Implementation of the ISO 14034 Standard into the ESTCP process requires that participants and their roles and qualifications are identified in the demonstration planning process and maintained throughout the demonstration period. Participant roles and requirements with respect to the ESTCP Program and the ISO Standard are provided here.

3.1 ESTCP / SERDP

SERDP and ESTCP develop and demonstrate innovative, scalable technologies that enhance military readiness, improve warfighter capabilities, and strengthen defense infrastructure.

The programs prioritize common sense, cost-effective solutions that support operational effectiveness and reduce regulatory burdens at military installations. SERDP and ESTCP promote partnerships and collaboration among academia, industry, the Military Services, and other Federal Agencies. They are independent programs managed from a joint office to coordinate the full spectrum of efforts, from basic and applied research to field demonstration and validation.

SERDP/ESTCP provide funding and overall technical and administrative programmatic oversight of the demonstrations. Through the SERDP/ESTCP demonstration selection process, as well as the process of demonstration planning, the program provides significant technical review.

Under the SERDP/ESTCP process, DoD liaisons are assigned to proposals from the private sector and non-DoD federal agencies that are selected to move on to the full proposal stage and that do not already involve a DoD partner. The role of the liaison is to assist in selecting and gaining access to an appropriate demonstration site. The liaison will also provide insight into DoD needs, as well as aid in validating the technology's cost and performance, interfacing with the regulatory and user community, and supporting the transfer of the technology across the DoD.

3.2 Stakeholders

The 14034 standard includes a technical review requirement that the performance claim for the intended application of the technology addresses the needs of the interested parties. Although current ESTCP processes include proposal and in-progress project reviews by an impartial Technical Review Panel, expanded use of reviewers and stakeholders could enhance the program and better conform to the standard. Development and implementation of broader stakeholder groups with expertise and interests specifically relevant to technological categories could improve the process and tech transfer. A broader group could involve more expertise in specific technology categories as well as purchasers, and participants with expertise in UFC regulation and technology finance, etc. The development and implementation of these groups would be demonstration specific and best executed by a project team as part of the ESTCP funded demonstration effort.

Stakeholders, or interested parties, are defined in the ISO Standard as a person or organization being concerned with, affecting, being affected by, or perceiving itself to be affected by the results of technology verification (or demonstration). Demonstrations conforming to the ISO Standard should seek to establish a broad stakeholder group including interested DoD users and decision makers, along with technology developers, to inform the project team on information and data needs with respect to applying the ISO Standard to SERDP/ESTCP demonstrations and outcomes. The goal is broad integration of stakeholder inputs that can help ensure that needed info is obtained and distributed, is of required quality, and addresses critical barriers to technology implementation at DoD installations.

These stakeholders, including SERDP/ESTCP technical review panels, provide technical review of demonstration plans, objectives, methodologies, and results. Technical reviews ensure that:

- the demonstration objectives and technology performance claims for the intended application of the technology addresses the needs of the interested parties;
- the information on the technology and its proposed application is sufficient to review the performance claim;
- proposed performance metrics and methodologies are sufficient to assess performance claims;
- sufficient demonstration outreach dissemination of results is planned.

3.3 Technology Supplier

Under the ESTCP program, the technology supplier can be defined as the demonstration party, or the organization or individual proposing to demonstrate the performance of a technology. This can be technology developers, suppliers, or other parties with an interest in demonstrating the technology performance. Under the ISO Standard, this role is defined as the "applicant". The applicant initiates the technology verification process which, in the case of ESTCP sponsored demonstrations, is completed through the ESTCP proposal and selection process. The technology supplier is responsible for:

- Drafting the application for verification and providing the information necessary to plan and implement the verification process as specified in clause 5.2.1 of ISO 14034 standard – via the ESTCP demonstration proposal process, the ESTCP Demonstration Plan, and conformance with this ISO 14034 guidance;
- Reviewing and accepting the verification plan and test plan(s);
- Providing timely access to the technology, accessories, user manuals and training related to the technology use and operation, if relevant;
- Finding a consensus with the verifier in defining, as a minimum, the final set of parameters, their numerical values and ranges to be verified as well as the requirements including testing methods, conditions and limitations for the verification to be included in the verification plan.
- Reviewing the test report(s), verification report and verification statement;
- Complying with the rules for use of the verification statement;
- Selecting and contracting with test or verification bodies.

The applicant can be any legal entity or person, which can be the technology developer, manufacturer, provider, or legally authorized representative of either. With consent of technology developer / provider / manufacturer, the applicant can be another stakeholder undertaking a verification process involving several technologies (e.g. as part of an innovation procurement or pre-procurement procedure).

3.4 Demonstration Host Facility

A key component of the ESTCP program is that demonstrations are usually hosted and conducted at relevant and representative DoD installations and facilities. These host facilities are normally identified in the ESTP demonstration proposal, selection, and planning stages and are a critical component of any demonstration. The roles and responsibilities of the demonstration host facility include the following:

- Access: Providing access and clearances to project participants to necessary facilities;
- Regulations: To Identify potential regulations at the federal, state or local level that are relevant to the project.
- Permits: Provide information on the status of applications submitted and appropriate references for emissions or other permits required for the demonstration to proceed. Describe the process or key points of contact involved in permitting and provide an approximate timeline involved.
- Agreements: Provide information on the status of applications submitted and appropriate references for electrical interconnection or other agreements required for the demonstration to proceed. Describe the process or key points of contact involved in agreements and provide an approximate timeline involved.
- Military Requirements: Identify any DoD-wide, service-specific, or site-specific requirements, approvals, or waivers that may impact the demonstration. Describe the requirements associated

with information security and information assurance and how they relate to communications associated with the demonstration.

- Identify property transfer or disposition plans and procedures relevant to the demonstration.
- Identify equipment removal considerations if applicable. Describe the process to remove the demonstration equipment and restore the site to near original conditions or better.
- Reviewing the test report(s), verification report and verification statement

3.5 Verifier

The verifier implements the verification process in accordance with the ISO 14034 standard. The independent verifier may be an accredited or qualified 3rd party verification entity, a 3rd party technical expert qualified to evaluate the technology and all data in accordance with ISO 14034, or a 3rd party within the organization or a partner organization that is not under the same management control as the technology developer;

Beside the implementation of the verification procedures as specified in ISO 14034, performing verification includes:

- Receiving a request for verification and conducting a preliminary review of potential applications;
- Ensuring compliance of the process with the relevant verification plan and the proposed test requirements contained therein for any verifications;
- Where appropriate, requiring or validating test methods, witnessing tests, assessing and accepting test data provided by a test body, or by the applicant in the case of in-house testing, as compliant with the requirements set in the ISO 14034 and the relevant verification plan;
- Ensuring that all aspects related to confidentiality are addressed as required as per ISO 17020:2012 (see annex A of ISO 14034);
- Providing technical advice to the applicants, in the context of the ETV procedures as well as the definition of the performance claim, the choice of test bodies and the use of the verification statement within limits required to remain impartial in accordance with ISO/IEC 17020.

The verifier must be capable of conducting technology verification in a competent, credible manner. The verifier may implement parts of the verification process through subsidiaries or *sub*-contractors or as specified in ISO /IEC 17020:2012.

Additionally, to ensure consistency, reliability, objectivity and traceability in its work, the verifier should:

- Be a legal entity that is able to enter into contractual arrangement with the applicant;
- Comply with the requirements of ISO/IEC 17020 or by other means demonstrate compliance to section 4.2 of ISO 14034 to perform ETV;
- Be a third-party body independent of the applicant and of any other party interested in the verification. It is recommended that the verifier demonstrates its independence by meeting the requirements for Type A inspection bodies as defined in the normative Annex A of ISO/IEC 17020.
- Not be directly involved in the design, manufacture or construction, marketing, installation, use or maintenance of the specific technologies submitted to this body for verification, or represent the parties engaged in those activities;

- Ensure that the activities of their subsidiaries or subcontractors do not affect the confidentiality, objectivity, or impartiality of their verification activities;
- Ensure that a process is in place to assess the quality of test data;
- Providing technical advice to the applicants, in the context of the ETV procedures as well as the definition of the performance claim, the choice of test bodies and the use of the verification statement within limits required to remain impartial in accordance with ISO/IEC 17020.

3.6 Verification Accreditation Entity

Accreditation is a statement from an accreditation body – an independent third-party entity – declaring that specified requirements related to conformity assessment bodies (independent verifiers, analytical laboratories, calibration laboratories, etc.) have been met and that the accredited body is competent to perform certain functions supporting the demonstration. These accreditation entities conduct the conformance audits of the performers, and issue and maintain accreditation certificates. Examples of accreditation entities relevant to verification of ESTCP demonstrations include ANSI National Accreditation Board (ANAB), American Association for Laboratory Accreditation (A2LA), or International Accreditation Service, Inc. (IAS).

4.0 ISO 14034 ETV PRINCIPLES

4.1 ISO Standard 14034

Impartial Verification of Technology Performance

A fundamental requirement of ISO 14034 is that verification of testing (or performance demonstration) be conducted by independent and impartial (third) parties. The purpose of ETV is to provide a credible and impartial account of the performance and as such, ETV is based on a number of principles to ensure that verifications are performed and reported accurately, clearly, unambiguously and objectively. This can be implemented by modifying the ESTCP demonstration processes such that demonstrations, or verification of demonstration findings, are conducted by independent and impartial parties.

The basic principles of the ISO 14034 Standard are listed in Section 4 of the standard:

- General - The purpose of technology verification is to provide a credible and impartial account of the performance of technologies. Technology verification is based on a number of principles to ensure that verifications are performed and reported accurately, clearly, unambiguously and objectively.
- Factual approach - Verification statements are based on factual and relevant evidence confirming objectively the performance of technologies.
- Transparency and credibility - Technology verification is based on reliable test results and robust procedures. The process is facilitated such that, to the greatest extent possible, methods and data are fully disclosed, and reports are clear, complete, objective and useful to the interested parties.
- Flexibility - To maximize the utility of results, technology verification allows for flexibility in the specification of the performance parameters and test methods. This is achieved through a dialogue between the applicant, verifier and interested parties.

4.2 ISO Standard 17020

Competencies

The ESTCP proposal and project selection processes address the qualifications of potential demonstration performers. However, this standard for verification bodies and ISO 17025 for laboratories, requires demonstration of specific qualifications, competencies, and procedures that are relevant to the technology under demonstration. Application of the competency and procedural requirements within this standard to the ESTCP process can significantly improve the quality of data generated, demonstration credibility, and broad acceptance of demonstration results. Requirements for demonstration of performer competencies with respect to the standards can be applied to primary demonstration performers, their subcontractors, supporting analytical laboratories, and/or independent verification bodies during the proposal and selection process. Conformance with those requirements could then be further documented during the demonstration processes (in the Demonstration Plan and Technical Reports).

It is likely that competency requirements may increase demonstration costs by requiring ESTCP applicants to utilize third parties to either conduct or at least independently verify demonstration activities. Availability of qualified demonstration performers or verifiers may also complicate the overall process. The benefits to the program of competency requirements however can be expected to increase acceptance and transferability of demonstration results.

Metrological Traceability

Under the current ESTCP guidance, performers are required to generally describe their approaches to and plans for data quality, and to quantify uncertainty in results for key performance parameters. A greater level of data quality, demonstration credibility, and acceptance of findings can be promoted by applying the metrological traceability requirements of the standard to ESTCP demonstrations. Further, the requirement of traceability to international reference standards, as verified by impartial performers or verifiers, can "level the field" of data quality for demonstrations of technologies within technological categories, adding value to the demonstrations from the perspective of stakeholders and decision makers. Adherence to the traceability requirements of the standard should be able to be applied at minimal or no additional significant costs to the program. More details about data quality recommendations with respect to measurement traceability and verifiability are provided in Appendix A.

Requirements of metrological traceability of critical measurements supporting a demonstration are not expected to add significant costs to demonstrations. It can generally be assumed that organizations applying for demonstration funding in efforts toward wide technology acceptance will inherently have data quality and critical measurement standards in place. That said, it can be expected that implementation of traceability requirements can significantly improve the credibility and transferability of demonstration results, particularly with respect to Section 6 of ISO 17020:

6.2.6 *Where appropriate, measurement equipment having a significant influence on the results of the inspection shall be calibrated before being put into service, and thereafter calibrated according to an established program.*

6.2.7 *The overall program of calibration of equipment shall be designed and operated so as to ensure that, wherever applicable, measurements made by the inspection body are traceable to national or international standards of measurement, where available. Where traceability to national or international standards of measurement is not applicable, the inspection body shall maintain evidence of correlation or accuracy of inspection results.*

Quality Management Systems

Section 8 of ISO 17020 provides the requirements for Quality Management Systems (QMS) of performers (demonstrators, verifiers, or supporting test and laboratory bodies). Generally, accreditation under ISO 17020 requires that performers be either accredited under ISO 9001 "Quality Management Systems" or can demonstrate conformance with the requirements of that standard which include:

- management system documentation (e.g. manual, policies, definition of responsibilities);
- control of documents;
- control of records;
- management review processes;
- internal auditing processes;
- corrective and preventive actions; and
- complaints and appeals processes.

These requirements are relevant to improvement of ESTCP demonstration data quality and credibility. For key QMS requirements of the standard, much of the required control of documents and records will be covered in the ESTCP contract – Federal Acquisition Regulation (FAR) systems, Clauses Incorporated by Reference.

Implementation of this requirement under the ESTCP program is expected to be difficult and could lead to a lack of qualified performers that are either accredited or meet all the standard requirements. A more acceptable implementation approach may be to require conformance to the requirements of ISO 17025 for laboratories and test bodies generating demonstration data, and then require independent review of demonstration activities under ISO 17020 where feasible or viable.

4.3 ISO Standard 17025

General requirements for the competence of testing and calibration laboratories

The ISO 17025 Standard specifies the general requirements for the competence, impartiality, and consistent operation of laboratories (which can include organizations performing or supporting demonstrations). Under ESTCP this standard can apply to organizations where field testing or analytical activities form part of demonstration, verification, inspection, or reporting of technology performance.

By requiring conformance with this standard for critical technology performance objectives under the ESTCP program, demonstrations can document increased relevance and quality, increased data quality, broader acceptance of reported performance, and greater technology transfer. Many credible laboratories used to support ESTCP demonstrations are either accredited under ISO 17025 or conform to most relevant requirements of the standard. Since there is wide acceptance of the standard globally and no shortage of laboratories that conform to the standard, a requirement for conformance to this standard should be a relatively simple implementation under ESTCP.

5.0 PROGRAM REQUIREMENTS – SETUP

Certain programmatic requirements of implementation of the ISO Standard to ESTCP include gathering input from relevant stakeholders to steer the objectives and approaches of the technology demonstration. Additionally, demonstration planners should conduct a thorough review of standardized test and verification protocols that are relevant to the technology and its intended use with respect to DoD applications.

5.1 Stakeholder Group Formation

The ISO 14034 standard includes a technical review requirement that the performance claim for the intended application of the technology addresses the needs of the interested parties. Although current ESTCP processes include proposal and in-progress project reviews by an impartial Technical Review Panel, expanded use of reviewers and stakeholders could enhance the program and better conform to the standard. Development and implementation of broader stakeholder groups with expertise and interests specifically relevant to technological categories could improve the process and tech transfer. A broader group could involve more expertise in specific technology categories as well as purchasers, and participants with expertise in UFC regulation and technology finance, etc. It is recommended that technology developers work with ESTCP to identify potential stakeholders (such as procurement, energy managers, policy and regulation developers, third party financers) and ensure their input is obtained and integrated in the demonstration plan and feedback sought throughout the demonstration.

Depending on the nature of the technology and the demonstration objectives, a project may potentially have multiple stakeholder groups including stakeholders with general interest in DoD programmatic objectives, or stakeholder groups with interest in a particular technology (e.g., operational efficiency or energy storage technologies), or categories of technologies (e.g., systematic DoD energy efficiency or DoD mission resilience). Stakeholder groups can consist of a few interested parties, or a broad and balanced range of stakeholders.

Potential stakeholders with particular relevance to SERDP/ESTCP demonstrations include: Energy Managers, DoD AUSD for Installations & Environment, DoD staff responsible for UFCs, Procurement officials, DoD Research Lab staff (i.e. CERL), Commercial utility representatives (i.e. UESC operators), energy service company representatives (i.e. those providing ESPCs), regulatory officials, other federal agencies with similar needs (i.e. GSA), product commercialization specialists, and others recommended by ESTCP. The SERDP/ESTCP Technical Review Panels used to proposal evaluation and project selection provides a good example of what a demonstration stakeholder group might resemble. Other examples of stakeholders or interested parties may include other technology end users, communities, equipment suppliers and developers, investors, and regulators.

5.2 Stakeholder Input

Stakeholder input can be solicited using surveys, questionnaires, meetings, or other means. Typically, the kinds of information required of stakeholders may include:

- Identification of technologies or technology categories of interest;
- Relevance to DoD applications;
- Performance parameters of interest, both qualitative and quantitative;
- Data quality needs;
- Identification of barriers to primary and secondary barriers to technology transition and broad technology deployment

Ultimately, the stakeholder input process will aggregate responses and identify primary and secondary barriers to technology transition and develop a list of targeted information needs to ensure barriers are addressed.

5.3 Standardized Test & Verification Protocols (Demonstration Planning)

During demonstration planning, use of existing standardized testing protocols, demonstration plans, verification plans, relevant technical references including standard test methods, and international standards of performance should be examined and considered. Use of existing and technology relevant ESTCP Demonstration Plans or verification protocols can identify performance objectives and metrics that meet stakeholder needs. Additionally, use and conformance to applicable specifications or standard test methods and procedures such as those published by organizations including ASHRAE, ASTM, EPA, LEED, IEEE, ICC Codes (IMC, IPC, IECC, etc.) will significantly increase the credibility of the demonstration and verification.

In cases where ESTCP has sponsored demonstration of multiple technologies within a technology category (e.g., energy storage or cybersecurity technologies) development and use of standardized approaches for demonstration and performance assessment should be implemented according to standard requirements (ISO 14034 4.1.4). Implementation of this process into ESTCP would facilitate standardization of the approach, the performance parameters required, the data quality, and demonstration conditions that would enhance stakeholder ability to assess and compare technology relevance and performance. For certain technology types, ESTCP may establish standardized verification protocols and requirements that ensure technologies are evaluated in a similar fashion, with similar performance parameters, data quality levels, and other requirements. If a Technology Specific verification Protocol has been established, that protocol should be followed to the extent possible, and all requirements of the protocol cited in the Demonstration Plan. If there are any anticipated deviations from the standard protocol, including specification of performance parameters, specific data not being collected, modifications to data collection procedures, including instrumentation, frequency, duration, or any other deviations, identify those in detail within the Demonstration Plan.

With respect to other standards, codes, or methods, the ETV Standard also requires consideration of the following:

- relevant legal requirements, or standards related to the technology and its use;
- a statement that the technology adheres to applicable regulatory requirements;
- conformance to existing verification plans and relevant technical references including standard test methods, preferably international standards.

6.0 PROGRAM REQUIREMENTS – DEMONSTRATION & VERIFICATION PLANNING & IMPLEMENTATION

For ESTCP or SERDP demonstrations to conform to the requirements of the ISO 14034 Standard, certain programmatic requirements, planning activities, and implementation processes are required. These provisions are detailed in the sections below. A review of all relevant existing ESTCP processes and guidance was compared to the ISO 14034, 17020, and 17025 requirements and processes and is summarized in Figure 1.

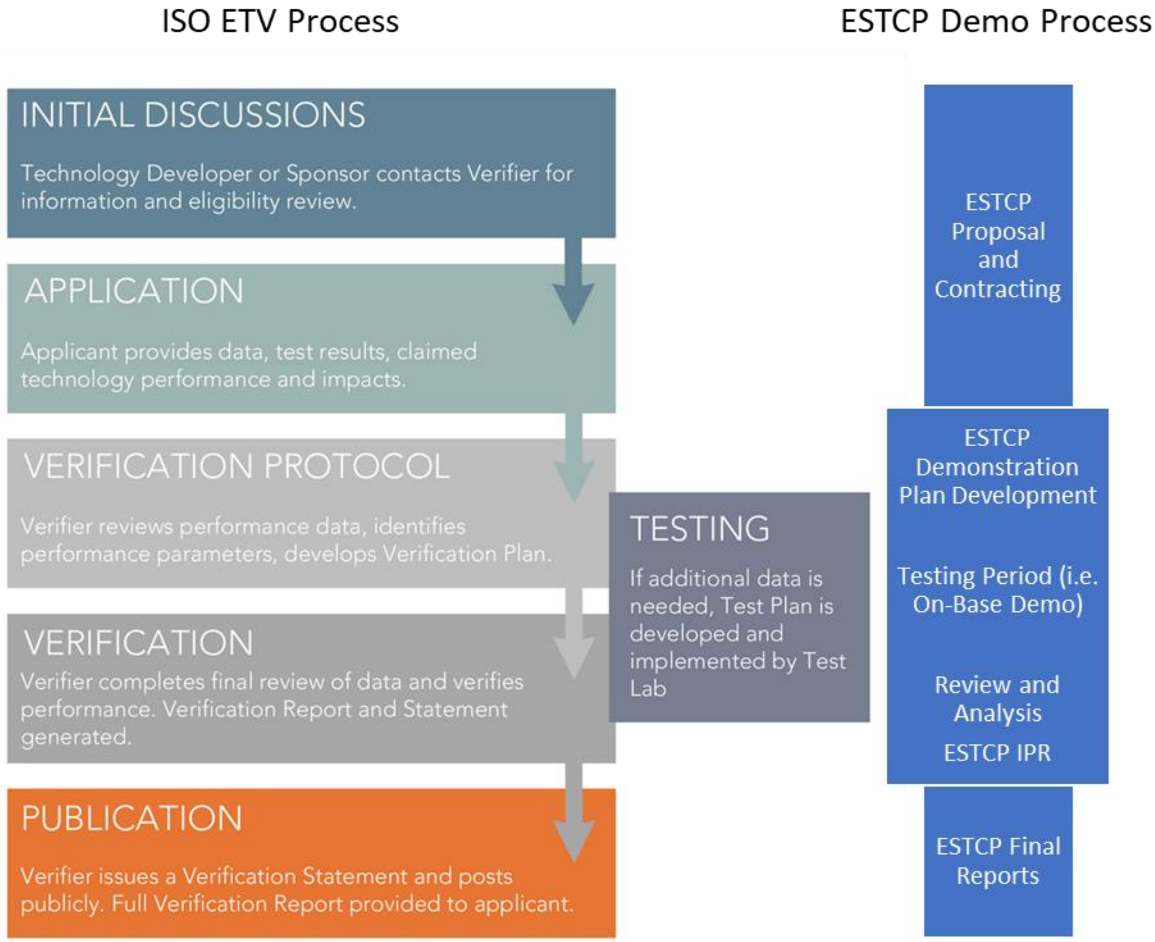

Figure 1. The ISO 14034 ETV Process & ESTCP Process Comparison

6.1 Required Planning Documents

For demonstration planning purposes, the ESTCP project selection and funding process will serve as a significant portion of the verification application review process. Similarly, the existing ESTCP processes for development of Pre- and Full Demonstration Plans coincides with the ISO required Verification Protocol (see Figure 1);

The ESTCP and SERDP programs have established processes for planning a DoD technology demonstration. Specifically, a Pre-proposal, a Full Proposal upon selection, and after project selection and contracting provisions, a Pre-Demonstration Plan, and a full Demonstration Plan.

The following ESTCP processes and documents are required for demonstration planning:

- **Relevant proposal requirements** [Reference documents: *PROGRAM ANNOUNCEMENT FOR FY 2020 ENVIRONMENTAL SECURITY TECHNOLOGY CERTIFICATION PROGRAM (ESTCP), BAA Pre-Proposal Submittal Instructions, Reference: Broad Agency Announcement (BAA) January 8, 2019; ESTCP Installation Energy Open Broad Agency Announcement (BAA), Full Proposal Submittal Instructions, BAA CY19*], https://www.serdp-estcp.org/page/dd2b9569-94cc-46f8-b85d-2ac562f86f62

- **Demonstration Plan Guidance documents:** SERDP and ESTCP manage projects in five program areas and issue guidance for the requirements of Demonstration Plans. Installation Energy and Water [*Reference document: ESTCP Demonstration Plan Guidance: Installation Energy and Water Projects*, *March 2018*], https://www.serdp-estcp.org/workingwithus/templatesandguidance#ESTCPdemo

The ISO ETV Standard has another set of documentation requirements [2]. To a large degree, these ESTCP processes align with the planning requirements of the ISO Standard, with some exceptions. Table 1 summarizes the planning documents of each program and how the ESTCP planning process can be enhanced to conform to the ISO requirements. The table identifies gaps between the requirements of the standard and current ESTCP processes that should be addressed to conform to the standard.

Table 1. ISO 14034 Compliant ESTCP Planning Processes

Required ISO 14034 Planning Docs (ISO 14034 Citation)	Principle Requirements	Aligned ESTCP Planning Documents	Conformance to the ISO Standard	Conformance Gaps
Application (Section 5.2)	Technical and administrative review, technology details; justification of performance claims; presence of relevant existing performance data; and initial approach for verification.	Pre-proposal and Full Proposal	ESTCP Proposal process requires significant technology details and justification, justifies performance and impact claims. ESTCP review panel selection process technical and administrative reviews ensure technologies are beneficial and ready for demonstration.	Presence of relevant existing performance data that may be used for demonstration of performance.
Pre-Verification Planning (Section 5.3.1)	Specification of performance parameters; relevance; review and use of existing protocols, standards, and methods; input of interested stakeholders.	Pre-demonstration Plans	Specification of performance objectives and parameters; technology relevance and applicability to DoD installations.	Plans for independent verification approaches, use of existing protocols, standards, and methods; input of interested stakeholders beyond ESTCP review panel.
Verification Plan (Section 5.3.2)	Detailed verification parameters and performance claims; test approaches and methods; operating conditions; data quality specifications and measurement metrology; identification of independent verifier and test bodies.	Demonstration Plan	Detailed verification parameters and performance claims; test approaches and methods; operating conditions; data quality specifications.	Measurement metrology; identification of independent verifier and test bodies.

When proposing a demonstration under the ESTCP Program using the **Relevant proposal requirements** cited above, it is recommended that proposers include a description of plans for demonstration conformance to ISO 14034 ETV guidance, and budget allowances to accommodate those additional project requirements summarized as conformance gaps in Table 1.

With respect to preparation of an ISO conformant ESTCP Demonstration Plan, the ESTCP Program issues specific guidance for development of the Plan (see **Demonstration Plan Guidance documents** cited above). When developing a Demonstration Plan for conformance with the ISO standard, it is recommended that supplemental information be added to the Plan Guidance document. Appendix B details the required supplemental information for Demonstration Plan conformance, with Section numbers provided that correspond to the organization of the current ESTCP Plan Guidance document. Inclusion of the information provided in these supplemental guidelines will ensure conformance with the standard with respect to demonstration planning activities.

6.2 Demonstration Requirements

The ESTCP and SERDP programs have established requirements for executing a technology demonstration. Conformance to the ISO ETV Standard presents additional requirements for planning and executing the demonstration as summarized here.

6.2.1 Data Collection

The standard requires that data collection or verification be conducted by impartial parties with demonstrated qualifications and competencies.

Impartiality. It is noted that current ESTCP processes include front end technical reviews through proposal reviews, as well as in-progress project reviews by an impartial Technical Review Panel. These reviews add to the process a level of impartial review and stakeholder input. The process does not however, require impartial verifiers or test bodies for of demonstration activities and generation of technology performance data needed to conform to the ISO requirements (ISO Standard 14034, Sections 4.1 and 4.2).

A potential implementation strategy to address this gap could be modification of the demonstration guidance and requirements that requires demonstrations be conducted or verified by impartial parties (that is, parties without vested interest or other conflicts with respect to promotion of the technology under demonstration). The costs associated with third party demonstrations can be largely offset by reducing the internal demonstration costs borne by demonstration applicants/performers. Alternately, short term independent verifications of demonstration activities conducted by applicants can be conducted by qualified and competent verification bodies, although it is assumed the cost of such third-party verifications will be borne by the ESTCP program (that is, built into the overall demonstration costs).

See also Appendix B, Section 5.1.

Performers. Data collection activities conducted in support of a technology demonstration should be conducted, where possible, by impartial and independent entities. Should data collection be performed by entities without demonstrated impartiality, then impartial and independent verification becomes a critical component of ISO conformance (see Section 6.3 below). Defined as test bodies in the ISO Standard, data collection performers are personnel, organizations, or entities providing the means for test implementation, including performing and reporting on the testing of an technology for the purposes of verification as specified in ISO 14034. To ensure consistency, reliability, objectivity and traceability in its work, the test body should:

- Be a legal entity that is able to enter into contractual arrangements.
- Have a management system in place capable of supporting and demonstrating the consistent achievement of the requirements of ISO/IEC 17025 relevant for the tests to be performed and assuring the quality of the test results. This includes documenting its procedures to the extent necessary to ensure competent, impartial and consistent testing and validity of the test results.
- Demonstrate accreditation or compliance with ISO/IEC 17025 for the relevant analytical methods and analyses used for performance testing. Note: The verification plan may add further testing requirements and it is necessary to ensure the quality of these tests and test data for the technology to be verified
- Made available to the verifier upon request routine analytical quality control data.
- Participate in proficiency tests for the analyses used.
- Have competent test personnel that are independent of the verifier. In the case where the applicant performs the necessary tests in-house, the applicant is expected to fulfil the requirements described above for test bodies. The verifier should confirm this for example by means of an audit.
- Be capable of carrying out all the tasks assigned to it as described in the section 4.2.1 on roles and responsibilities in the technology areas for which it is operating, whether those tasks are carried out by the verifier itself or by another entity on its behalf and under its responsibility.
- Ensure that the activities of their subsidiaries or subcontractors do not affect the confidentiality, objectivity or impartiality of their testing activities.
- Take responsibility for the tasks performed by subcontractors and subsidiaries.

It is important to note that the applicant in consultation with the verifier can designate the test body, to perform tests if needed. Although the designation of the test body is a decision made by the applicant, the applicant should consult with the verifier to ensure that the qualifications set forth in 4.2.2 are met.

6.2.2 Data Quality

Verification of ESTCP demonstrations should evaluate the quality of the test data against the requirements defined in the Demonstration Plan as specified in subclause 5.2.5. of the ISO 14034 standard and the general requirements specified in ISO/IEC 17025 that directly contribute to or influence the validity and quality of the tests and the resulting test data. See Appendix A of this guidance for additional details.

Requirements on data and data quality should refer to the quality level (e.g., reproducibility, repeatability, ranges of confidence, accuracy, and uncertainties) generally accepted by the scientific community for the technology, or in the industrial sector concerned. The Demonstration Plan should include relevant technical references including applicable standardized test methods (preferably international standards) to be used or referred to for test data generation. In validating the test method and the operational and statistical significance of the test data, the verifier should confirm the assumptions and the applicability of the statistical tools used to evaluate the test data.

This refers to both the reporting of existing test data and new test data generated during the verification process. In the case of existing test data, the verifier should confirm the quality of the test data by checking documentation, including the test plan used for data generation, raw test data, quality control during data generation, and the test report.

If relevant, the verifier may perform an assessment of the test system that generated the test data. When performing test system assessment, the verifier should focus in particular on the issues specified in ISO /IEC 17025 that may directly contribute to or influence the quality and validity of the tests and produced test data, for example:

a) Resources, including personnel involved in the testing, facilities and conditions of test performance, equipment used for the testing, metrological traceability, use of externally provided products and services if applicable (as in the case of subcontracting), etc.
b) Process requirements, including validation of methods, sampling, handling of test or calibration samples, maintenance of technical records, evaluation of measurement uncertainty, validation of test results, reporting of results, control of data and information management.

In the event that the test body producing the test data was accredited according to ISO/IEC 17025 for the relevant methods of testing and calibration at the time of production of these test data, it may be presumed to comply with the requirements of ISO/IEC 17025.

Measurement Instrumentation Guidance

Appendix C of this guide presents additional guidance with respect to measurement and instrumentation used for ESTCP demonstrations. The primary objectives of this guidance for Best Practices for Measurement and Impact on Performance Evaluations are to utilize the ISO 14034/17020 framework for ETV, establishing its relevance to demonstration projects within ESTCP.

This document provides a non-exhaustive overview of the various data collection methods and analytical considerations for use under ESTCP/SERDP energy and water demonstrations and recommended best practices. It also aims to provide a basic understanding of the implications of certain instrumentation technologies and measurement techniques that impact the accuracy, precision, and reliability of data, and the ultimate utility of the data. Approaches for measuring temperature, flow, power, solids/mass rates, and gas composition are explored, followed by a discussion about how error and uncertainty analysis can be used in technology verification and evaluation, as well as in selection of appropriate instrumentation. This document is not intended to mandate certain technologies nor measurement specifications, but rather to explore the opportunities and challenges that can be expected when evaluating innovative technologies and incorporating data quality as part of a technology verification and selection process.

6.2.3 Data Validation

All data, generated by verifiers or demonstrators, that is used to validate or verify performance claims or performance objectives should be reviewed on a regular ongoing basis and classified as valid, incomplete, or invalid.

Verifiers provide for internal and external independent review for all planning, data collection and analysis activities conducted as part of demonstration/verification projects. This review is conducted by verifiers with demonstrated competencies that are not directly connected or involved with the project activities or by external reviewers as deemed necessary or appropriate. See also Appendix A - Data Quality Recommendations.

6.2.4 Analytical Methods

For demonstrations requiring analytical analyses of materials, reference or standardized methods and procedures should be followed where possible. Acceptable methods, procedures and protocols include those developed by a recognized authority in testing such as a regulatory body such as Standard Methods, EPA, ASTM, etc., or specified in standardized test methods (preferably international standards). For analytical testing, acceptable methods, procedures and protocols are used for sample collection, preservation and transport.

Test bodies and verifiers should demonstrate accreditation to, or compliance with ISO/IEC 17025 for the relevant analytical methods and analyses used for performance testing. Note: The verification plan may add further testing requirements and it is necessary to ensure the quality of these tests and test data for the technology to be verified.

Appendix A "Data Quality Requirements" and Appendix C "Best Practices for Measurement and Impact on Performance Evaluations Additional" provide additional details regarding the requirements for analytical testing or services including guidance for:

- qualifications and competencies of test bodies,
- sampling protocols and matrices,
- planned analytical methodologies,
- data quality and equipment calibration.

6.2.5 Existing Data

The standard allows for use of existing technology data to demonstrate performance potential. The standard provides specific existing data criteria with respect to relevance toward potential DoD applications and quality of data. Although a fundamental aspect of the ESTCP program is that demonstrations be conducted in relevant and broadly applicable DoD facilities, it is likely that there may be cases where existing technology performance data that are representative of DoD applications is available. In such cases, significant cost savings could be realized through independent verification of existing data as it applies to certain DoD applications.

This gap could be addressed by allowing the use of existing data that is relevant to DoD installations, of sufficient quality, and transferrable to broad applicability to DoD. In the interest of cost and efficiency, it is likely that the burden of assessment of existing data with respect to those characterizations could be placed on the applicants during the demonstration proposal and selection process.

Any existing performance data used to demonstrate performance claims should be validated and verifiable.

6.3 Verification Requirements

The requirements and processes for verification activities are detailed in the ISO 14034 Standard [2] and the ISO 14034 Implementation Guide [7] and summarized in the following subsections.

6.3.1 Verifier Requirements

Verifiers must be capable of conducting technology verification in a competent, credible manner. Section 4.1.2 and Annex A "Guidance for demonstrating competence to conduct verifications [7]" outlines the primary verifier requirements and competencies necessary for effective technology verification in accordance with the ISO 14034 standard. To ensure consistency, reliability, objectivity and traceability in its work, the verifier should be ISO 17020 accredited or able to demonstrate these requirements:

- Be a legal entity that is able to enter into contractual arrangement with the applicant.
- Comply with the requirements of ISO/IEC 17020 or by other means demonstrate compliance to section 4.2 of ISO 14034 to perform ETV.
- Be a third-party body independent of the applicant and of any other party interested in the verification. It is recommended that the verifier demonstrates its independence by meeting the requirements for Type A inspection bodies as defined in the normative Annex A of ISO/IEC 17020.
- Not be directly involved in the design, manufacture or construction, marketing, installation, use or maintenance of the specific technologies submitted to this body for verification, or represent the parties engaged in those activities. This pertains to the verifier, its top-level management and the personnel responsible for carrying out verification tasks. This should not preclude the use of technologies that are necessary for the operations of the verifier or the use of technologies for personal purposes.
- Ensure that the activities of their subsidiaries or subcontractors do not affect the confidentiality, objectivity or impartiality of their verification activities.
- Ensure that a process is in place to assess the quality of test data.
- Be capable of carrying out all the tasks assigned to it as described in the section on roles and responsibilities in the technology areas for which it is operating, whether those tasks are carried out by the verifier itself or by another entity on its behalf and under its responsibility.
- Take responsibility for the tasks performed by subcontractors and subsidiaries as agreed by the applicant.

6.3.2 Verification Activities

Section 5 of the ISO 14034 Standard outlines key procedures of the technology verification:

- **Application:** The ISO equivalent of the ESTCP proposal and project selection process, as detailed in Section 6.1 above.

- **Pre-verification:** The ISO equivalent of ESTCP Pre- and Full Demonstration Plan process, as detailed in Sections 6.1 and 6.2 above.

- **Verification:** Actual verification activities are detailed in Section 5.5 of the ISO 14034 Implementation Guide [7] and consist of two primary requirements:

    - Confirmation of data quality - The verifier should evaluate the quality of the test data against the requirements defined in the verification plan as specified in subclause 5.2.5. of the ISO 14034 standard and the general requirements specified in ISO/IEC 17025 that directly contribute to or influence the validity and quality of the tests and the resulting test data.
    - Confirmation of technology performance - The verifier reviews the performance claim and the test data to determine whether the data meet the objectives of the verification process and the requirements as outlined in the verification plan. The data related to the technology performance must be of sufficient quality and quantity to permit statistical

analysis of the data in relation to the performance claim. The verifier should confirm the assumptions and the applicability of the statistical tools used to evaluate the test data.

Both verification components are conducted by qualified impartial verifiers in accordance with the standard and the standard guidance. Appendix D of this guidance document, Tables D-1 through D-4 (Administrative Review, Technical Review, Test Data Assessment, and Data Quality Assessment) provide verification guidance in checklist format that detail the reviews and assessments necessary to verify the quality of data and technology performance. Verification and completion of the verification checklists are typically completed through a series of verifier activities:

- Document reviews – application, demonstration and verification plans, technology description, demonstration objectives and approaches;
- Site visit(s) – an initial demonstration site visit for observation and documentation of demonstration activities and performance data, and potential subsequent site visits for long-term demonstrations;
- Data assessment and validation - reviews of representative subsets of collected data for assessment of data quality, completeness, and representativeness;
- Data processing review – review of all data logging, validation, and management procedures, review of all data calculations;
- Quality assurance and control assessments - reviews performer qualifications, equipment calibrations and metrology, and all other required documentation.

- **Reporting:** See Sections 6.3.3 below.

- **Post-verification:** See Sections 6.3.4 below.

6.3.3 Verification Report and Statement

Verification Report. The verification report compiles or summarizes all information relevant for the verification and includes all relevant documents produced during verification process as appendices.

Annex E of "Guidance for demonstrating competence to conduct verifications [7]" provides an outline for the verification report content that can also be used as a checklist by the verifier. If the verification procedure is not completed, the applicant is informed of this, and the verification report compiles the information made available to the verifier. Appendix E of this guide provides guidance for verification report content.

In some instances, it may be of use to include information regarding the technology, its applications, or other information that may provide context for the market or interested parties. In many cases, the verifier will not verify this additional, supplementary information. When such information is included in a report and is not verified it must be clearly identified to ensure the user of the report does not assume it has been verified.

Verification Statement. The statement should include any information necessary to understand and use the verified performance claim; if this includes any additional information not verified during the ETV process, this should be clearly stated and explained.

The verification statement may include a disclaimer related to legal compliance of the verified technology, e.g., "Unless stated otherwise, this verification has not evaluated and cannot guarantee compliance with specific legal requirements. Ensuring legal compliance is the responsibility of the applicant".

Annex F of "Guidance for demonstrating competence to conduct verifications [7]" and Appendix F of this guide provides guidance for verification report content. When the verification procedure is not completed, a verification statement is not produced.

6.3.4 Publication

The ETV Standards' clause on publication refers principally on the availability of the verification statement for key stakeholders but also for the overall public. The availability of this information is mandatory. There are no specific requirements on how it should be made publicly available, but it could be posted on the verification statement on the verifier's website and/or the applicant's website and/or any other parties involved in the verification (i.e. accreditation body's website, ETV program website, etc.). It is to the applicant's advantage that the verification statement be available at different places which would help marketing the verified technology through various ways. The more detailed Verification Report will also be provided for files which may or may not be published.

6.4 Marks, Monitoring, Logo Use

Although it is not specifically mentioned in ISO 14034, logos or trademarks can also be used for marketing purposes. It is understood that the legal usage of any potential logos would be included in any contractual arrangements with the applicant and the party owning the rights of the logo. The owner of the logo rights would follow-up and enforce the proper use of these in contractual agreements. For example, follow-up and enforcement of verified technologies can include ensuring the proper use of ETV logos or setting time limits on licence agreements for usage of logos. It is however, important to indicate that the value of ETV does not lie within a logo or a trademark: being "ETV verified" has no meaning without the clear mention to what has been verified which information is part of the verification statement.

Therefore, the logo should be used in well-defined conditions, specifying clearly what has been verified. The proposer would therefore not use the ETV logo alone either on products or on published (printed, web or other) matter other than with the verification. Consequently, the logo could be used on publications together with the reference to the verification statement as long as the meaning of ETV is correctly reflected by the publication, avoiding in particular any confusion with endorsement or approval of the technology.

7.0 REFERENCES

[1]. Environmental Security Technology Certification Program (ESTCP), Alexandria, VA 22350-3605. https://www.serdp-estcp.org/About-SERDP-and-ESTCP/About-ESTCP.

[2]. ISO 14034:2016 Environmental Management – Environmental Technology Verification (ETV), International Organization for Standardization. November 2016. [https://www.iso.org/standard/43256.html].

[3]. SERDP/ESTCP Project #EW20-5333, Demonstration Plan "Improving ESTCP Demonstration Outcomes & Tech Transfer via Integration of Standardized Third-Party Technology Verification using ISO 14034, Version 3.1", January 14, 2021, https://www.serdp-estcp.org/Program-Areas/Installation-Energy-and-Water/Energy/Conservation-and-Efficiency/EW20-5333.

[4]. 350Solutions, Inc., "ESTCP / ISO 14034 Gap Analysis Report v 2.0", SERDP/ESTCP Project #EW20-5333, November 2022.

[5]. 350Solutions, Inc., "ISO 14034 Verification Report & ISO 14034 Implementation Gap Analysis and Case Study Report for Nanofiber-Based Low Energy Consuming HVAC Air Filters (ESTCP Project No. EW201724)", SERDP/ESTCP Project #EW20-5333, August 2022.

[6]. 350Solutions, Inc., "ISO 14034 Verification Report & ISO 14034 Implementation Gap Analysis and Case Study Report for Next Generation Advanced High-Efficiency DX Air Conditioner (ESTCP Project No. EW-201717) v1.3", SERDP/ESTCP Project #EW20-5333, January 2023.

[7]. International Standards Organization (ISO), Technical Committee 207, *Draft Environmental Technology Verification – Guidance to Implement ISO 14034*, ISO/PDTR WD1:2017(E), 10-16-2017.

[8]. ISO 17020 :2012 Conformity Assessment – Requirements for the Operation of Various Types of Bodies Performing Inspection, International Organization for Standardization. March 2012. [https://www.iso.org/standard/52994.html]

[9]. ISO/IEC 17025:2017 – General Requirements for the Competence of Testing and Calibration Laboratories. International Organization for Standardization. March 2018. [https://www.iso.org/standard/66912.html]

APPENDIX A: Data Quality Recommendations

To increase acceptance and transferability of demonstration results, the data collected during the demonstration must be of documented and sufficient quality so that the results derived from that data will meet the decision-making needs of project stakeholders and other parties with an interest in the technology. Under the ETV standard, specific requirements for data quality, and the objectives that follow from these requirements, depend on the type of result reported as well as the end use of those results by decision makers.

Data Quality Assessment for Key Performance Objectives - The following sections discuss data quality for key demonstration objectives and describe the means by which verifiers measure, document and assess data quality to provide assurance that the results will be of documented quality sufficient to meet stakeholder needs.

During verifications and performance assessments, uncertainty calculations are estimated based on manufacturer sensor accuracy specifications and predicted system performance and using standard formulas for propagation of error. In these estimates, the covariance terms in the error propagation formulas can be neglected, although in most cases the values are in fact correlated. Sensor manufacturer accuracy figures are generally taken as 1-sigma values.

- Ancillary Data Quality - Ancillary data are those data that will be collected that do not directly support determination of demonstration objectives. As these data are not critical measurements and do not directly affect achievement of data quality objectives, the most stringent QA/QC requirements are unnecessary.

- Instrument Calibrations and Quality Checks - Calibration records and/or procedures for all monitoring instruments to be installed by verifiers or applicant will be reviewed and documented for measurement validation for at least the duration of the demonstration period. This includes any measurements or combination of measurements used to validate performance criteria or objectives.

  Where appropriate, measurement equipment having a significant influence on the results of the demonstration should be calibrated before being put into service, and thereafter calibrated according to an established program (NIST or suitable substitute attestation as determined by verifier using sound professional judgment). The overall program of calibration of equipment should be designed and operated so as to ensure that, wherever applicable, measurements made by the demonstration or verification body are traceable to national or international standards of measurement, where available. Where traceability to national or international standards of measurement is not applicable, the inspection body should maintain evidence of correlation or accuracy of inspection results. Reference standards of measurement held by the inspection body shall be used for calibration only and for no other purpose. Reference standards of measurement shall be calibrated providing traceability to a national or international standard of measurement.

- Data Quality Review and Validation - All data, generated by verifiers or demonstrators, that is used to validate or verify performance claims or performance objectives should be reviewed on a regular ongoing basis and classified as valid, incomplete, or invalid.

  Verifiers provide for internal and external independent review for all planning, data collection and analysis activities conducted as part of demonstration/verification projects. This review is conducted by verifiers with demonstrated competencies that are not directly connected or involved with the project activities or by external reviewers as deemed necessary or appropriate.

- Data Management – As a critical component of traceability and verifiability, all field data generated during demonstrations should be collected, stored, and retrieved from technology demonstration data acquisition systems, in whichever form these systems may present (manual recordings, electronic files, etc.). Verifiers retrieve data through demonstrations at relevant intervals and frequencies that are specified in verification plans.

APPENDIX B: Supplemental Requirements to ESTCP Demonstration Plan Guidance for ISO 14034 Conformance

The following supplemental guidance to the ESTCP Demonstration Plan Guidelines should be included in Demonstration Plan development for ISO 14034 Conformance. https://www.serdp-estcp.org/workingwithus/templatesandguidance#ESTCPdemo

Section 1.4. ISO 14034 – ETV

A standardized verification approach – ISO 14034: 2016 –
ETV [1], should be applied to relevant ESTCP demonstrations (the standard is not applicable to demonstrations based on modeling or other qualitative analyses or approaches, nor demonstrations falling under the Technology Transfer project category). Implementation of a standardized verification process for technology demonstrations can address some of the barriers that currently exist between technology demonstration and broad technology acceptance and deployment. The approach includes the following requirements that ensure that, if implemented properly and accepted by the DoD community, interested parties have information they need to encourage more rapid acceptance, appropriate technology transfer, and broader implementation of validated technologies. The requirements of ISO 14034 ETV process is summarized below, with detailed implementation guidance provided in Section 7.1 of this guidance document. The ISO 14034 ETV process includes:

- Implementation of standardized, consistent approaches to technology evaluation as adopted by ESTCP;
- Requirement for verification of technology performance data by a qualified independent third party – including selection and procurement of qualified third party verification and test bodies (see Section 7.1);
- Requirements for quality of data provided by test labs and other performers and data providers;
- Mechanisms for stakeholder input at planning and verification stages to ensure those in the future deployment decision chain get information they need;
- Potential use of existing performance data that conforms to the requirements of the standard;
- Broad applicability to a variety of technology types, applications, and interested party needs.

Additional details regarding the process of implementation of ISO 14034 to the demonstration are provided in the standard referenced throughout this guidance document. Full copies of the standard are available for purchase at the ISO website: https://www.iso.org/standard/43256.html

Note that ISO 14034 integrates with two additional important standards that may apply to the demonstration:

- ***ISO 17020: Conformity assessment -- Requirements for the operation of various types of bodies performing inspection*** [2], which establishes qualifications for independent entities to perform verification work.
- ***ISO 17025: General Requirements for the Competence of Testing and Calibration Laboratories*** [3], to ensure data used in evaluation of new technologies meets consistent standards and is provided by qualified entities.

Full copies of the standards are available for purchase at the ISO website: https://www.iso.org/standard/43256.html.

Section 1.5. Technology-Specific Verification Protocol

RESERVED (until standard protocols are developed)

For certain technology types, ESTCP has established standardized verification protocols and requirements that ensure technologies are evaluated in a similar fashion, with similar performance parameters, data quality levels, and other requirements. If a Technology Specific verification Protocol has been established, identify that protocol here, and review and incorporate all requirements of the protocol in the Demonstration Plan.

If there are any anticipated deviations from the standard protocol, including specification of performance parameters, specific data not being collected, modifications to data collection procedures, including instrumentation, frequency, duration, or any other deviations, identify those here and in detail within the Demonstration Plan.

Section 4.0. Performance Objectives

Supplemental requirements:

- Existing Protocols or Standards: Existing ESTCP Verification Protocols and other international standards for evaluation of the technology performance may enable measurement of the contribution of the technology to DoD Installation Energy and Water goals and what metrics are being measured and should be considered when developing objectives.
- Stakeholder Input: The data and information needs of users and other technology relevant stakeholders involved in the future deployment of the technology.

Section 4.1. "Table 1" Summary of Performance Objectives

Provide a summary of proposed performance objectives in Table 1 in a manner similar to the example provided in Table 1 below.

Table 1. Example Performance Objectives
[- Adjust as appropriate for specific technologies.]

Performance Objective	Metric	Data Requirements			Success Criteria
		Quantitative Performance Objectives			
		Data Type	***Data Frequency / Duration***	***Data Source***	
Utility Supplied Energy	Energy Intensity (MMBtu/ ft^2 or kWh/ft^2)	Meter readings of energy used by installation; square footage of buildings using energy	15-min average energy usage / full year of data	Revenue quality power meter	% Reduction compared to baseline, or, targeted threshold value
On-Site Energy Usage	RE Used on Installation (kWh, MMBtu)	Meter readings of on-site energy usage	15-min average energy usage / full year of data	Revenue quality power meter	% Increase or targeted threshold value
Water Usage	Water (Gallons)	Meter readings of water used by installation	Daily total water usage / full year of data	Revenue quality water meter	% Reduction compared to baseline, or, targeted threshold value
Facility Metering	Number	Number of metered buildings			% Increase
System Maintenance	Number or Level	Scheduled and unscheduled maintenance events; downtime; survey data	Annual total of events	Maintenance log / datalog	% Reduction or increase compared to industry standard or similar systems
System Economics*	%, $, Years	Dollar costs, discount rate, usable life	NA	NA	% Reduction or increase
Other					
Qualitative Performance Objectives					
User Satisfaction	Degree of Satisfaction	Likert Scale Survey	Once	Survey	% Increase in satisfaction over baseline
ISO 14034 Conformance	Data quality	Conform to the requirements of ISO 14034/ 17020 and 17025	NA	NA	Independent, 3rd party Verification Statement

Section 4.1. Independent Verification & Qualitative Performance Objectives – Conformance to ISO 14034

Describe plans for conformance to the ISO 14034 standard with respect to planning and execution of the demonstration. The primary purpose of the information provided here is to provide demonstrators details regarding the requirements of the ISO standard and guidance for Demonstration Plan content that will ensure that the demonstration conforms to the standard. Of primary interest when describing the conformance to ISO 14034 are the following:

- Identify the independent verifier that will be performing the verification as part of the demonstration. The independent verifier may be an accredited or qualified 3rd party verification entity, a 3rd party technical expert qualified to evaluate the technology and all data in accordance with ISO 14034, or a 3rd party within the organization or a partner organization that is not under the same management control as the technology developer;
- Identify external laboratories or testing agencies that will be performing analyses as part of the demonstration program, and establish their qualifications, such as ISO 17025 accreditation for analytical labs;
- Summarize critical data sources, preferably via reference to Table 1 (Performance Objectives) and Section 5. To provide further detail, a table of all critical measurements that will be recorded via on site instrumentation, as well as analytical testing proposed. This should be different from Table 1 – Performance Objectives, as typically, each performance objective might be calculated from multiple independent measurements. See example in Table 2.
- ESTCP recognizes that certain aspects of a demonstration plan may not fully conform to the standard for a variety of reasons including project budgets and costs, the availability of verifiers that meet the qualification requirements of the standard, or equipment or materials that meet the standards' metrology requirements. However, the demonstration plan should include plans to conform to the standards where possible and identify components of the demonstration that are expected to be non-conformant to the standard as well as potential impacts of these non-conformities on the demonstration outcomes, data quality, and the potential for verification.

Table 2. Critical Measurements
[Example - Adjust as appropriate for specific technologies.]

Performance Objective	Critical Measurements						
	Data Type	**Instrumentation (make/model**	**Units of Measure**	**Instrument P&ID Tag**	**Data Frequency / Duration**	**Instrument Accuracy**	**Calibration Interval**
Facility Energy Usage	Electrical energy use	Power meter	kWh		15-min average energy usage / full year of data	± 1% reading	Once before use
	Thermal energy use	Energy metering	Btu			± 2% reading	Weekly
	other						
On-Site Energy Usage	Electrical energy use	Power meter	kWh		15-min average energy usage / full year of data	± 1% reading	Once before use
	Thermal energy use	Energy metering	Btu			± 2% reading	Weekly
	other						
Water Usage	Meter readings of water used by installation	Water meter	gpm		Daily total water usage / full year of data	± 1% full scale	Weekly
Direct Greenhouse Gas & Air Pollutant Emissions	Pollutant concentration(s)	Emissions monitor(s)	ppm		15-min average	± 1% full scale	Daily
	Exhaust gas flow rate	Mass flow meter	scfm		Hourly average	± 1% full scale	Once before use

Section 4.2. Performance Objectives Descriptions

Supplemental requirements:

- Data: Describe the data required to calculate or evaluate the metric. Summarize details regarding the specific equipment being used (make, model, type), frequency and duration of data collection and recording (i.e. 15 minute averages of 1-s data, quarterly sampling), duration of monitoring period for each critical measurement (i.e. 1-month, one quarter, full year (to address seasonal changes). For any laboratory analytical testing, describe the test method (and method standard, if available), the sampling method (i.e. grab, composite, or a specific protocol), and the sample frequency.

- Analytical Methodology: Briefly address the type of analytical methodology the investigator will use, such as type of statistical or graphical analysis outlined in Section 6. Identify any other standards being utilized in the analysis that are relevant to the performance of the technology (e.g., IEEE, ASHRAE, etc.).

Section 5.1. Conceptual Test Design

Supplemental requirements:

- Independent Performance Verification: ISO 14034 specifies that technology performance evaluations are conducted or verified by impartial and independent parties (ISO/IEC 17020:2012, Section 4.1. In the context of ESTCP demonstrations, this can be addressed in the Demonstration Plan by including plans that:
    - The demonstration activities are planned and conducted in collaboration with a qualified and independent/impartial party,
    - Demonstration activities and resulting performance data are verified according to the standard by a qualified independent/impartial party, or,
    - Performance data is reviewed and verified by a qualified independent/impartial party.

OPTIONAL: Use of existing performance data:

The ISO 14034 standard allows for the use of existing technology performance data that is relevant to DoD installations and of sufficient quality to conform to the requirements of the standard. Performance data proposed by the applicant that were generated prior to demonstration and that can provide additional relevant information regarding performance (such as at additional operating conditions, at different scale, or previous technology or product testing) is subject to approval by ESTCP program managers with the following considerations:

a) The performance data are relevant for the technology under demonstration and the performance objectives to be demonstrated;

b) The data are relevant to the technology application under demonstration, and transferrable to other suitable DoD installations;

c) The performance data were produced and reported according to the requirements of ISO/IEC 17025.

In cases where existing performance data is proposed to offset some or part of performance data generated through on-site DoD testing, the data should be independently verified by a qualified impartial verification party to confirm that the data are directly relevant to the technology and application being demonstrated for DoD.

Section 5.4. Operational Testing

Supplemental requirements:

- Modeling and Simulation: Describe any modeling and simulation that may accompany the operational testing. Note that ISO 14034 generally does not apply to any modeling and simulation efforts. It is focused on measurable data (which could be verified inputs to models) but would not apply to results of models or simulations.

Section 5.6. Equipment Calibration and Data Quality Issues

Address the following topics to ensure data collection is valid. Additional guidance for Best Practices for Measurement and Impacts on Performance Evaluations are provided in Appendix C.

- Equipment Calibration: Indicate which equipment requires regular calibration and who will ensure the calibration occurs and how it will be documented. For equipment items which may not require regular calibration (i.e. a one-time calibration for a power meter or current transformer), ensure that a NIST-traceable factory calibration or similar initial calibration is provided or purchased.
- Quality Assurance Sampling: Describe the activities associated with data collection to ensure data quality, such as duplicate sampling or optimization of sampling frequency.
- Conformance to ISO 17025:
    - Describe how analytical activities and performers conform to Sections 6.2 and 6.3 of ISO 17025, in particular these key requirements of the standard:
        - 6.2.1. All personnel of the laboratory, either internal or external, that could influence the laboratory activities shall act impartially, be supervised and competent and shall work in accordance with the laboratory's management system.
        - 6.2.2. The laboratory shall define and document the competence requirements for each function involved in laboratory activities, including requirements for education, qualification, training, technical knowledge, skills, experience, duties, responsibilities and authorities.
        - 6.2.3. The personnel shall have the competence to execute the activities for which they are responsible and understand the significance of and response to deviations found with regard to the laboratory activities.
        - 6.2.7. Records of competence, such as education, training, technical knowledge, skills, experience, authorizations and monitoring for all personnel involved in laboratory activities, shall be maintained.
        - 6.2.8. The laboratory shall manage the risk to impartiality arising from over-familiarity between its personnel and the customer.
    - Describe how measurement equipment and systems conform to Section 6.4 of ISO 17025 with respect to equipment selection, calibration, and traceability. Key requirements include:
        - 6.4.1. The laboratory shall have access to all equipment required for the correct performance of the laboratory activities. Equipment shall include software, measurement standards, reference materials, reagents and consumables or auxiliary apparatus or combination thereof necessary to realize a measurement process and which may influence the measurement result.

- 6.4.3. The laboratory shall have documented processes for appropriate handling, transport, storage, use and planned maintenance of equipment to ensure proper functioning and in order to prevent contamination or deterioration.
- 6.4.5. The laboratory shall identify equipment used for measurements and capable of achieving the accuracy required and complying with the specifications relevant to the laboratory activities concerned. It shall establish a documented calibration program for such equipment to ensure metrological traceability of the measurement results.
- 6.4.7. Records shall be maintained for equipment significant to the laboratory activities.
- 6.4.12. The laboratory shall select and use reference materials that are fit for the specific purpose in the measurement process.

- Post-Processing Statistical Analysis and Data Validation: Describe any statistical or other data analysis to ensure reasonableness of collected data and to identify possible discrepancies, such as incorrect readings or faulty measurement equipment.
- Uncertainty Analysis: Describe statistical or other approaches for estimating uncertainty of reported Performance Objective values, based on measurement error for key data streams, system or process variability, and other factors. Wherever possible, performance values should be reported as the calculated value with an estimated uncertainty.

Section 7.0. Independent Verification

Implementation of the ISO 14034 standard to ESTCP sponsored demonstration will follow the procedures of ETV – Guidance to Implement ISO 14034 guidance document [4]. This Technical Report provides information to support the process of ETV in accordance with ISO 14034 and is a companion document to the published ISO 14034 standard. It explains the responsibilities of applicants, verifiers and test bodies. It describes each step of the ETV procedure, including application, pre-verification, verification, reporting and post-verification. An overview of the implementation guidance and key processes is provided here for consideration during development of ESTCP Demonstration Plans. Much of the ISO requirements detailed here are fulfilled under the current ESTCP selection and demonstration process. This information is included in this guidance to provide PIs with detailed considerations when planning a demonstration, such that the implementation of the standard to the ESTCP process can be executed with a minimum of additional requirements or costs.

Section 7.1 Roles and Responsibilities

Verifier: The verifier implements the verification process in accordance with ISO 14034. Besides the implementation of the verification procedures as specified in the standard, performing verification includes also:

- Development of a verification plan, specific to the technology under demonstration and the associated performance objectives relevant to the ESTCP project.
- Ensuring compliance of the process with the relevant verification plan and the proposed test requirements contained therein for any verifications;

- Where appropriate, requiring or validating test methods, witnessing tests, assessing and accepting test data provided by a test body, or by the applicant in case of in-house testing, as compliant with the requirements set in ISO 14034 and the relevant verification plan; and;
- Providing technical advice to the demonstration body, in the context of the ETV procedures as well as the definition of the performance claim, the choice of test bodies and the use of the verification statement within limits required to remain impartial in accordance with ISO/IEC 17020.

Test Body: A test body is an organization providing a space for testing, test-implementation and means for performing and reporting on the testing of a technology for the needs of a technology verification as specified in ISO 14034:

- Entering into contractual arrangement with the demonstration body;
- Drafting a test plan, in accordance with the requirements included in the verification plan and in agreement with the verifier and the demonstrator. Test bodies are responsible for applying the requirements set in the ISO 14034, the verification plan in the demonstration plan where applicable;
- Performing the tests according to the test plan ensuring the level of quality required by ISO/IEC 17025 and the verification plan;
- Performing analyses, ensuring the level of quality assurance required by ISO/IEC 17025 and the verification plan; and,
- Drafting the report on tests performed and providing it to the verifier and the applicant. The report on the quality of analytical data should include the uncertainties and limits of detection.

ESTCP Demonstration Body: Defined in the ISO standard as the applicant, the demonstration body is the organization sponsored by ESTCP to plan and conduct the demonstration. The demonstration body initiates and supports verification of the performance of the technology from the first contact with the verifier until completion of the ETV process and use of the verification statement generated at the conclusion of the ESTCP demonstration.

- Drafting the application for verification, providing the information necessary to plan and implement the verification process as specified in subclause 5.2.1 of ISO 14034;
- Identifying, procuring, and coordinating verification and test bodies as required.
- Reviewing and approving the verification plan and test plan(s);
- Providing timely access to the technology under demonstration; accessories; user manuals and training for the verifier and test bodies; as well as performance data, data collection, storage, manipulation, and calculations; and specifications and calibrations of supporting measurement instruments;
- Finding a consensus with the verifier in establishing the final set of parameters, their numerical values and ranges to be verified as well as the requirements, conditions and limitations for the verification to be included in the verification plan;
- Reviewing the test report(s), verification report and verification statement.

Section 7.2. The Verification Process

The ETV process consists of three primary components:
1) The application procedure;
2) Pre-verification; and
3) Performance verification.

Descriptions of the process components are summarized below. Detailed descriptions of the requirements of the ISO standard that are relevant and applicable to ESTCP demonstrations are provided in Appendix C. Appendix D (Section 13.4) provides a series of generic verification checklists that are appropriate for use in verification of ESTCP demonstrations and cross references those cited requirements with the demonstration guidance provided in this document.

Section 7.2.1 - The Application Procedure

Under the ISO 14034 process, the application procedure includes assessments of the applicants (demonstrators) ability to proceed through the process, completeness and relevance of the technology, quality of performance claims, and the added value of the technology. Under the ESTCP program, it is assumed that the application procedures are satisfied during the ESTCP proposal and selection process and not specifically repeated during the verification of ESTCP demonstrations.

Section 7.2.2 - Pre-verification

As a result of the ESTCP technical review of a Demonstration Plan, the verifier may determine the need to modify or supplement the performance claim and the performance parameters to be verified proposed by the demonstrator. This pre-verification process will provide a consensus between ESTCP, the verifier, and demonstrators, establishing the final set of parameters, their values to be verified as well as the requirements, conditions, constraints and limitations for the verification to be included in the verification plan. During pre-verification, verifiers will assess considerations:

- Relevance of existing test data for the specification of the performance parameters – as amenable to ESTCP program managers;
- Performance ranges to be verified with respect to possible relevant regulatory requirements;
- Performance ranges to be verified with respect to the needs of the interested parties;
- Constraints and limitation that apply to the performance to be verified. Performance parameters that are modeled or estimated (for example, economic performance over broad DoD technology deployment), will not be included in ETV verifications.

Additional details regarding the pre-verification process are provided in the ETV Guidance to implement ISO 14034 [4].

Section 7.2.3 - Verification Procedures

As detailed in the ETV Guidance to Implementation document, verification procedures include the following components. Demonstrators will work interactively with verifiers and test bodies where applicable to complete the process.

- **<u>Development of a verification plan:</u>** A verification plan, consistent with ISO 14034, is developed by the verifier responsible for performing the verification. The verification plan describes the verification procedure specific to the technology and the performance to be verified. It explains how the verification is to be conducted, including the performance parameters to be verified, and all relevant requirements on tests and test data (e.g. test method selection, test design, data quality, data assessment, etc.). The level of detail of information included in the verification plan should be sufficient for the verifier to assess during the verification procedure whether the existing test data provided by the applicant together with the application is relevant and can be accepted to verify the performance of the technology or, if this is not the case, for the test body to develop a test plan to in order to generate new test data, respectively. Annex C1 of the ETV Guidance to Implementation provides a summary of the verification plan contents.

- **Confirmation of Data Quality:** The verification plan should establish the specification of the requirements for the test data needed to confirm the verified performance of the technology. During the verification procedure these test data requirements should also serve as a basis for the verifier to assess the applicability of the test data provided by the applicant.
- **Confirmation of technology Performance:** The verifier reviews the performance claim and the test data to determine whether the data meet the objectives of the verification process and the requirements as outlined in the verification plan. The data related to the technology performance must be of sufficient quality and quantity to permit statistical analysis of the data in relation to the performance claim. The result of the verification should be confirmation of the performance of the technology, achieved under the same conditions, constraints and limitations as those specified in the verification plan. Guidance on the implementation of verification process including review of the existing test data, assessment of test data quality is outlined in Annex D of ETV Guidance to Implementation.

In some cases, the technology performance achieved, as verified using the test data qualified to be used for verification, may not match the performance originally anticipated by the applicant in the performance claim provided in the application. In that case, the achieved performance should be considered the verified performance and be confirmed and documented by the verifier.

- **Verification Report and Statement:** The verifier should prepare a report detailing all the steps taken and results obtained in the implementation of the verification process. A summary of the verification results, in the form of a verification statement, is also required. The verification report compiles or summarizes all information relevant for the verification and includes all relevant documents produced during verification process as appendices. The statement should include any information necessary to understand and use the verified performance claim; if this includes any additional information not verified during the ETV process, this is clearly stated and explained.

Section 7.2.4 - Verification Costs

The costs associated with ETV, particularly under the ESTCP program, can vary widely depending on a number of factors:

- The scope of performance objectives;
- The scope and duration of the demonstration;
- The existence of relevant and verifiable existing performance data;
- The need for use of independent verifiers or test bodies to assess certain performance objectives and parameters;
- Supplemental measurements or instrumentation required to assess performance objectives.

Due to the robust nature of ESTCP sponsored technology demonstrations, it is the intention of ESTCP to minimize additional costs to demonstrations to implement ETV. In cases where additional costs are incurred, verifiers and test bodies will provide cost proposals to the demonstrating body prior to initiation of the verification planning and process.

APPENDIX C: Best Practices for Measurement and Impact on Performance Evaluations for ESTCP/SERDP Energy and Water Technology Demonstrations

Introduction:

Innovative energy technologies are rapidly developing, driven by a growing need for clean water, energy security, and emission mitigation. As new technologies are developed, the need for credible data on their performance and claimed impact grows. The quality of the data and how it is expressed and utilized can impact investment decisions, market uptake, funding, and awards. ESTCP and SERDP sponsored demonstrations of innovative technologies relevant to DoD operations and security require credible performance data to fully evaluate the efficacy of these technologies for use in DoD applications.

Projects conduct formal demonstrations at DoD facilities and sites in operational settings to document and validate improved performance and cost savings. To ensure the demonstrated technologies have a real impact, ESTCP collaborates with end-users and regulators throughout the development and execution of each demonstration. Transition challenges are overcome with rigorous and well-documented demonstrations that provide the information needed by all stakeholders for acceptance of the technology. However, the transfer of technologies and market uptake is still limited, and challenges remain. In many markets, including the DoD, transfer of knowledge to end users, purchasers, regulators, and others is often done in an ad hoc, inconsistent manner, which can result in critical stakeholders having to try to repeatedly compare options, review barriers, assess performance, and estimate impact on their own, relying on information from various disparate resources.

A standardized verification approach now exists and is outlined in the international standard – ISO 14034: 2016 - ETV [1]. The approach includes the following requirements that ensure that, if implemented properly and accepted by the community, interested parties have information they need to encourage more rapid acceptance, appropriate technology transfer, and broader implementation of validated technologies. The ISO 14034 ETV process includes:

- Standardized, consistent approach to technology evaluation;
- Requirement for verification of tech performance data by a qualified independent third party;
- Requirements for quality of data provided by test labs and other data providers;
- Mechanisms for stakeholder input at planning and verification stages to ensure those in the decision chain get information they need;
- Flexible, generic approach that allows same principles to be applied for different technology categories via development of specific Verification Plans for each technology and type;
- Development of a standardized Verification Plans for technology types – instead of potentially varying approaches;
- Broad applicability to a variety of technology types, applications, and interested party needs.

The primary objectives of this guidance for Best Practices for Measurement and Impact on Performance Evaluations are to utilize the ISO 14034/17020 framework for ETV, establishing its relevance to demonstration projects within ESTCP.

This document provides a non-exhaustive overview of the various data collection methods and analytical considerations for use under ESTCP/SERDP energy and water demonstrations and recommended best practices. It also aims to provide a basic understanding of the implications of certain instrumentation technologies and measurement techniques that impact the accuracy, precision, and reliability of data, and the ultimate utility of the data. Approaches for measuring temperature, flow, power, solids/mass rates, and gas composition are explored, followed by a discussion about how error and uncertainty analysis can be used in technology verification and evaluation, as well as in selection of appropriate instrumentation. This document is not intended to mandate certain technologies nor measurement specifications, but rather to explore the opportunities and challenges that can be expected when evaluating innovative technologies and incorporating data quality as part of a technology verification and selection process.

Performance Parameters and Critical Measurements

ESTCP/SERDP demonstrations establish technology specific performance objectives during the demonstration planning stage. Focusing on the HVAC and energy storage categories of technologies that are prevalent in recent ESTCP Energy and Water demonstrations, typical primary and secondary performance objectives include those summarized in Figure 1.

Primary Performance Objectives

HVAC technologies	**Storage Technologies**
energy efficiency	energy use
energy reduction to baseline	resilience
energy use	load capability
cost savings	power flow
O&M qualitative	cost savings
	GHG reductions
	improved control
	LCOE

Secondary Performance Objectives

HVAC technologies	**Storage Technologies**
load reduction	power factor
load capability	operating cost
install cost	payback
operating cost	IRR or SIR
payback	reliability
IRR	O&M qualitative
GHG reductions	Water usage
Indoor air PM or CO_2	
reliability	
comfort qualitative	
O&M against baseline	
Water usage	

Figure 1. Common demonstration performance objectives for HVAC and Energy Storage technology categories.

Each performance objective requires determination of specific performance parameters that enable evaluation of those objectives. Each performance parameter is calculated and analyzed based on measured data generated during the demonstration period.

Quantitative performance parameters require single or multiple measurements to enable the final calculation of the parameter over a defined technology operating period. For example, evaluation of a technology designed to increase energy efficiency over a baseline scenario may involve several concurrent measurements such as power consumption, fuel consumption, and delivery of heat, cooling, or work. Further, these measurements may require real time determinations of contributing variables such as current, potential, fluid flow rates, fluid temperatures, etc. Each of these measurements, required for the overall evaluation of a performance objective, are deemed critical measurements, and each has an impact on overall certainty in the final calculated value of a performance parameter.

Critical measurements for any demonstration can vary widely based on the nature of the technology under demonstration, and the specific demonstration performance objectives. A list of example critical measurements as they contribute to the evaluation of common ESTCP quantitative performance objectives are summarized in Table 2.

Table 2. Example performance objectives and supporting critical measurements.

Performance Objective	Metrics/Parameters	Data Requirements	Critical Measurements
Energy use reductions	Baseline and demonstration energy use	Power consumption	Power, voltage, amperage
		Fuel consumption	Fuel flow, fuel heating value
Energy efficiency	Energy use	Power consumption	Power, voltage, amperage
		Fuel consumption	Fuel flow, fuel heating value
	Energy delivered	Heating or cooling	Transfer fluid flow, temperature, pressure, composition
		Work	Technology specific (e.g., power output, torque, speed)
GHG emission reductions	Baseline and demonstration emissions (mass/time)	GHG emissions	Gas flowrate, temperature and pressure, gas composition
	Unit of normalization	System output (power, heat/cooling, unit work)	See above

Instrumentation & Data Collection Practices

Each critical measurement may have several instrumentation options with varying technical needs, cost, accuracy, and output. The instrument characteristics and their impact on data quality and overall performance parameter calculation and uncertainty can be significant and should be assessed early in the planning process according to the demonstration performance objectives. This can help determine an optimal suite of instrumentation that balances accuracy and data quality with system costs with the level of sensitivity needed to evaluate the objectives.

The following sections introduce general recommendations for good measurement practices for processes undergoing demonstration and evaluation, particularly with respect to metrological traceability conformance to ISO standards. These practices may not apply to small scale proof of concept or laboratory scale technologies, where the focus is a core technology (such as catalyst performance) and not overall process performance. They may also not apply to fully developed process technologies, where additional data resolution is not required, as the primary concern becomes process control and optimization, and less focused on performance determination, as that has likely been established.

Temperature Measurement

Table 3. Recommended Temperature Measurement Practices

Instrument	Characteristics	Typical Specifications/Data Quality		
		Typical Output	Typical Accuracy	Recommendation
Thermocouple	Simple, reliable, low-cost. Voltage generated from dissimilar metals.	4-20mA	Accuracy ±0.5% - 1%	Preferred
Resistance temperature detector (RTD)	High accuracy, smaller range, and expensive. Measure of resistivity for metal, which changes based on temperature.	4-20mA (typical)	±0.1%-0.3%	Preferred
Handheld IR or thermocouple	Handheld infrared or thermocouple devices should be avoided due to their manual nature of data recording.	Digital Display or can be mA or mV	±0.1% - 4% (depends on emissivity)	Not preferred

There are five main avenues for measuring temperature: thermocouples, resistance temperature detectors (RTDs), infrared (IR) Thermometers, integrated circuit (IC) Sensors, and thermistors [2]. While all instruments are useful and have advantages in certain applications, perhaps the most common conventional approaches for good quality lab/pilot scale experimental data collection are thermocouples and RTDs. These are easy to connect with a control/historian software system (and are often pre-configured) to capture periodic measurements.

Thermocouples are inexpensive, robust, fast responding, and can be purchased for a wide range of temperature applications. Their flexibility is also their primary challenge: they must be specified correctly. Thermocouple design attributes include type, probe length, process connection, connection assembly, junction type, probe diameter, sheath composition, etc. It is good practice to keep spares on hand due to the difficulty in recalibrating or repairing. RTDs are generally more expensive and have lower extreme operating ranges than thermocouples but are more accurate and can be repaired or recalibrated more simply than thermocouples.

Infrared thermometers are a useful tool, especially when contact with the object to be measured is difficult or impossible. However, these instruments can typically only tolerate a moderate ambient space and are usually handheld devices that limit automated recording potential. While fixed instruments with automated measurement exist, the larger concern is also the dependency on emissivity for accurate absolute temperature measurement. Each object (e.g. wood, plastic, metals, stainless or polished metals, etc.) has its own emissivity value that must be taken into consideration for an absolute temperature reading. The emissivity of a polished metal surface for instance also inhibits any absolute temperature measurement, resulting only a trending of temperature to be captured by the device. These instruments can be extremely useful tools in facility operations, process commissioning, or maintenance contexts, but should not be relied upon for the collection of critical process data.

The integrated circuit sensors and thermistors have their own niche markets that are best, but are generally too fragile, limited in their temperature range, or slow responding to be of great use in process engineering and experimental application.

Flow Measurement

Table 4. Recommended Flow Measurement Practices

Instrument	Characteristics	Specifications/Data Quality		
		Example Output	Typical Accuracy	Recommendation
Coriolis	Mass flow meter, liquid and some gas measurements, high accuracy, causes some pressure drop.	4-20mA, Ethernet, HART, …	±0.1% - 0.75%	Preferred
Thermal-mass	Compact, reliable, calibrated mass flow device.	4-20mA, 0-5Vdc	±1%	Acceptable
Orifice, Venturi	Volumetric flow meters using pressure drop measurement.	4-20mA, 0-5Vdc	±1-5%	Acceptable
Positive Displacement, Turbine	Direct volumetric flow meters using mechanical principles (high viscosity fluids)	4-20mA, 0-5Vdc	±0.5% of value	Acceptable
Rotameter	Velocity measurement, variable area flow meter with manual recording	Visual float indication, manual record	±5% of full scale	Not preferred

Flow is typically determined by using a mathematical relationship between a set of conditions measured as the result of a fluid transitioning through a device. This can involve pressure drop, deflection of an element due to momentum transfer, heat transfer or wave deflection [2].

The gold-standard for flow measurement is usually the Coriolis flow meter. In the lab or pilot scale environments, electric mass flow meters and mass flow controllers based on either thermal or Coriolis technology are excellent tools for homogenous or relatively stable heterogeneous fluids.

Orifice and venturi flow meters in general are probably the most common type of flow meter, with a relatively simple, low cost, high accuracy design relative to a widespread base of applications. These differential pressure flow meters require long runs of straight pipe upstream and downstream of the restriction for accurate measurement, and additional temperature and pressure measurements are required to calculate the flow through the device [3]. These devices have poor turn-down performance as much of the pressure drop is lost at low flow rates.

Positive displacement flow meters directly measure the volume of fluid passing through the device through the rotation of a known volumetric element. The ability to seal these elements limit the accuracy of these devices as low viscosity fluids can slip through these seals unmeasured, therefore low viscosity fluids and gasses such as CO_2 would not be appropriate for these devices. Typically, the accuracy claims for positive displacement flow meters are viscosity limited.

A major consideration in specifying flow measurement instruments is whether mass or volumetric flow is of primary interest. If accurate mass flow measurements are required a Coriolis style or thermal mass style meter may be preferred, otherwise a differential pressure style meter may be sufficient. And while Coriolis meters are known for their accuracy, differential flow meters are capable of very accurate measurements when installed & calibrated properly and operated within their optimal flow range. Many flow meters require a certain length of straight pipe prior to and following the measurement device so as to ensure laminar or roughly consistent cross-sectional flow through the measurement zone. Analog instruments such as rotameters should be avoided for crucial control or data gathering.

It is important to ensure that devices are compatible with the intended service and calibrated properly: Meters must be compatible with the fluids being measured, calibrated with the service fluid, and operated within the acceptable limits of temperature and pressure.

Finally, most flow meters are intended for either gas or liquid flow. Ensure that either gas or liquid are the elements flowing through the device. If the device is intended for gas only, a filter or drain may be necessary to ensure accurate measurement. If the device is intended for liquid, a reservoir of some sort upstream (even as slight as a U bend) may be necessary to ensure continuous liquid contact. If the device is intended for a heterogeneous stream, it may be necessary to measure the gas or liquid composition upstream or immediately downstream to validate individual component flow rates.

Power Measurement

Table 5. Recommended Electrical Power Measurement Practices

Instrument	Characteristics	Specifications		
		Typical Outputs	Typical Accuracy	Recommendation
Revenue Quality Power Meter	Real-time power consumption readings and transmission w/ time stamps	RS-485, Ethernet, etc.	<±0.1-1% error	Preferred
Induction Clamp	Magnetic induction provides electricity flow data	None/SD card, maybe Modbus.	Minimal error	Acceptable w/data logging
Mechanical meter	In-line mechanical motion for measurement of power consumption, manual record	No outputs	Minimal error	Not preferred

Power measurements can be taken typically using any number of induction or current transformer technologies. Typically, a digital electronic power meter is the best choice for inline measurement of power draw. A mechanical meter (such as an older utility style meter) is not preferred due to the manual nature of the data recording. Similarly, an induction type meter that clamps around a power wire is less than optimal due to the inability to continuously transmit and/or store data on power consumption. In addition, users should be aware that typical power meters will also require use of separate current transformers (CTs) which must be properly selected for the current and voltage being metered and have their own accuracy specifications which may vary based on CT quality and must be incorporated in overall measurement accuracy determination.

Digital power meters for measurement of total electricity usage, with accuracy of ±0.2% are readily available and cost effective. Because of the low cost, it may be beneficial, if not critical, to monitor electrical loads separately (sub-metering), to ensure accurate electrical consumption information is obtained for the process itself and not for ancillary loads, such as building heat and lighting. The U.S. Department of Energy document *Metering Best Practices: A Guide to Achieving Utility Resource Efficiency*, *Release 3.0* [4] provides an extensive overview of best practices for metering.

Solids / Mass Measurement

Table 6. Recommended Mass Measurement Practices

Instrument	Characteristics	Specifications		
		Typical Outputs	Typical Accuracy	Recommendation
Loss in Weight Feeders	Screw, belt, or vibrating feeders on load cells for high accuracy mass data	RS-485, Ethernet, digital etc.	<±0.25-1% error real time.	Preferred
Industrial high accuracy load cell platform scale	Electronic interface capable of transferring data on a batch wise basis	RS-232, Ethernet	Large error due to single position	Acceptable for low impact data, not preferred
Volumetric continuous feed	Screw, belt or vibrating feeders that have been manually calibrated for mass vs VFD setting	RS-232, Ethernet, digital	Error can be large at extremes of VFD	Acceptable, Not preferred
Pre-weighed measurement or mechanical scale only	Manual reading on a visual scale or a recorded value on a container	None	Moderate accuracy	Not preferred

Solids and fluids can be measured either by volume or mass, and can be conveyed in numerous ways from screw augers, to belt conveyors, to vibrational/gravity feeding systems. The highest quality data methods utilize direct mass measurement with calibrated scales or load cells (i.e. strain gauges, piezoelectric elements, variable capacitance or newer piezoresistive technology). When properly calibrated, these devices provide the highest quality measurement. An alternative to direct mass measurement is volumetric measurement correlated to mass with experimental data. For instance, a variable frequency drive (VFD) motor can be used to turn an auger at a specified frequency and deliver a correlated mass of feed. While less expensive, this method increases the error at the extreme ranges of the VFD significantly, which also gets worse depending on the consistency and type of feedstock. The least favorable means of measuring solids product or feed is to utilize a mechanical scale with manual recording. While the scale may be accurate pending proper calibration, manual recording and data entry is always a larger risk for uncertainty.

Gas Compositions

Table 7. Gas Composition Measurement Recommendations

Instrument	Characteristics	Specifications		
		Typical Outputs	Typical Accuracy	Recommendation
Online Gas Analyzer	GC, FTIR, MS, FID, etc. complex gas analysis and digital recording/ transmission of data	RS-485, Ethernet, digital etc.	<±0.5% RSD	Preferred
Online gas (specific) gas monitor	Limited data for 1 or 2 gases only. Lower accuracy than option 1. Continuous measurements with digital data exchange	Ethernet, RS-485, 4-20mA, digital, etc.	1% of scale	Acceptable
Gastec/Draeger tube samples	Calorimetric reading for a chemical reaction with manual recording	Visual	±10-25%	Not preferred

Many options are available for measurement of gases. Online automated instrumentation may include any combination of gas chromatography, infrared analysis, and numerous spectroscopy techniques (such as mass spectroscopy). More simplistic approaches may involve calorimetric gas tube samples or other types of chemical reaction/adsorption methodologies. While gas detector tubes may be convenient, inexpensive and intrinsically safe, they have poor accuracy and can vary widely in response due to tube manufacturing, temperature, and the operator. For this reason, the highest quality data can be expected from online electronic instrumentation.

The highest quality data will evolve from online analyzer systems, such as gas chromatographs (GCs), Infrared analyzers, spectroscopic techniques. While these may achieve a high degree of accuracy, they are highly dependent upon correct application, operation and service by the user. Only a properly conditioned gas stream, free from inhibiting compounds, and adequately handled on a calibrated system will return high quality data [5].

One of the main concerns when analyzing gas composition revolve around conditioning the sample gas to meet the requirements of the instrumentation. For instance, many GC columns do not respond well to certain types of liquids, such as water, and may require upstream filtration or removal of those compounds. Other preconditioning may require cooling or heating the vapor stream to promote or inhibit certain molecules from condensing and being removed. Removal of particles is typically necessary as well using a number of filtration methods.

Other General Good Practices

For measurements where high data quality levels are required, equipment should be purchased with a factory calibration. The best practice is to also require that the calibration be completed by an accredited calibration lab – preferably ISO 17025 accredited, and that materials be utilized in calibrations (weights, gases, sensors) that are traceable to a national or international standard (e.g. National Institute of

Standards and Technology (NIST)). In addition, users must ensure that instruments are re-calibrated on a schedule dictated by the instrument manufacturer, which could be annual (e.g. weigh scales), weekly (e.g. gas chromatograph), or otherwise. For certain equipment items which are utilized regularly in commercial business transactions and are factory certified to a high accuracy, such as a revenue quality power meter with a 0.2% accuracy, the need for a separately purchased NIST traceable calibration is diminished. However, for equipment such as flow meters, temperature and pressure sensors, such calibrations are critical.

Table 8. Additional Good Measurement Practices and Considerations

Practice	Recommendation
Optimal Range	All instruments have a limited operating range in which the % error is minimized. This affects all parameters of measurement: temperature, pressure, flow rates, etc.. Ensure range is appropriate.
Transient Conditions	Continuous vs batch processing or bimodal operating conditions may require provisions for multiple sets of instrumentation in order to capture the likely ranges of data within the instrument optimal measurement zones
Interference	May include electronic as well as physical interference, such as when power wires are collocated with signal wires with insufficient shielding or when two gases co-elute from a GC and peaks cannot be separated sufficiently for quantification.
Wire discipline	Adequate labeling is unfortunately an incredibly common issue, as well as keeping signal wire shielded and grounded. A new and increasingly common technique is wireless transmission from instruments to a centralized control cabinet.
Grounding/Shielding	Imperative for minimizing signal drift and interference. Should be sufficient for surges in electricity flow as well. Common practice is to separate power wires from signal wires within conduits and to use all shielded signal wires.
Redundancy	All crucial control or historical data should be measured with a redundant means of acquiring the information or cross-checking to verify instruments are operating correctly. This may involve two identical sensors in line, or it may utilize two separate measurements (such as a mass flow meter for a process gas and a level sensor for the gas when condensed in a container).
Reliability	Certain types of measurements are more reliable than others. For instance, measuring a complex inlet gasses with water and multiple gas constituents is more accurately and easily quantified after condensing out and adsorbing the humidity to measure water by mass and a microGC for gas constituents.
Ambient and operating conditions	Exposure to the elements or a classified space (e.g. Class 1 Div 2) will affect what types of instrumentation AND control techniques are permissible and feasible. For instance, utilizing an advanced system like a GC may require extensive standoff and corresponding heat trace in order to meet classification standards, adding to design considerations of where to emplace sampling ports.
Calibrations	Calibration certificates or any standard verification of equipment/material authenticity are required to verify accuracy/quality. This can typically be bought when buying the instrument from the vendor.
Protect Instrumentation	Most instrumentation requires certain environments to operate properly. For example, use filters upstream of flow devices and keep gas phase pressure transducers free from liquid contact.

Measurement Uncertainty and Error Propagation

Measurements from each technique discussed in Section 3 are collected and utilized to calculate values of specific parameters. Integrating the accuracy or error associated with each measurement provides an indication of the quality and certainty around each reported data value. Error and uncertainty become critical when comparing two results, as two different results may be within the margins of error when compared, resulting in a conclusion that they are indistinguishable from one another.

The analysis of uncertainty can be broken down into three separate steps: (1) propagation of measurement error to final reported performance values (Type B Uncertainty), (2) data validation or determination of which data is included versus excluded due to operational or other criteria, and (3) analysis of the random variability of the collected data over time (Type A Uncertainty).

Type B uncertainty is calculated first, as it can be completed in the design phase or prior to data collection. Type B uncertainty is calculated using the measurement instruments accuracy or error as defined in their calibration certificates or specifications. Type B uncertainty is calculated to provide insight into the measurement scheme of the system. Evaluation of the impact of the Type B measurement uncertainty on uncertainty of final reported calculated performance metrics can allow for the opportunity to identify the instrumentation with the most impact on uncertainty and select appropriate measurement devices to reduce overall uncertainty or optimize instrument costs by selecting less accurate instrumentation for measurements with little impact.

Data validation is required to separate valid data from that which is invalid for a variety of potential reasons. Data validation ensures reported performance values are based on representative operations and measurements. However, care must be taken with data validation to prevent selective analysis of data, aka 'cherry-picking'. Data validation includes the following primary steps: (1) identification of valid operating periods (e.g excluding process upsets or out of specification operations); (2) identification of invalid measurements, such as those from out of calibration instruments or from instrument failure or communication drops, and (3) potential identification of statistical outliers. Identifying periods of stable operation and valid data should be done using pre-determined logic tests, such as a defined set of operating conditions for which data is valid, or an outlier analysis approach such as documented in the ASTM E178 standard. For instrument failure, fault values can be programmed for exclusion. Known system disruption, for instance, interruptions in feed gas flow, product extraction, or safety related faults can be flagged for exclusion as well as a pre-determined wait time for the system to return to steady state operation.

Type A uncertainty is calculated last, after the data has undergone an initial quality check, calculations can be performed, and statistical variability can be produced. Type A uncertainty is the most well-known measure of uncertainty, as it is an analysis performed on the measured and/or calculated data to determine how much variability there is around the mean value. This is typically represented by the standard deviation of the data. This type of uncertainty can be useful when analyzing large data sets with thousands of data points as the effects of outlying data points will be dampened, however, in processes with only a few measurements (such as batch type processes), an outlying measurement can have a significant effect on the uncertainty.

Propagation of error from measured values

Any time a calculation requires more than one variable to calculate, propagation of error is necessary to properly determine the uncertainty. Therefore, calculation of the propagation of error from the measured values all the way through to the final calculated value. The most common equations used for propagation of error calculations when independent variables are added/subtracted shown in Equation 1 and those that are multiplied/divided shown in Equation 2, where x and σ_x are the parameter and its uncertainty respectively, and a/σ_a, b/σ_b, etc are the critical measurements and their uncertainties [6]. These equations will be used to show the importance of measurement uncertainty.

$$\sigma_x = \sqrt{(\sigma_a)^2 + (\sigma_b)^2} \quad (1)$$

$$\frac{\sigma_x}{x} = \sqrt{\left(\frac{\sigma_a}{a}\right)^2 + \left(\frac{\sigma_b}{b}\right)^2} \quad (2)$$

As an example, consider the determination of a gas input to a system. The calculation relies on gas input flow rate and gas concentration as the primary variables. Each of these values had an uncertainty associated with it, which can be derived from measurement instrumentation accuracy. For example, to calculate the gas flow into the system, the gas concentration in the gas stream and its flow rate would be multiplied, with potential corrections made for temperature and pressure, depending on the measurement technology. Therefore, the uncertainty equation would take the basic form of Equation 3.

$$\frac{\sigma_{Op.size}}{Op.Size} = Constant * \sqrt{\left(\frac{\sigma_{flow}}{flow}\right)^2 + \left(\frac{\sigma_{conc}}{conc}\right)^2 + \left(\frac{\sigma_{temp}}{temp}\right)^2 + \left(\frac{\sigma_{press}}{press}\right)^2} \quad (3)$$

Using the values in Table 3 through Table 7, the uncertainty of the operational size would have a base range from 0.5% to 2% for optimally selected instrumentation. This base uncertainty is multiplied by a constant which is dependent on the nature of the temperature and pressure corrections required and is comprised of the gas constant, molecular weights or densities, and unit conversions.

Data Validation

After data has been collected, the data must be checked for quality and validity. There are a number of reasons that data may be intentionally and reasonably be excluded from analysis. Examples of reasonably excluded data include: when an instrument breaks or fails to perform the measurement, during expected and unexpected process interruptions, during automated safety or emergency protocols, or simply during startup or shutdown procedures. These situations all would produce data that would not be reflective of the true performance of the system.

Many of the listed reasons can be detected almost instantaneously with proper instrumentation. The interruption of feed gas flow would be registered on the feed flow meter. An emergency protocol might be initiated due to high or low temperatures. The collection of product materials might cause rapid fluctuations of system pressure. Therefore, it is good practice to establish *valid operating conditions* for which any operation outside of the conditions can be automatically excluded from reported data files. These conditions would generally be selected to reflect steady state operations of the system and would naturally exclude transient operations (unless those are inherent in process operations). Conditions such as flow rates, temperature, and pressures in a specified range, applied electrical potential, or the positioning of valves which might direct flow towards system components or towards a vent could all be used to select valid operating conditions. Establishing a data filter that would highlight time periods where all valid operating conditions have been met would then make it possible to select data that falls within steady state operating time periods.

In addition to valid operating conditions, users must also review data to ensure reported or logged data is complete, especially when using automated datalogging connected to instrumentation. Instances of signal dropout, out-of-range conditions, communications issues or syncing problems can all result in blanks, null values, instrument failure signals (e.g. reported value of ‘99’ for an instrument with a range of 0-5) can all appear in data sets. This data must be identified, filtered, and either removed or, if an appropriate approach to data gap-filling is available, replaced.

Statistical Analysis of Calculated Values

After the data has been collected over a long enough period during steady state operation or sufficient batches have met quality criteria, variability of the data can be observed and quantified. This is presented as the standard deviation of the collected data.

Figure 2 shows a range of variability of some anonymized and normalized conversion values (in this example the performance parameter is CO_2 conversion to another compound. Values were divided by the mean CO_2 conversion to highlight process variability rather than the actual conversion values. The bounds of 95% confidence interval are shown as dashed lines.

The data in Figure 2 shows normalized conversion data from two teams that were observed. One shows, a team with high Type A variability and another that does not appear to have much variability at all. The Example Conversion 2 data was from a smaller system that was instrumented with very precise measurement devices that were selected specifically to match the original system design. The Example Conversion 1 data was from a system that was smaller than the original design and was outfitted with instruments that were repurposed from the larger original design.

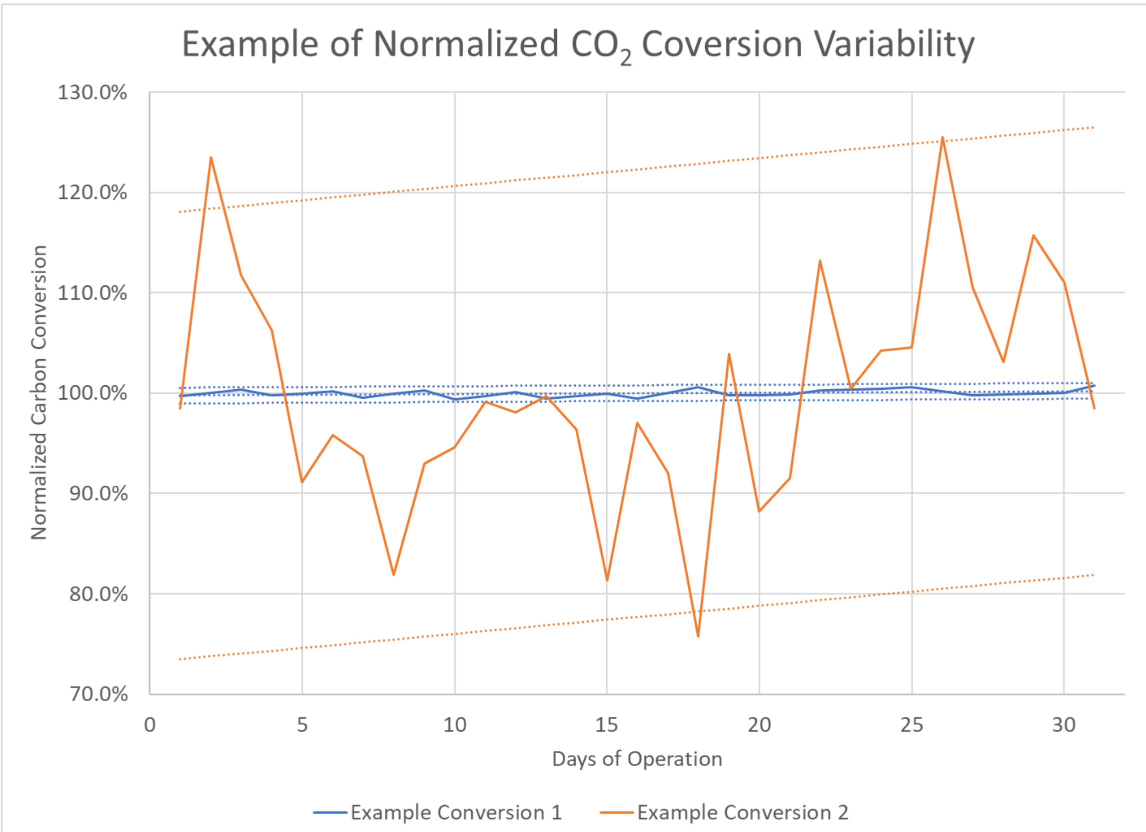

Figure 2. Example CO_2 Conversion variability and 95% confidence Interval

In batch systems, where certain measurements are measured after a set period at operational conditions, uncertainty can be influenced by the presence of a single outlying measurement. For example, a 24 hour batch process may only have 30 data points over a period of a month, while a similar continuous process sampling every 5-10 minutes would have between 4,000-9,000 data points for analysis. A single outlying point out of 30 points, which represents only a 1.5% change in the mean can represent a nearly 70% change in the Type A uncertainty.

However, in continuous processes the control scheme is also important to maintain equilibrium in the reactor. If the control scheme is not sufficiently tuned, the system may oscillate between the bounds of the automated controls and produce data variability that is not reflective of the process itself.

Combining Type A and Type B Uncertainty

Finally, once the Type A and Type B uncertainties have been calculated, they can be combined to produce a total system uncertainty. This would be accomplished by inputting the two calculated uncertainties into Equation 18.

$$\sigma_{tot} = \sqrt{\left(\sigma_{Type\ A}\right)^2 + \left(\sigma_{Type\ B}\right)^2} \qquad (18)$$

This is important because taken independently the Type A and Type B uncertainties only give you a partial picture. For instance, while the Example Conversion 2 data in Figure 2 had a much higher Type A uncertainty than the Example Conversion 1 data, the overall uncertainties were close in value. This was because the orange data was recorded using well-chosen measurement instruments that matched the size and data needs of the technology, which produced a small Type B uncertainty. While the blue data was recorded with dramatically oversized instrumentation, which lead to a small fluctuation in the measured values, however, the measurement intervals were very large relative to the values that were measured, which lead to a high Type B uncertainty.

Conclusions

The analytical assessment of early commercial technologies is crucial as it is the bridge between the demonstration/validation and the commercial embodiment. The demonstration stage offers the opportunity to observe the fundamental performance of scientific ideas at scales more representative of commercial operation. The quality of data produced during a demonstration can be critical to numerous parties – investors, regulators, project developers and others critical to the continued development, deployment, and market penetration of new innovations.

Several key factors are considered to be critical to the quality of the final verified dataset:

1. Implementation of good engineering practices and design early in the design process: Process and equipment designs which incorporate good engineering practices, including considerations for instrumentation and data collection early in the process typically have limited requirements for re-work or field installations associated with measurements, and also have more rapid commissioning and optimization, in part as a result of available, reliable data to provide visibility into operations and enable evaluation and analysis of the process. In addition, early evaluation of the impact of measurements on final process performance parameters can enable selection of instruments with appropriate accuracy and potentially reduce costs associated with simply buying the ‘best’ instrument, while also ensuring uncertainties are as low as possible.
2. Selection of quality instrumentation and regular datalogging – quality instrumentation – as discussed in this paper, with continuous datalogging, provided teams with improved certainty, larger and more time-resolved data sets to evaluate process operations and identify issues, and overall improved accuracy, leading to decreased uncertainty and improved credibility.
3. Development of a thorough Analytical Plan – Many aspects of demonstrations rely on evaluation of final technology outputs to determine if they meet specifications and will be viable in the market. A well thought out analytical plan can provide critical, credible information on these key parameters. A poorly thought-out plan can result in high variability in results and increased uncertainty. Correct sampling approaches, as well as analytical methods and laboratory qualifications can all have significant impacts.
4. Management and optimization of process operations – In some cases, processes themselves may not be fully optimized, or may be inherently unsteady or difficult to repeat. In these cases, even with the highest quality instrumentation, the process variability, and resulting uncertainty

associated with it, can easily override any uncertainty associated with instrument error. For these cases, it is important to focus more on process optimization than on highest quality instruments.

With proper pre-planning, good engineering practice, and good measurement practice, it is possible to optimize uncertainty while optimizing costs and usability of instrumentation and data systems. Because uncertainty is a combination of system variability as well as instrumental error, accounting for all considerations can optimize data quality. The measurement practices outlined here can contribute to improved data quality, reduced effort and costs, and improved credibility and utility of data regarding performance of new technologies and innovations.

Appendix C References:

[1] ISO 14034:2016 Environmental Management – *Environmental Technology Verification (ETV)*, International Organization for Standardization. November 2016. [https://www.iso.org/standard/43256.html].

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[3] Husain, Z D. *Theoretical uncertainty of orifice flow measurement*. United States: N. p., 1995. Web. https://www.emerson.com/documents/automation/white-paper-theoretical-uncertainty-of-orifice-flow-measurement-daniel-en-43824.pdf

[4] Pacific Northwest National Laboratory, 2015. *Metering Best Practices: A Guide To Achieving Utility Resource Efficiency, Release 3.0*. Richland, WA: U.S. Department of Energy. Available at: https://www.wbdg.org/FFC/DOE/NLCRIT/mbpg_2015.pdf (Accessed 14 May 2021).

[5] Flavio A. Franchina, Giorgia Purcaro, Alison Burklund, Marco Beccaria, Jane E. Hill, *Evaluation of different adsorbent materials for the untargeted and targeted bacterial VOC analysis using GC×GC-MS*, Analytica Chimica Acta, 10.1016/j.aca.2019.03.027, (2019). https://onlinelibrary.wiley.com/doi/full/10.1002/3527600418.amsampgase0011

[6] *Propagation of Error* https://chem.libretexts.org/@go/page/353 (accessed May 14, 2021).

APPENDIX D: Guidance for Conducting the Verification

Table D-1 - Administrative review checklist

Review criteria	Yes	No	Comments
D1.1 Signed application with applicant name, address, contact and physical location.			
D1.2 Information to describe the technology provided, including: **D1.2.1** Technology unique identifier (e.g., a commercial name, an identification number or applicable version). **D1.2.2** Intended application of the technology. Including its purpose, type of material for which the technology is intended, the measurable property that is affected by the technology and the way in which it is affected.			
D1.3 Market readiness of the technology is provided (i.e., development status of the technology proposed for verification and its readiness for market). (Note: Technology proposed for verification shall be either already available on the market or available at least at a stage where no substantial change affecting its performance will be implemented before market entry) **D1.3.1** The technology and all its components (apparatus, processes, products) are full-scale and commercially available, and data supplied to the verifier is from the use or demonstration of a commercial unit of a unique identifier (e.g. registered commercial name of the technology, an identification number or version number etc); or **D1.3.2** The technology is a final prototype design prior to manufacture or supply of commercial units. (Note: Verification of the performance claim for the technology is valid if based on a prototype unit, if that prototype is the final design and represents a pre-commercial unit. The verification will apply only to any subsequent commercial unit which design is identical to the prototype unit design. The verification will not be valid for any commercial unit that includes any change in the technology design compared to the prototype unit used to generate the supporting test data used for the			

verification of performance); or **D1.3.3** The technology is a pilot scale unit used to provide data which, when used with demonstrated scale up factors that do not influence its performance, proves that the commercial unit satisfies the performance claim. Note: Definitions of Technology Redainess Level (TRL) could be used – e.g., - TRL 7 – system prototype demonstration in operational environment - TRL 8 – system complete and qualified - TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space).			
D1.4 Information allowing a determination that the technology proposed for verification fulfils the definition of an environmental technology, including information on: -The technology life stages where significant environmental impacts may occur, either positive or negative, compared to relevant alternative; - The added environmental value of the technology; -Measureable parameters indicating environmental impacts.			
D1.5 Information on relevant alternatives (where they exist) to the technology, including relevant performance and environmental impacts. Note: Some guidance on this is provided in Annex C of ISO 14034.			
D1.6 A description of how the performance claim for the intended application(s) of the technology address the needs of the interested parties (to be specified), including the specific problems of users that the technology addresses as well as the specific opportunities that may arise.			
D1.7 Information sufficient to understand the operation and performance of the technology, including technical principles, process flow diagram(s), design drawings, photographs, equipment specification sheets (including response parameters and operating conditions), and/or other information identifying the unit processes or specific operating requirements of the technology. (Note: A site visit to inspect the process could be part of the technology assessment).			

D1.8 A description of each performance claim to be verified. Note: More than one technology purpose, type of material and measurable property can be provided. **D1.8.1** The declared performance of a technology for a specified, intended application expressed as a set of parameters and their numerical values. **D1.8.2** The specified installation and operational conditions for which the declared performance is achieved. **D1.8.3** Constraints and limitations that apply to the declared performance **D1.8.4** A description of how the performance claim addresses the minimum requirements for any relevant standards and guidelines, as determined by the applicant Note: In the case of existing test data, the verification plan used to produce this test data may specify other minimum requirements.			
D1.9 In the case where existing performance test data are available information: **D1.9.1** If the test data specifies and quantifies the performance parameters and the results achieved by the technology (i.e., measurable performance and numerical values as determined by independent testing). **D1.9.2** Information on test body(s) that performed the testing **D1.9.3** Information on any test plan followed, testing methods used, test report, etc.			
D1.10 Specification of standard operating practices and a description of operating conditions for each individual performance claim.			
D1.11 References describing or supporting the scientific and operation principles of the technology.			
D1.12 Information on significant human or environmental health and safety issues associated with the technology, if relevant.			
D1.13 Information on the operational requirements (e.g., qualifications, expertise, skills, training, etc.) needed for safe,			

effective operation of technology (with a list of available documents describing these requirements), if relevant.			
D1.14 Supplemental materials offering additional insight into the technology application and performance, for example: A copy of patent(s) for the technology, patent pending or submitted User manual(s) Maintenance manuals Operator manuals Quality assurance procedures Sensor/monitor calibration program Technical brochures.			
D1.15 Sufficient documentation and data have been provided.			
D1.16 If relevant, a statement that the technology adheres to applicable regulatory requirements (e.g., the technology complies with applicable regulations and guidlelines for management of contamined and/or treated soils,air emissions, etc.			
D1.17 Additional comments as needed.			

Table D-2 - Technical review checklist

Review criteria	**Yes**	**No**	**Comments**
D2.1 The technology is based on sound scientific and technical principles. Note: It is necessary for the verifier to read the key documents, articles and citations listed in the Application			
D2.2 Information indicating that the technology is designed, manufactured, and operated reliably. (Note: Historical data on the technology performance from the applicant may be useful for the verifier to assess the reliability of the technology).			
D2.3 The technology is designed to provide an environmental added value – e.g.: - Life stages that may result in environmental impacts of the technology, either positive or negative, compared to the relative alternative(s) have been defined. - The associated impacts have been specified to determine whether the technology at any of its life stages i.e. material acquisition, design, production, use or end of use does not result in a more hazardous and/or unmanaged environmental impact than the relevant alternatve and it does not result in the transfer of an environmental problem from one media to another media without appropriate management. If a technology results in negative environmental impacts at any of its life stages , these should at least be balanced by positive impacts ocuring in other life stages.			
D2.4 All operating conditions affecting technology performance and the performance claim have been identified, including descriptions of the installation, operating requirements, conditions and limitations; the service and maintenance requirements; and the expected length of time the technology functions under normal operating conditions.			
D2.5 The relationships among operating conditions and their impacts on technology performance have been identified.			

(Note: It is important for the verifier to understand the relationship between the operating conditions and the performance of the technology and to ensure that the impacts of the operating conditions and the responses of the technology are compatible).			
D2.6 The technology is designed to respond predictably when operated at normal conditions. (Note: The verifier must be satisfied that these data do not demonstrate performance that is different than the performance indicated in the performance claim to be verified).			
D2.7 The effects of variable operating conditions, including start up and shut down, are important to the performance of the technology and have been described completely in the performance claim under assessment.			
D2.8 The effects of variable contaminant loading or throughput rates have been assessed and input/output limits established for the technology. (Note: If the application of the technology is to a variable input (e.g., waste source) or expected variable operating conditions, then it is necessary to establish acceptable upper and lower ranges for the operating conditions, applications and/or technology responses. Sufficient, quality data must be supplied to validate the performance of the technology at the upper and lower ranges for the operating conditions, applications and or technology responses detailed in the performance claim).			
D2.9 Other relevant parameters and variables - The verifier is expected to understand the technology and identify and record all relevant criteria, parameters, variables or operating conditions that potentially can or will affect the performance of the technology being verified.			
D2.10 Additional comments as needed.			

Table D-3 - Test data assessment checklist

Table D-3 is a checklist to evaluate the suitability of the test plan, the verifiability of the test data and the acceptability of the test report for verification and to review and assess the test plan based on which thes test data has been generated

Review criteria	Yes	No	Comments
D3.1 An expert with specialized capabilities was involved in the test plan design prior to the completion of performance testing. (Contact details should be provided).			
D3.2 Performance parameters were identified, testing objectives were developed, and a specific test or set of tests were implemented to generate sufficient quality-assured, statistically relevant test data for verification of the technology performance claim(s).			
D3.3 The test plan is sutable for testing the objective being postulated and for generating supporting data. Namely: **D3.3.1** The parameters used in the performance claim hypothesis were measured; **D3.3.2** The test controls for extraneous variability were performed; **D3.3.3** The performance test addresses those effects attributable to the technology being verified.			
D3.4 The test report provides sufficient data to perform statistical analysis and meets the requirements related to test data specified in the verification plan.			
D3.5 The test report documents quality assured data according to requirements of ISO/IEC 17025 and the requirements specified in the verification plan.			
D3.6 The test report provides suitable description of test samples and confirming that they are representative of process characteristics at specified locations. Namely: **D3.6.1** Test samples collected in a manner representative of typical process characteristics at the sampling locations (e.g., the samples are collected from the source stream fully mixed, etc.); **D3.6.2** Performance data representative of the current technology.			

D3.6.3 Test samples collected after a sufficient period of time for the process to stabilize. **D3.6.4** Test samples collected over a sufficient period of time to ensure that the samples are representative of process performance. (Note: The testing and verification plans should be prepared with the final data analysis in mind to facilitate interpretation and reduce costs).			
D3.7 The test report is acceptable and confirms that : **D3.7.1** A test plan established prior to testing to ensure collection of performance data using a systematic and rational approach. **D3.7.2** A test plan defines the acceptable values or ranges of values for key operating conditions, and the data collection and analysis methodology. **D3.7.3** A test samples collected while technology operating under controlled and monitored conditions.			

Table D-4 - Data quality assessment checklist

Review criteria	Yes	No	Comments
D4.1 Appropriate sample collection methods were used (e.g. random, judgmental, systematic etc.) For example: simple grab samples are appropriate if the process characteristics at a sampling location remain constant over time. Composites of aliquots instead may be suitable for flows with fluctuating process characteristics at a sampling location.			
D4.2 The apparatus and facilities used for performance testing were adequate for generation of relevant data (i.e., testing was performed at a location and under operating conditions and environmental conditions for which the performance claim has been defined).			
D4.3 The personnel who performed the testing were competent and worked in accordance with the test body's management system.			
D4.4 Operating conditions during the test were monitored and documented.			
D4.5 Information and data on operating conditions and measuring equipment measurements and calibrations were provided to the verifier.			
D4.6 Acceptable methods, procedures and protocols were used for sample collection, preservation and transport. (Note: Acceptable methods, procedures and protocols include those developed by a recognized authority in environmental testing such as a regulatory body, or specified in standardized test methods (preferably international standards) .			
D4.7 Quality assurance/ quality control (QA/QC) procedures (e.g., use of field blanks, standards, replicates, spikes etc.) were followed during sample collection. Quality assurance procedures were applied throughout data generation and collection.			
D4.8 Samples were analyzed using approved analytical methods, procedures and protocols (e.g. samples were analyzed using methods, procedures and protocols recognized by an authority in environmental testing such as Standard Methods, EPA, ASTM, etc.)			

D4.9 The chemical analyses conform to standard operating procedures (SOPs) and data quality requirements (i.e., for data produced by analytical and calibration laboratories in accordance with ISO 17025).			
D4.10 Samples were analyzed within recommended analysis times.			
D4.11 QA/QC procedures were followed during sample analysis. Namely: **D4.11.1** Maintaining control charts **D4.11.2** Establishing minimum detection limits **D4.11.3** Establishing recovery values **D4.11.4** Determining precision for analytical results **D4.11.5** Determining accuracy for analytical results			
D4.12 Chain-of-custody (full tracing of the sample from collection to analysis) methodology was used for sample handling and analysis - Namely: **D4.12.1** Completed and signed chain-of-custody forms were used for each sample submitted from the field to the analytical lab. (Note: These should be provided for inspection by the verifier). **D4.12.2** Completed and easily readable field logbooks are available for the verifier to inspect. **D4.12.3** Other chain-of-custody methodology actions and documents are available for the verifier to inspect (e.g., sample labels, sample seals, sample submission sheet, sample receipt log and assignment for analysis).			
D4.13 The performance test data are acceptable (i.e., the quality of the data submitted is accepted based on the best professional judgment of the verifier).			
D4.14 Additional comments as needed.			

APPENDIX E: Guidance for Producing the Verification Report

The following can be used as a checklist by the verifier to ensure proper content is included in the Verification Report.

Verification Report Content Including references to ISO 14034	**Requirements**
E1. Identification of the verifier (clause 5.5.1 a))	Organisation name: Address of the physical location: Organisation registration number: Accreditation status or equivalent e.g., ISO 17020, peer assessment, other Organisation contact: Phone number: Email address: Website Note: The Verification Report should specify the identity of the verifier, including company, and lead individual performing the verification. The specific technical focus areas they are accredited for should also be identified as related to the verified technology.
E2. Information about the applicant (clause 5.5.1 b))	Organisation name: Address of the physical location: Organisation registration number: Organisation contact: Phone number: Email address: Website
E3. Unique identifier of the statement and date of issue (clause 5.5.1 c))	A unique verification report document number should be assigned
E4. A summary description of the	A narrative regarding the technology and its technical

technology (clause 5.5.1 e))	and scientific principles , intended application(s) for which the technology has been verified anticipated environmental benefits, markets, and applications should be provided
E5. Verification results including the verified performance (subclause 5.5.1 f) and g)) **E5.1** Description on how the test data were assessed against the requirements specified in the verification plan. **E5.2** Description on how the test data confirm the performance of the technology, achieved under the same conditions, constraints and limitations as those specified in the verification plan. **E5.3** Information if the performance specified in the verification plan was verified as originally stated in the document. Alternatively, if the performance was not verified as originally stated in the verification plan, information on the deviations, their reasons and how it was modified.	A concise summary of the verification results should be provided as indicated. Note that the report should specify the verified performance of the technology clearly, regardless of the initial performance claim provided by the applicant.
E6. A summary description on how the requirements specified in the verification plan were met (clause 5.5.1 h))	Details of the testing plan and approach, including test methods, operating conditions should be described. The verifier should explicitly identify any deviations from the Verification plan, including their impact on the verification and the technology performance.
E7. Any other information necessary to understand and use the verification report	It may include information that has been not verified but is included in the report such as additional parameters related to information about the technology that is useful for the interested parties but that may not necessarily be measurable through tests and therefore not included as verified performance. Examples of possible additional parameters may include qualitative information on environmental impacts of the technology, the expected service time during which the claimed performance is respected, overall service life, health and safety issues, installation and maintenance requirements and operating costs.
E8. A brief description of how quality	Details regarding the verification approach, such as test

assurance measures were implemented to assure the quality of the verification	data assessments, test results, data validation, test system audits, etc. should be described.
E9. Signature or other indication of approval by the verifier (clause 5.5.1 i))	
E10. Include as appendices, documents obtained during the verification process: • Application Form • Verification Plan • Test Plan • Test Report	

APPENDIX F: Guidance for Producing the Verification Statement

The following can be used as a checklist by the verifier to ensure proper content is included in the verification statement.

Verification Statement Content Cf. reference to ISO 14034	**Requirements**
F1. Identification of the verifier (cf. 5.5.2 a))	Organisation name: Address of the physical location: Organisation registration number: Organisation contact: Accreditation status or equivalent e.g., ISO 17020, peer assessment, other Phone number: Email address: Website: Note: The Verification Report should specify the lead individual performing the verification. This should also include information regarding the verifier's credentials.
F2. Identification of the applicant (cf. 5.5.2 b))	Address of the physical location: Organisation registration number: Organisation contact: Phone number: Email address: Website:
F3. Unique identification of the statement and date of issue (cf. 5.5.2 c))	A unique verification statement document number should be assigned
F4. A summary description of the technology (cf. 5.5.2 d))	A brief narrative regarding the technology and its scientific and technical principles, intended application (s) for which the technology has been verified anticipated environmental benefits, markets,etc. should be provided

F5 . Verification results including the verified performance (clause 5.5.1 f) and g)) **F5.1** Confirmation that the test data were assessed against the requirements specified in the verification plan **F5.2** Confirmation that the test data confirm the performance of the technology, achieved under the same conditions, constraints and limitations as those specified in the verification plan. **F5.3** Confirmation that the performance claims are verified as originally stated. Alternatively, if the performance claims are not verified as originally stated, information on how the performance claim was modified. **F5.4** A statement that the verification plan has been addressed, together with justification for any deviations that may have occurred.	A concise summary of the verification results should be provided as indicated. Note that the statement should specify the verified performance of the technology clearly, regardless of the initial performance claim provided by the applicant.
F6. Any other information necessary to understand and use the verification statement (cf. 5.5.2 g)	This may include information that has been not verified but is included in the statement such as additional parameters related to information about the technology that is useful for the interested parties but that may not necessarily be measurable through tests and therefore not included as verified performance. If such information is included in the statement it should be clearly stated and explained.
F7. Signature or other indication of approval by the verifier.	