



NYSERDA

Guide for Measurement and Verification of Wood-Heating Systems

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Guide for Measurement and Verification of Wood-Heating Systems

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Acronyms and Abbreviations

| | |
|--------------------|--|
| ANSI | American National Standards Institute |
| ASHRAE | American Society of Heating, Refrigerating and Air-Conditioning Engineers |
| BOP | Balance of Plant |
| Btu | British Thermal Unit |
| CT | Current Transducer Sensors for measuring Amperage and/or On/Off Motor Status |
| Cx | Commissioning |
| DBT | Dry Bulb Temperature |
| DDC | Direct Digital Control |
| E/A | Engineering/Architectural |
| EEM | Energy Efficiency Measure |
| EMCS | Energy Management and Control System |
| EMS | Energy Management System |
| EP | Electric/Pneumatic Relay or Switch |
| EUIs | Energy Utilization Indices |
| GPH | Gallons per Hour (measuring oil flow into the boiler burner) |
| HELE | High-Efficiency Low-Emissions |
| HVAC | Heating, Ventilating and Air-Conditioning Systems |
| IPMVP | International Performance Measurement and Verification Protocol |
| LAN | Local Area Network |
| Linkage Burner | Boiler burner set to a fixed air-to-fuel ratio through a mechanical shaft, also referred to as a jackshaft control, likely calibrated once or twice a year. Serves many old / existing boilers. Can be set to either high or low fire but very few have modulation between high and low. This fixed relationship across the firing range results in lower efficiencies than linkageless burners. |
| Linkageless Burner | Boiler burner programmed to use a linkageless modulating burner that varies air-to-fuel ratio across the firing range and is equipped with VFD forced draft fans and an O ₂ trim package. Represents an available control option in many modern boilers. Varying relationship across the firing range results in better efficiencies than linkage burners. |
| M&V | Measurement and Verification (can be for a plan, report or process) |
| MEP | Mechanical, Electrical and Plumbing |
| NYSERDA | New York State Energy Research and Development Authority |
| OA | Outside or Outdoor Air |
| OAT | Outside Air Temperature |
| PE | Pneumatic/Electric Switch |
| PID | Piping and Instrumentation Diagram |

| | |
|-------|---|
| Psig | pounds per square inch gauge pressure (applies to hot water or steam systems) |
| R&R | Range and Relational Checks (to verify the quality of collected data) |
| SCADA | System Control and Data Acquisition |
| Sqft | Square Feet |
| SSPC | Standing Standard Project Committee by ASHRAE |
| TES | Thermal Energy Storage |
| VFD | Variable Frequency Drive |

1 Introduction

1.1 Purpose

The purpose of this guide is to provide support for engineers on developing high-efficiency, low-emission (HELE) biomass heating technologies in New York State.¹ The information provided in this document explains how to plan and implement a successful measurement and verification (M&V) program to help ensure the development of well-designed, well-operated, and well-maintained HELE biomass heating systems.

In general, the guide includes how to:

- Organize the M&V Plan.
- Define the necessary pre-installation, installation, and post-installation M&V and metering activities.
- Ensure quality control.
- Develop an annual M&V Report that documents findings and measured savings.
- Collect and analyze current and future energy consumption data to determine the operating characteristics and effectiveness of the existing heating system and the new biomass system.

More specifically, this guide provides information such as:

- Suggestions for what to include in an M&V Plan.
- Suggestions for managing the M&V process.
- Recommendations for assigning roles and responsibilities.
- Information on data collection and analysis, including when, where, and how to collect and analyze data during the pre-installation, implementation, and post installation stages of biomass system development.
- Suggestions for how to process energy consumption data and share that information in a standardized manner to ensure quality, completeness, and consistency.
- Suggestions for what to include in an M&V report.
- Discussion of the distinction between one-time collection of baseline information and ongoing data collection requirements.
- Recommendations for frequency and length of data collection.
- A comprehensive list and discussion of data points to collect and equations for data analysis.

¹ Visit nyserderda.ny.gov/Cleantech-and-Innovation/Biomass for information about high-efficiency, low-emission wood heating systems and NYSEERDA's Renewable Heat NY (RHNY) program, which provides incentives toward the installed costs of these systems for homeowners and businesses (nyserderda.ny.gov/All-Programs/Programs/Renewable-Heat-NY).

1.2 Benefits of Measurement and Verification

An effective M&V process can help support and verify the proper design and performance of wood-heating systems and their control and monitoring systems. This process helps ensure increased boiler efficiency, reduced emissions from biomass fuels, and reduced boiler cycling. Unlike liquid and gaseous fuels, the performance of heating systems for wood, a solid biomass fuel, decreases more rapidly under reduced loads. Boiler oversizing and lack of thermal energy storage lead to suboptimal performance of biomass heating systems and result in low efficiency, high emissions, frequent boiler cycling, higher operating and maintenance costs, frequent operation at low loads, and shorter equipment lifetime. These problems are often compounded by the lack of integration between the new and existing heating systems.

Effective M&V will help ensure consumers of biomass heat will receive maximum effectiveness from their HELE biomass heating systems by guiding the design, planning, and monitoring of the systems. With a carefully-designed M&V process, quantifiable and objective monitoring data can be collected and used to independently evaluate project performance and identify shortcomings (Box 1).

Box 1. The Benefits of Measurements and Verification

Properly conducted M&V can:

- Quantify energy savings and fuel displacement, and validate performance.
- Verify properly sized boilers and proper integration of control systems, existing and new heating systems, heat distribution, thermal energy storage (TES), and other support systems. This verification ensures correct operation, reduces boiler cycling, and enhances lifespan by providing better boiler protection.
- Address the complexities of two or more boilers operating in tandem.
- Facilitate building and system commissioning (Cx) and troubleshooting activities.
- Facilitate billing with heat (or chilled water) sale agreements among multiple parties.
- Explanation of how needs may differ for different projects, including various biomass heating system sizes: residential, small commercial, large commercial, institutional, and industrial.
- Advice on how the collected data can benefit ongoing building and system commissioning and troubleshooting activities.

1.3 What this Guide Covers

Although this guide does not cover residential stove applications intended to heat only one room, it does apply to the following project sizes, fuels types, and heating systems:

- Project sizes
 - Large, commercial installations, defined as more than 300,000 Btu/hr (88 kW) up to 5,000,000 Btu/h (1,465 kW)
 - Small residential or commercial projects, defined as less than 300,000 Btu/hr, which may have less rigorous M&V requirements. (Since cut off points to define small vs. large projects can vary among different programs, their M&V requirements can also vary.)
- Fuel types - Although the focus is on wood pellets, most of the guidance also applies to cordwood (see Appendix B). Wood chips and non-woody biomass are not specifically addressed, but would still benefit from the guidance.
- Heating systems - Although the focus is on pellet boilers, the following other heating systems are briefly addressed in Appendix B:
 - District heating.
 - Radiant slabs.
 - Pellet furnaces.
 - Steam systems (see also Appendix D).

This guidance surveys M&V methods and Cx actions. However, it does not provide complete site-specific procedures for collecting building data, conducting energy audits, or performing commissioning activities. Detailed specifications or site-specific installation instructions for any intrusive or non-intrusive data loggers are also excluded.

1.3.1 Contents of Guide

The remaining sections of the guide are:

- **Section 2, Overview of the M&V Plan** - Provides a suggested outline for an M&V Plan. It presents a high-level discussion of what to include in a plan, including pointers and best practices for creating a plan that will help ensure an effective biomass heating system.
- **Section 3, Writing the M&V Plan: Project Description and Management** - Provides specific guidance on how to write an M&V Plan, focusing on describing your biomass project and project management approach (i.e., cost, specific tasks, schedule, and roles and responsibilities).
- **Section 4, Writing the M&V Plan: M&V Activities** - Focuses on how to write the technical aspects of your M&V plan. It provides specific guidance on data collection requirements and how to plan M&V activities during each phase of the M&V process: pre-installation, installation, and post-installation. It also describes procedures for ensuring quality assurance (QA) and quality control (QC) and for developing annual M&V reports.

- **Section 5, Resources for Data Collection and Analysis** - Includes examples of specific data that to collect and equations that may be used throughout the M&V analysis process.
- **Section 6, Wrap-Up** - Summarizes key steps to a successful M&V effort.

Appendices include:

- **Appendix A, M&V PowerPoint Slides** - Provides a link to a training PowerPoint on M&V planning. This training provides detailed information about all aspects of M&V planning and is referenced throughout this guide.
- **Appendix B, Fuel Types and Alternative Heating Systems** - Discusses several types of fuel and heating systems.
- **Appendix C, Thermal Energy Storage (TES)/Buffer Tank Reminders** - Summarizes tips for designing and maintaining thermal storage tanks, which help optimize system response time and minimize boiler short-cycling and overheating upon unexpected shutdown.
- **Appendix D, Boiler Protection Reminders (Thermal, Chemical, Water Level, and High Temperature/High Pressure)** - Provides tips for ensuring the protection of both new biomass boilers and existing supplemental oil or propane fired boilers and systems.
- **Appendix E, Additional Stack Placement Precautions and Code Compliance Reminders** - Presents important information on the design and placement of exhaust stacks.
- **Appendix F, Energy Audits** - Offers specific recommendations and examples on how to conduct energy audits.

2 Overview of the M&V Plan

An M&V Plan describes how to measure the performance and energy efficiency of a new biomass heating system and how to verify the system's performance and energy consumption over an entire heating season. Box 2 provides a suggested outline for an M&V Plan, and provides references to the sections of this guide that describes each item.

As illustrated in Box 2, M&V work occurs in three phases: pre-installation, installation, and post-installation. The M&V Plan should address each phase as appropriate. Write the plan before beginning the work, and modify or update it as necessary (Box 3).

When writing the M&V plan, consider the following recommendations:

- Carefully examine the intended purpose of the plan and the customer's particular facilities, objectives, and budget and adjust your plan accordingly. Not all options and procedures included in this document are required for all M&V and Cx activities.
- Make recommendations that are vendor neutral; there are many data loggers in the market with varying price ranges, options, features, access methods, capabilities, reliability levels, and accuracy levels. Appropriate selections should be made for each project's site-specific conditions including the required level of monitoring accuracy, controllability, and access.
- Account for metering and logging provisions so they are implemented properly and become the responsibility of a specific entity, be it the customer, their MEP or E/A firm of record, or their contractors. Responsibilities should be clearly defined from the beginning of the project.

Box 2. Suggested Measurement and Verification Plan Outline

Project Description and Management (Section 3)

1. Plan overview (3.1)
2. Biomass project description (3.2 and 5.1.2)
 - Project summary
 - Building and systems background information
 - Assumptions
 - International Performance Measurement and Verification Protocol (IPMVP) M&V option
3. Project management (3.3)
 - Project Costs
 - Project Tasks
 - Project Schedule
 - Roles and responsibilities

M&V Activities (Section 4)

1. Introduction (4.1)
2. Data collection (4.2, also see resources in 5.1 and 5.2)
3. Pre-installation Activities (4.3)
 - Conduct inspection
 - Develop a baseline
4. Installation Activities (4.4)
5. Post-installation Activities (4.5)
 - Conduct inspection
 - Conduct monitoring
6. Quality Control (QC) and Quality Assurance (QA) Procedures (4.6)
7. M&V Reporting (4.7)

Box 3. Best Practices for Measurement and Verification Plan Development

- Use clear tables that include column and row headings
- Minimize the number of footnotes
- Use standard metrics and units
- Make your plan clear, concise, and specific
- Organize the M&V plan with a clear outline that identifies section and page numbers
- Document all assumptions, calculations, and special conditions, as appropriate
- Use pictures where possible and highlight important areas with arrows and labels
- Use a piping and instrumentation diagram (PID) to clearly identify sensor and logger locations.

3 Writing the M&V Plan: Project Description and Management

The first sections of an M&V Plan provide a description of the overall plan, information about the biomass project, and a discussion of project management activities.

3.1 Plan Overview

The M&V Plan should begin with a general introduction of the project. Specifically, this section could include a brief discussion of:

- Project objectives.
- The existing system and the proposed biomass installation.
- The M&V method and International Performance Measurement and Verification Protocol (IPMVP) option (see Section 3.2.4 for a description of IPMVP options).
- Any variables that may have a significant effect on energy consumption in the facility, project special conditions, or other items of note.

Box 4 provides sample text for this section.

Box 4. Example of M&V Plan Overview Text

This plan describes our approach for measuring and verifying the energy savings and fuel displacement associated with replacing (and/or adding) a high-efficiency, low-emission wood pellet fired two-stage gasification boiler.

The plan is based on a hybrid between IPMVP continuous metering Option B (Retrofit Isolation) and Option C (Whole Facility Utility Analysis) to best suit the project.

IPMVP has four clearly defined Options: A, B, C and D. Option E is a customized hybrid approach for a well-integrated and complete biomass heating system assessment (as opposed to only a biomass boiler assessment).

3.2 Biomass Project Description

This section of the M&V Plan describes the project including information about the building and building system, assumptions about the existing heating system, and the IMPVP option that the project will follow.

3.2.1 Project Summary

In this section of the M&V plan, provide a detailed summary of the biomass project. Include information on the building, such as its location, owner, and function. Include comments about existing problems such as over- or under-sizing of existing systems and redundancy and backup levels, and why the customer elected to install the new biomass system. Box 5 presents sample text for this section.

Box 5. Biomass Project Summary

The xx building is located in *TOWN*, NY. The x-story building occupies an area of xx square feet, including the original *YEAR* xx sq. ft. section and the newer *YEAR* xx sq. ft. addition. The owner of the facility has been awarded XX funding for properly-sized eligible HELE technologies.

3.2.2 Building and System Background Information

This section of the plan provides a building and system description of the project, including background details about the baseline energy usage, current equipment, and proposed systems. Describe the existing infrastructure and its condition, and provide reference information about the new system. Include estimates or notes about assumptions you have made (with a reference to the full discussion of the assumptions in Section 3.2.3). Some information about the existing system may not be easily available, but try to obtain as much as possible. Additionally, some details may not yet be available for the proposed system, especially before the design and specifications are completed. See Section 5.1.2 for further information on specific data to collect for building and system background information.

Box 6 provides sample text for this section.

Box 6. Building and System Background Information (Sample Text)

The building is currently served by [number] of boilers. The current operating boilers are xxx model, with an estimated output capacity of xxx Btu/h at low fire and xxx Btu/h at high fire, based on oil nozzle ratings of xxx GPH and xxx GPH, respectively and/or based on recent test results completed on [date] by [entity] or based on nameplate data, or based on short term or long-term metering, etc... The boilers were installed in [year] and have an estimated nameplate efficiency of xxx% and seasonal efficiency of xxx%.

Given that part of the anticipated incentives from [entity] are paid based on illustrated savings and fuel displacement, having a reliable baseline for energy consumption and measurable energy consumption in the retrofit are keys to success.

The owner of the building is planning to replace one of the old oil-fired boilers with a new, high efficiency, low-emission, properly sized wood pellet-fired boiler with an output rating of xxx Btu/hr. The project will be partially funded using xxxx Program Incentives for eligible technologies following the xxxx program rules. Program rules dictate the new biomass boilers must be sized to meet no more than 50% to 60% of the peak building heating demand, and thus are expected to operate in conjunction with the existing supplemental oil fired boilers and displace 80% to 95% (TBD) of the baseline fuel oil [or propane] use.

Our analysis calculated a Proposed Biomass Boiler Capacity of xxxx Btu/h. With an estimated peak heating load of xxxx Btu/h, this represents about 50% (xxxx / xxxx Million Btu/h) of peak. This would suggest a commercially available xxxx Btu/hr pellet boiler (xx kW) (if results are in between two available sizes, generally the smaller one is a better choice). As discussed in the heat load determination, our analysis of the fuel bills, site observations, and results of the [name of heat load calculator] heat load calculation program were jointly used to estimate the peak heating load on the building.

Box 6 continued

This project will include installing and metering a HELE pellet boiler heating system at the xxx building, with goals of attaining high pellet boiler thermal efficiency and low emissions. The project will optimize the integration of the heating system including but not limited to the wood pellet boiler, thermal energy storage (TES), the existing #2 Fuel Oil boiler, and control systems. It will also address existing system operation, maintenance and comfort issues.

Although the focus is on monitoring the central heating plant (primary system), other parts of this project include significant secondary system enhancements for responding to the heating load in a manner that optimizes the operation of the properly sized biomass boiler and thermal energy storage tank (steam accumulator). Both the proposed boiler and thermal storage tanks were sized properly according to an independent feasibility study and/or energy audit completed by [entity] and dated xx/xx/xx.

3.2.3 Assumptions

Throughout the M&V planning process, it may be necessary to make assumptions in cases where there is insufficient information about the existing heating system. It is important to describe:

- What each assumption entails
- How each assumption has the potential to affect M&V measurements or analysis
- The provisions you have in place if the assumptions are not correct
- Which assumptions are verifiable during M&V
- Which assumptions, if any, that will be used over the duration of the project

Box 7 presents examples of assumptions that might be relevant.

Box 7. Possible Assumptions Underlying M&V Implementation

The following examples of possible assumptions cannot be applied to a single building, nor is this list meant to be comprehensive. Assumptions should be customized to each specific project application.

- The building operating schedule will not change because of this project.
- Space temperature setpoints and setbacks will not change as a result of this project because secondary systems are not impacted.
- The outdoor air ventilation schedule will not change as a result of this project.
- The past years of fuel oil and electricity bills from [year] to [year] are (or are not) representative of the operation of the facility and can (or cannot) be used as the source of the facilities' baseline model.
- Baseline computer simulation modeling will not be performed. Instead, the baseline development will rely on regressed fuel oil usage as a function of outdoor air temperature, based on fill date/quantities and/or fuel oil tank level readings.
- Heat supplied to the new wing now under construction will be submetered separately. Fuel displacement figures will be calculated and the necessary baseline adjustments will be made to account for the 25% area addition, which does not necessarily represent a 25% load addition. (Or alternatively, a note that there are no planned occupant operational changes that would significantly alter the current building occupancy rate or schedule and there is no impact to plant loads.)
- We assumed that the main AHU fan speed varies with outside air temperature and that the estimated annual hours of operation are more than 5,000 hour per year. Despite our confidence in this assumption, fan speed will be logged once the new EMCS upgrade project is completed.
- To simplify the M&V process, this M&V Plan assumes that the basic building heating loads of both the baseline fuel oil plant and the new hybrid (wood/oil) plant are the same (except for weather variations). No savings or fuel displacements will be claimed for any changes in load except for weather adjustments via reliable regressions as discussed later in this project.

3.2.4 IPMVP Options

A critical aspect of the M&V process is to select the IPMVP option that your project will follow. In this section of the plan, include a discussion of which IPMVP M&V option that were selected and why they were chosen for this project.

There are four widely-used IPMVP M&V options. Select the option that makes the most sense for your project based on parameters such as the type of project, desired level of accuracy, and available M&V budget. Box 8 describes four established IPMVP options as well as a hybrid approach that might be more suitable for larger projects.

Box 8. Summary of IPMVP M&V Options

Option A - Retrofit Isolation: Key Parameter Measurement. This option is also called Stipulated Savings. Savings are determined by using field measurements of key performance parameters while stipulating (or estimating) parameters not selected for field measurement. This option is used if the savings are very well supported and relatively simple (e.g., a lighting system where the fixture input power is measured but the operating hours are stipulated or estimated).

Although Option A is not suitable for entire biomass heating systems, it can be used for some of the components if they are fixed-speed systems that do not experience variable flows. For example, a fixed-speed boiler primary pump (gallons per minute of hot water) or a fixed-fuel oil boiler nozzle (gallons per hour at high versus low fire) can benefit from certain one-time measurements because the reading will be the same whenever the equipment is energized. Equipment runtime can be measured using an appropriately sized split-core current transducer (CT) on the power wires serving the pump or burner to measure runtime.

Option B - Retrofit Isolation: All Parameter Measurement. This option is also called Metered Savings of Equipment and Systems. Using this option, the savings are determined by using field measurements of the entire project, before and after EEM implementation. An example is a variable-speed drive to a motor to adjust pump flow. A kilowatt meter is installed on the electrical supply to the motor, which reads the power every 15 minutes.

Option B is suitable for most biomass heating systems due to its higher accuracy level and attention to detail.

Box 8 Continued

Option C - Whole Facility Utility Billing Data Analysis. Under Option C, the savings are determined by comparing utility bills for the entire facility (or submeters) before and after energy efficient measures (EEMs) are installed. An example is a building that has numerous EEMs implemented but no building operational changes.

This is a good option if there is an electrical or fuel meter serving equipment that is directly impacted by the EEM. The savings can be seen by comparing the energy usage shown on the utility bills (or sub-meter) before and after the EEM implementation. Despite this option's apparent simplicity, multi-variable regression analysis and normalizations may be required to account for factors such as changes in building occupancy, schedules, setpoints, and weather. Energy savings (or fuel displacements) can then be determined once the variables are reconciled and adjusted to match pre-installation conditions.

Option D - Calibrated Computer Simulation Models. Under Option D, the savings are determined through simulation of the whole facility. The pre- and post-retrofit models need to be calibrated to the respective measured data.

This option is useful when there are numerous EEMs that affect the entire facility, but no meter exists to compare the facility's post-retrofit energy usage with previous usage. With Option D, end use savings can be estimated in advance. However, this option can be challenging because computer modeling requires data collection and then the computer simulation model must be calibrated using the collected data.

Option E - Hybrid Approach. Although IPMVP does not list a fifth option, a thorough M&V plan for complex projects will likely be a hybrid of the options discussed above. A hybrid approach is likely to have Option B as the dominating approach with certain elements from Option C, as appropriate, to measure and report realistic savings. The approach might also include certain Option A components since not every parameter can or must be measured. This hybrid option has been used successfully in large and complex projects

3.3 Project Management

This section of your M&V Plan includes a discussion of your project management approach, including the project cost, schedule, task breakdown, and division of roles and responsibilities.

3.3.1 Project Cost

Create a project budget that includes line items for each piece of equipment and labor costs, along with a project total. Include operations and maintenance costs; see Section 5.2.4 for further information.

3.3.2 Project Tasks

Identify the specific tasks that you will conduct during each phase of your plan (pre-installation, installation, and post-installation). Table 1 provides an example of tasks for each phase of an M&V Plan; develop a similar list as a step-by-step guide for conducting your M&V work.

Table 1. Summary of Pre-Installation, Installation, and Post-Installation M&V Tasks

| | Task | Description |
|--|--|--|
| Pre-installation (conduct inspection, develop baseline) | | |
| 1 | Conduct inspection | Pre-installation site inspection |
| 2 | Develop baseline | Pre-installation baseline determination, including baseline billing analysis, taking spot measurements of baseline equipment, analysis of baseline EMS data if available, or plant logs, etc. |
| 3 | Prepare and submit a peak heat load determination [also called a Detailed Energy Analysis (DEA)] | A full peak heat load determination may or may not be required. If required, it should include a building peak heat load determination (see Section 5.2.3) and an explanation of how the biomass system size was determined. |
| 4 | On-going design and design reviews | Independent design reviews and Cx may also be required. |
| 5 | Order boiler and TES | Do this after approval of the design and system sizing |
| 6 | Prepare and submit M&V Plan | Obtain approval to order the M&V equipment after the M&V Plan is completed. |
| 7 | Get approval to proceed with construction | Based on the preceding peak heat load determination, design review, biomass system sizing and the M&V plan to the extent possible |
| 8 | Obtain necessary construction permits | Since this can take some time, it may be preferable to start with preliminary construction documents to expedite the approval process |

Table 1 continued

| | | Task | Description |
|--------------------------|--|--|---|
| Installation | | | |
| 9 | | Install and commission a new boiler plant including TES | Include all equipment for the balance of plant, control integration, system protection, and M&V |
| 10 | | Complete the installation of the metering equipment | |
| Post-installation | | | |
| 11 | | Perform post-installation inspection, Cx, troubleshooting and startup, during Installation and first operation | |
| 12 | | Final post-installation site inspection | |
| 13 | | Develop and submit post-installation and Cx report | If possible, include a sample data file from whatever may have been collected as part of the M&V-enabled control system at startup |
| 14 | | Obtain approval of the post-installation and Cx report | |
| 15 | | Year-1 data collection and checks on-going | |
| 16 | | Complete year 1 M&V data collection | |
| 17 | | Submit year 1 M&V report | Include all metered data, properly tabulated in electronic format. |
| 18 | | Year 2 data collection and checks ongoing | |
| 19 | | Complete year 2 M&V data collection, | Include all metered data, properly tabulated in electronic format |
| 20 | | Submit year 2 M&V report | Include all metered data in electronic format. Year 2 M&V report may be the final report, although the applicant is encouraged to continue the M&V process. Some projects may require more than two years of M&V. |

3.3.3 Project Schedule

Assigning a timeline to each task is a good way to establish an overall project schedule and track the project. The timeline can include a clear description of the components needed for planning and project management, including:

- Project title.
- Building location.
- Contact information.
- Overall duration of monitoring.
- Task number.
- List of tasks and a brief description.
- Responsible party.
- Beginning date.
- End/completion date.
- Comments and/or relevant notes.

Add other entries that as appropriate.

Figure 1 provides a template for presenting and tracking your project schedule using a project management spreadsheet called a Gantt chart. Figure 1 assumes a three-year schedule: one year for planning and construction and two years for M&V data collection. Some projects require heating year-round, some do not. The difference between an 8- and 12-month M&V period can be indicated on the Gantt chart by using solid dots (●) for the actual M&V period and hollow dots (o) when the heating system is not used.

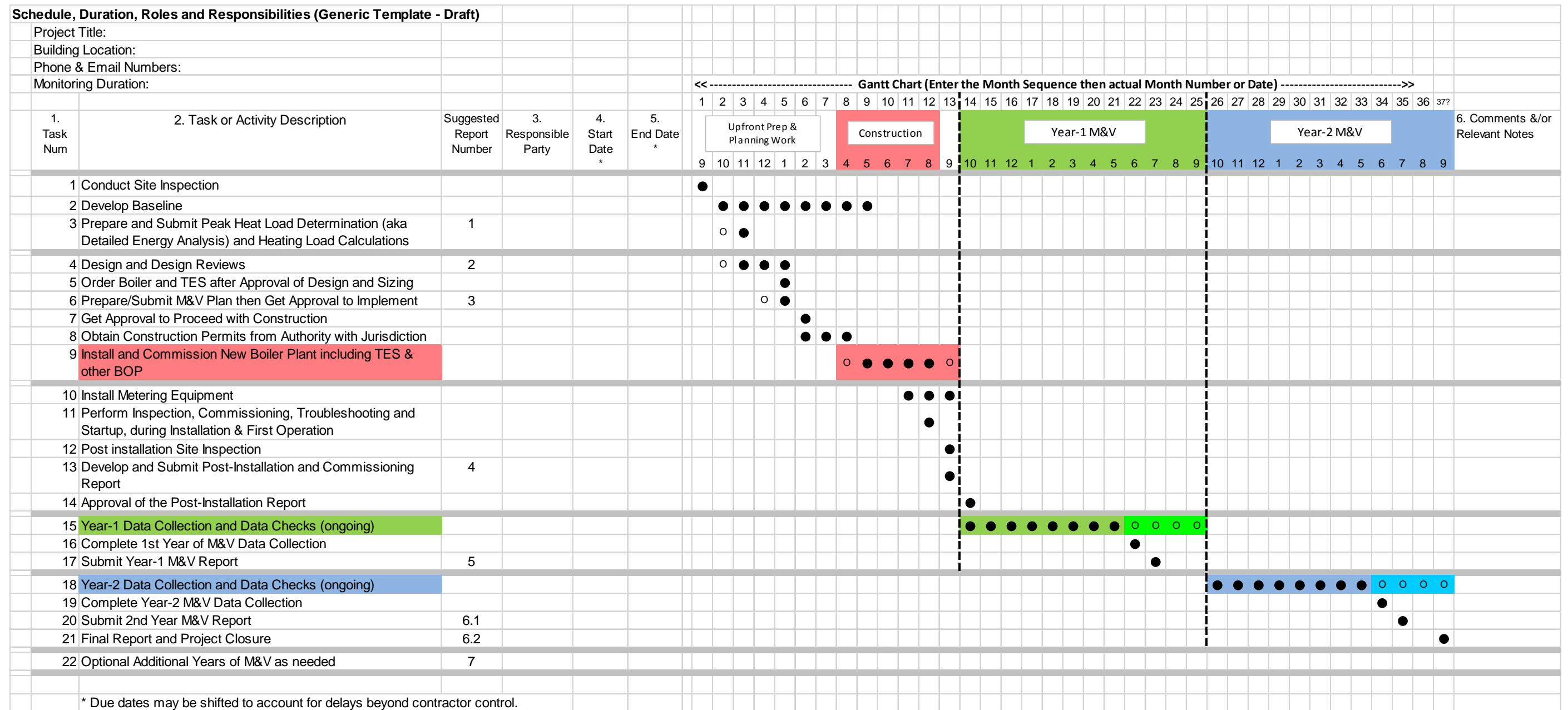
3.3.4 Roles and Responsibilities

It is also essential to assign roles and responsibilities for each task. Responsible parties and their level of responsibility will vary from project to project and depend on project size, complexity, and how the owner structures their professional support team. The final project responsibility may rest with the general contractor or the design engineer but, depending on the project size, a large number of individuals can be involved. Therefore, it can be extremely helpful if the general contractor clearly defines each party's roles and responsibilities in writing prior to the projects' beginning. Be sure to consider issues unique to your project, such as the need for any special training and who is responsible for providing annual O&M services (e.g., if specialized services are to be awarded or competitively selected to supplement the facility operator).

Responsible parties may include, but are not limited to:

- Customer for the heat.
- Owner of the building or heating equipment.
- Applicant for funding.
- Funding agency.
- Architect.
- Design engineer, with special focus on the mechanical or HVAC design professional.
- General contractor.
- Mechanical contractor.
- Specialty sub-contractors (especially in large projects, e.g. controls system integration contractor).
- Construction manager and/or project coordinator.
- M&V contractor, also called an agent, or consultant.
- Commissioning (Cx) contractor, also called an agent, consultant, oversight consultant, or authority.
- Local authorities or authorities having jurisdiction over the project (needed for obtaining certain permits and/or to ensure compliance with codes, rule and regulations).
- Boiler manufacturer, vendor, and/or other equipment manufacturers/suppliers.
- Thermal energy storage tank manufacturer/vendor.
- EMCS vendor, system integration contractor, low voltage contractor.
- Electrical contractor.
- Boiler testing and boiler Cx contractor.
- Test, adjust, and balance contractor (TAB)
- Energy services company (ESCO).

Figure 1. Example Gantt Chart



4 Writing the M&V Plan: M&V Activities

This section of the guide covers how to describe your M&V data collection, pre-installation, installation, and post-installation activities. Quality control issues and reporting requirements are also covered in this section.

For each M&V task, include:

- A description of the task.
- Suggestions for how to implement each task.
- Important information to include in the M&V plan.
- Where available, we include a sidebar with relevant resources for completing that task, such as related regulatory information, expert tips, examples, or illustrations.
- Where possible, examples or suggestions are offered that can be modified as needed to fit your project.

When writing this section of your M&V Plan, refer to Section 5.1 for information on data collection and Section 5.2 for data analysis resources.

4.1 Introduction

This section of your M&V Plan describes the technical details of how to approach each task before installation of the biomass heating system (and its controls), during installation, and after the system has been installed, as well as the data you will collect to monitor the system.

4.2 Data Collection

When developing your data collection approach, work with the building owner and facility staff to describe the data measurements required to verify performance over the entire heating season, record instrumentation details, and document this information in your M&V Plan.

Installing an M&V-enabled control system will allow the facility staff to track system performance over the long term, ensuring proper operation. Alternatively, temporary, battery-powered data loggers can be used during the M&V period. In this case, the facility staff must support efforts to install the temporary equipment at the site. Collect data loggers on-site at the end of the M&V period or mail them back, as appropriate.

At every step of the M&V process, a significant amount of data will need to be collected. Data are collected to (1) describe the baseline (or existing) situation and (2) identify data collection needs for future monitoring. Data points that are common to both the baseline and the future can be identified as common data points. Consequently, when collecting data, consider mapping each type of data point to one of these three groupings:

- Common data points, which are the same for both baseline and future measurements.
- Baseline data points, which are used for pre-installation, baseline development, pre-conditions evaluation, or pre-installation monitoring.
- Future data points, which will be used in future, post-installation monitoring such as biomass boiler plant, post-conditions evaluation, or post-installation monitoring.

There are many common data points. For example, when a baseline fuel oil boiler will continue to be used for supplemental and peaking heat needs, there will be baseline and future data for that boiler. Weather data points are also common. These are all appropriate to include on the common list. Ensure that adequate descriptions and specifications are provided for each data point (see Section 5.1).

Your M&V Plan should include a description of all of the data that you will collect for the pre-installation baseline (or existing) analysis and for post-installation analysis, including the type of metering that will be employed, the equipment that will be used, how the equipment will be calibrated, the specific equipment that will be metered, and the length of time metering will be conducted.

Clearly identify what data you will collect. See Section 5.1 for a detailed list and description of key data points related to your biomass heating system, building, and related systems. For each data point to be collected, it is important to summarize information on the following descriptive parameters (or metadata):

- *Data point name or number.* Frequently, large metering systems have numbering for all points. Other times it is part of the numbering scheme of an EMCS. They are not always the same.
- *Data point abbreviation, designation, or symbol.* For example, T_{oa} usually denotes outdoor air temperature sensor and T_s usually denotes supply temperature sensor. This is true regardless of its location or whether it is a resistance temperature detector (RTD) or a thermocouple (TC). Ensure clarity by using industry-accepted data point abbreviations and naming conventions.
- *Data point category.* Describe the type of data (e.g., temperature, fuel, flow, electrical, emissions, volume, miscellaneous).

- *Engineering units.* Clearly define which units you are using and use them consistently throughout the project. For example, temperature may be expressed in degrees Fahrenheit or degrees Celsius. Pressure (e.g., Psig, Psia, or Bar) and flow units (e.g., GPM or L/s, GPH) can also have various units, which must be defined. Other units are dimensionless, such as percentage (%) and On/Off. When different data points use different units, select a standard unit and conduct the necessary conversions. Make sure to note your decisions and calculations in your M&V Plan.
- *Data point or sensor location.* Describe as specifically as possible or indicate on the Piping and Instrumentation Diagram (PID) where the data point will be located. For example, when describing a data point that is in the mechanical room, you might write, “the hot water supply flow sensor is located on the pipe connecting the biomass boiler and the buffer tank.” Note that flows can also be measured at the return pipe between the buffer tank and the inlet to the boiler. If a stack gas monitor or combustion analyzer is to be installed, it is not sufficient to say “install in stack downstream.” Instead, indicate the precise location, defining where the sensor will be deployed in feet from the breaching. Carefully review the boiler and instrument specifications, including manufacturer instructions, as you specify how to obtain readings.
- *Metering interval.* For each data point, identify the metering interval at which the data is recorded – for example, 15-minute, 1-hour, or COV (Change of Value). Within the interval, it can be an average, cumulative, or integrated. Collect, record, and verify “raw” as well as “compiled” electronic data from the monitoring devices so it can support the M&V process as evidence of system operation, energy and cost savings, and fuel displacements. Program the monitoring equipment to record data points at the necessary metering interval, preferably 5 to 15 minutes. (When justified, use shorter or longer metering intervals for varying data points). Specify the type of reading collected (e.g., average, cumulative, continuous, COV, short term, or spot reading). For example, flow is typically cumulative over the metering interval, temperature is typically average, auger runtime time is typically COV, and instantaneous power for fixed speed devices can be spot read (runtime is collected through another method). Projects may have tens or even hundreds of data points, each with their own aggregation method.
- *Monitoring duration* (or duration of measurement). For each data point, specify for how long the monitoring will occur. For example, spot measurements, short-term logger, 1-year or 2-years.
- *Metering instrument used.* Specify all equipment and instruments that will be deployed to complete the M&V plan. This can include a BTU meter, watt meter, TOU data logger, current transducer, and temperature logger (e.g., TC, RTD, or thermistor). Specify how the data are being collected (e.g. online, in-person readings).
- *Make and model of the metering instrument.* Ensure that the make and model of your metering instrument provides the needed quality, accuracy and reliability to match the M&V Plan’s objective.

- *Specification of the metering instrument.* Include data such as metering range, accuracy, data storage or memory capacity, battery operated vs. powered, communication and interface (such as RS-232, Ethernet, 0-10 Volt DC signal, 4-20 Milliamp (MA) signal, or wireless). Specify if flow meter type is an insertion type, which is intrusive to the piping, or non-intrusive (e.g., turbine, positive displacement, clamp on ultrasonic, magnetic, or coriolis). This can be a lengthy field because it can include numerous specifications. Sometimes, instrumentation specifications are finalized after completing the project piping design when you have a better idea about desired sensor locations.
- *Notes.* Use this area to highlight specific conditions in your M&V Plan that require additional commentary. Spell out as much as you need upfront to avoid issues with ordering or installation of metering equipment.

Not all of these parameters can be populated while preparing an M&V Plan, but major data points and their locations should be included upfront and details added as they are determined. It is preferable to present data points in a table, (see Figure 2) although some use of text descriptions will also be necessary. Some M&V data points can be presented in a Piping and Instrumentation Diagram (PID). For an example of a PID, see Slide 222 in Appendix A. Color coding of the PID is strongly suggested, with red for supply (hot) lines and blue for return (cold) lines. See Box 9 for troubleshooting tips.

Box 9. Troubleshooting Data Collection

For troubleshooting, spot readings or short-term metering results can be collected using portable and/or battery power data loggers, which may have wireless communication capabilities. Short-term metering equipment can be installed at the same time spot-metering readings are being taken. Short-term metering equipment data loggers can also record readings at intervals of 5 to 15 minutes or less.

Section 5 provides more detailed information about each type of data point, as well as additional information you will need to collect to prepare the M&V Plan and a sample data collection table. The section also includes recommended data collection methods and equations for use in data analysis and savings calculations.

4.3 Pre-Installation Activities

4.3.1 Conduct Inspection

Description: The first task in an M&V project is to conduct an inspection of the existing heating system.

How to implement this task. During the pre-installation inspection, ensure that the assumptions used in the technical feasibility calculations for energy savings are valid and agree with existing boiler plant parameters (e.g., capacity, efficiency, controls). During this task, the M&V contractor and the customer receiving the new biomass system should familiarize themselves with the site, and review available system documents, drawings, and records. Familiarization might include review of a multiyear fuel billing, boiler logs, fuel oil tank level readings, and any available energy management system (EMS) electronic trend logs, which may be hard to find in old plants. During this task, the M&V contractor can also begin to identify some of the current and potential sensor locations that may support either the existing boiler or the future system.

What to include in the M&V plan. Note what you observed during inspection. Verify whether the existing boiler plant parameters are in agreement with the assumptions or stipulations found in the technical feasibility calculations. Note if there are any discrepancies, and describe the corrections that need to be made.

4.3.2 Develop a Baseline

Description: A key part of your M&V Plan is developing a baseline using the data that you identified. Baseline data parameters establish a reliable energy baseline against which future performance of the biomass heating system can be compared in terms of thermal efficiency and economic considerations. A proper baseline represents a core on which many energy projects are built. The energy baseline will later be compared with future consumption to quantify the project savings and/or fuel displacement.

Good baseline development also supports energy audits (see Appendix F). Energy audits improve heating system integration and sizing. This section of the M&V plan focuses on the thermal baseline, but also addresses the electrical baseline, which is still a key component of a full energy assessment and part of the suggested energy audit. For more information on data collection, see Section 5.1.

Notes:

- It is preferable to separate the list of baseline data points from the list of data points that will be collected in the future, although there may be some overlap if the baseline oil boiler will continue to be used in the future as a supplemental boiler. Ensure clarity among the baseline case, proposed case, and common data points.
- The M&V contractor should perform a cursory heating system energy design review and provide recommendations on biomass system integration (boiler and TES tank), protection, sizing, controls, and communication with the existing building systems. For more information on TES and boiler protection, see Appendices C and D.

How to implement this task. Review the system documents, drawings, and records. Document relevant observations. Determine the baseline boiler plant consumption. Where possible, conduct a regression of the baseline data against weather data.

What to include in the M&V Plan. The baseline development discussion can cover some or all of the topics described below, depending on your project. These topics can be reordered to fit your needs. In most cases, it is possible to address each topic in about one paragraph.

Introduction

- Describe the existing building fuel oil, propane, kerosene, wood chip, cordwood, and other biomass fuels as well as the electricity bills for the building(s) to establish an energy baseline against which both biomass and EEMs savings can be compared.

Billing Analysis

- Identify the period for which bills were reviewed. This time period must be at least one year; three years is preferred, and in some cases the period can be as many as six years. Longer periods better capture variables such as weather, occupancy, or local factors such as major rehabilitations or building expansions.
- Indicate where bills were entered electronically in spreadsheets.
- The majority of the billing analysis should be completed before an on-site walkthrough. Discuss energy billing observations with site staff during the walkthrough and describe any further information, edits and corrections. (Obtain their consent on needed adjustments and corrections, and assure they are in agreement with the final baseline.) The billing analysis helps the owners understand their own buildings and how they can enhance building efficiency, comfort, reliability and compliance with regulations. See Section 5.2.1 for example equations that will support savings calculations.

Savings

- Present information on energy and cost savings (e.g. heating cost savings, net savings, fuel displacements, or other energy savings). See Section 5.2.1 and 5.2.2 for more information.

Heat Load Analysis

- Discuss how the analysis of the fuel oil bills coupled with site observations were used to estimate the peak heating load. As a reminder, good biomass projects size their facility at no more than 60% of the peak heating load (with the existence of supplemental fuel boilers). See Section 5.2.3. for more detailed information on peak heat load determination.
- Identify unit fuel costs using the appropriate units for each fuel.

Preliminary Sizing

- As part of a thorough billing analysis, complete electrical- and fuel-based calculations to determine figures of merit for the overall heating system efficiency. Include existing boiler capacity and examine the normalized peak building heating demands (Btu/h/ft²). Develop the heating load profile and calculate annual equivalent full load hours (EFLH) using multiple definitions as shown in slides 151 to 162 of Appendix A.
- After completing the analysis, check that the system would be sized to less than 60% of the peak heating load. In the case of a district heating system, complete individual analyses for each of the buildings and ensure that energy baselines for all individual buildings were properly developed, examined, and grouped together to ensure that the proposed pellet plant is properly sized to less than 60% of the combined peak heating load.²

Additional Baseline Information

- The baseline development may also include verification of the operation of existing boilers using logs if available, review of baseline combustion efficiency testing results as available, detailed interviews with building personnel, observations made during inspection, review of baseline bills, detailed examination of numerous figures of merit calculated during the course of the work, and comparisons to other available benchmarks and to other similar buildings.

² Ideally, sizing is finalized after accounting for implementation of EEMs (e.g. envelope, infiltration or other heating load reductions) resulting from an energy audit. If not, biomass boiler sizes should be even lower than 60% of peak heating load. Ensure the future biomass heating plant is not oversized after the implementation of EEMs.

Document Data Points and Variables in Table Format

- Indicate where you will record data from electrical and thermal variables. The variables listed below are based on inputs, outputs, calculations, and inferences that need to be made during billing analysis and biomass system sizing³:
 - Building area served by heating systems, heating EFLH, boiler normalized output capacity (Btu/h/sqft) to examine oversizing, peak building heating load (Btu/hr), peak normalized heating load (Btu/h/sqft), average \$/fuel unit cost, baseline fuel cost (in dollars), and normalized fuel cost (\$/sqft/year).
 - Building area served by electrical systems, peak electric demand (kW), annual equivalent full load hours (EFLH), annual electric load factor or fraction (LF), electric energy use (kWh), average blended (aggregate) electric cost (\$/kWh), electric energy cost, normalized electric kWh/sqft/year (compare against similar benchmarks), electric \$/sqft/year, peak watt/sqft, and capacity of emergency generators (kW).
 - It is good practice to present the site energy needs for fuel oil in kBtu/sqft/year and electricity in kWh/sqft/year, then combine them to reflect total building consumption (kBtu/sqft/year).

Other Variables and Figures to Support Final Sizing and Design

- The analytical spreadsheet should include a column that denotes important baseline values such as: normalized energy utilization indices (EUIs), energy costs (\$/million Btu), normalized capacities (Btu/hr/sqft), EFLH, important input variables, and variables that will be kept the same after the new system is in place. These values can be color-coded and sequenced to ease comparison for the reader. They should also be used to support the future system sizing and MEP design process. For additional information about analytical components, refer to Slides 256 to 261 in Appendix A.

Billing Observations

- Indicate any additional billing observations after the accuracy of the baseline billing analysis is confirmed. Some examples and advice are presented in Box 10 and Box 11.

³ If the boiler sizing was not based on information gathered from data loggers, then flow and temperature sensors may be deployed at each of the boilers during a heating season to establish a reliable energy baseline that is supported by actual measurements and not just utility bills. This data may then be used to finalize the sizing. More about baseline metering can be found in Section 5.1.1, which also offers simplified alternatives to meter baseline boiler operations.

Box 10. Example of Miscellaneous Billing Observations from a District Heating Example (May Apply to Individual Buildings)

- It was observed that the unit fuel costs paid by the customer (a public entity) were significantly lower than that paid by general commercial customers and/or statewide averages, which is likely caused by bulk procurement. Using less expensive baseline fuel unit costs in this analysis has elongated the economic payback period.
- Electricity unit costs appeared fairly reasonable.
- In a multi-building situation, put the buildings in rank order. For example, “based on a general investigation of the fuel bills, the A building had the lowest combined EUI of 47.7 kBtu/sqft/yr with an annual cost of \$1.24/sqft/year, then B building (70.3 kBtu/sqft/yr and 1.85/sqft/year), then C building with the higher values (134.9 kBtu/sqft/yr and \$3.62/sqft/year). All three (3) buildings combined averaged 85.9 kBtu/sqft/year and \$2.28/sqft/year.”
- State additional EUI comments based on the completed baseline billing analysis. For example, “the low EUI identified at the D building was a result of progressive management practices regarding EEM implementation. Because of its past use of best practices, this building may not easily attain the same percentage of savings targeted in the other buildings.”

Box 11. Example of Miscellaneous Billing Observations for a Single Building Project

- The unit fuel cost paid by the X building was slightly lower than that paid by general commercial customers and/or statewide averages; this was likely caused by well negotiated municipal purchasing. The less-expensive baseline fuel unit costs of \$3.11/gallon may have slightly elongated the economic payback period. Bills from 2010, 2012 and 2013 were used for the baseline. Using a more realistic recent 2013/2014 average of \$3.50/gallon slightly shortens the economic payback. This 12.5% increase in unit cost may be more reliable because there were suspicions about the accuracy of some of the data. In addition, fuel cost from 2010 was only \$2.32/Gallon, which lowered the average down to \$3.11/gallon. All agreed to use \$3.50/gallon (based on the average cost of 2012/2013 and early 2014 and excluding 2010), although some thought it was slightly lower than the state average. (Note: Baseline fuel prices fluctuations are an important consideration in biomass projects.)

Box 11 Continued

- Electricity unit costs appeared fairly reasonable for 2011 at \$0.122/kWh, blended for an annual usage of 156,640 kWh/year; however, in 2013, data reflected a higher blended cost of \$0.152/kWh caused by a much lower annual usage of 93,040 kWh per year. The 63,600 kWh/year reduction was a result of the installation of 50 kW of PV arrays during 2012. The utility rate structure led to a slightly increased blended unit cost due to a significant reduction in usage without a paralleling reduction in electricity peak demand (56.6 kW in 2011 down to 44.8 kW in 2013). The 63,600 kWh reduction converts to 1,272 EFLH (63,600 kWh / 50 kW) which is a reasonable expectation for production from a PV array in this region.
- The 2011 normalized electricity EUIs of 4.35 kWh/sqft/year went down to 2.58 kWh/sqft/year in 2013. These are both fairly low despite further available opportunities in lighting efficiency, which are lower than those in similar commercial buildings. Although occupancy sensors were not present, the site staff were very conscious about turning off unnecessary lights. Aside from a few sporadic direct-expansion cooling units, the building has minimal air handling, cooling, and fan power needs.
- The site was also characterized by a very low electricity demand of 1.60 Watt/sqft in 2011 (57.6 kW / 36,000 sqft), which was further decreased to 1.24 Watt/sqft in 2013 (44.80 kW / 36,000 sqft). The energy audit did not generate many electricity EEMs besides lighting. The audit focused more on the heating system EEMs, system protection and reliability.
- Based on a general investigation of the fuel oil and electricity bills, the building has a fairly reasonable or low combined electricity and fuel oil EUI of 57.4 kBtu/sqft/yr with an annual cost of \$1.62/sqft/year.
- In addition to the actions of an energy conscious staff, the low EUI was attributed to simple mechanical systems. The building is currently under low occupancy and therefore requires less outdoor air (and less heating of that air). Natural window ventilation reduces mechanical fan usage.
- Building occupants suffered from seasonal temperature complaints (mostly when it was cold). Low fuel oil usage may have been a result of cold rooms, not energy efficiency. (Low EUI is not always a result of energy efficiency.)
- Although the analysis of heating bills from three partial years averaged 10,878.2 gallons/ year, it was agreed to use 12,600 Gallons per year (a 15.8% increase) to account for suspected missing fuel oil bills and to adjust for the higher fuel usage to be expected if better thermal comfort had been attained. We made no adjustments for OA since the customer was satisfied with the IAQ levels with minimal OA. Note: To avoid overestimating savings, baseline adjustments must be done in a responsible manner by experienced energy professionals.

Graphs and Tables

Include graphs and tables covering both fuel and electrical baselines similar to those discussed in Box 12. All graphics should be clear and provide text references for calculations.

Box 12. Resources for Developing Tables and Graphs

Helpful resources for determining the baseline are included in Appendix A. The examples in the slides are based on actual data from real projects. Use them with caution in your project.

The following slides are most relevant:

- Slides 151 to 162 provide examples of baseline billing analyses, establishing a multi-year energy baseline, and heating and electrical figures of merit for baseline and proposed cases. Prominent baseline figures of merit and biomass boiler sizing hints are also included,
- Slides 163 to 180 provide additional sizing discussions, including but not limited to: methods and examples, building peak heating load determination, biomass system sizing, tandem boiler options, and buffer tank sizing calculations,
- Slides 256 to 261 provide an example and additional information about numerous analytical components used in a full biomass heating feasibility analysis.

4.4 Installation Activities

Description: The next section of your M&V Plan will cover the installation phase, including first operation inspection, Cx, and troubleshooting. Discuss oversight during construction and installation of key systems.

How to implement this task. In addition to the new biomass heating system itself, a new M&V-enabled control system will aid in ongoing data collection (see Section 5.1 for more discussion on data collection). This M&V-enabled control system will allow the facility staff to track system performance over the long term, ensuring proper operation. Alternatively, temporary, battery-powered data loggers may be used during the M&V data collection period. Collection of the data loggers at the end of the M&V period may be done in person or the data loggers may be mailed back, as appropriate. See Box 13 for additional information.

Box 13. Tips about Installation of Metering Equipment

- To address QC, especially with ultrasonic flow meters, ensure flow sensors are deployed with the correct pipe diameters and as far upstream and downstream from bends and fittings as is recommended. Follow manufacturer specifications carefully – turbulent or non-laminar flows caused by valves, fitting and bends can lead to inaccurate readings. Also, observe recommendations regarding meter installations on vertical versus horizontal pipes. Read the instruction manual carefully for other tips and tricks such as applying the proper adhesive or conducting gel between the ultrasonic flow sensor and the pipe, or cleaning the pipe properly to get a good contact/reading.
- All sensors should be appropriately mounted in proper locations to accurately measure the variable being metered. For example, the outdoor air temperature sensor should be mounted so it is not affected by heat from a mechanical room grill or exposure to solar radiation.
- Do not mix ultrasonic flow meters and electromagnetic flow meters. Ultrasonic flow meters can be challenging to calibrate - follow manufacturer specifications.

4.5 Post-Installation Activities

The post-installation section is the final section of the M&V Plan. It includes a discussion of inspection and monitoring that will occur after you have installed the new heating system.

4.5.1 Conduct Inspection

Description: After commissioning, conduct an inspection to verify that the system components (i.e., boiler, thermal energy storage, controls and balance of plant [BOP]) are installed properly and consistent with what was proposed. Ensure that the sequence of operation for the controls addresses the entire system and not just individual components.

How to implement this task. Proper programming for the controls is often missed. A representative from the controls manufacturer should be present during inspection of the heating system to confirm proper installation, commissioning and integration of the controls with the system. Note any discrepancies. Be sure to arrange for potential disruptions in equipment operation to accommodate the inspection. Note: design of control sequences and integration of controls into the system is often one of the weakest points in many biomass heating projects. Use care and attend to details.

Obviously, cold weather inspections are more meaningful than hot weather inspections because the boiler will be operating during that time. However, because most construction takes place during non-heating months, many inspections occur during the summer. Because only a limited inspection can be completed in hot weather, it is preferable to conduct a full inspection after the entire heating system has been fully installed, tested, commissioned, and operating according to the design intent.

Depending on timing, there might be two post-installation inspections: one after the installation is completed and another during system operation under heating load. Every inspection should be as comprehensive as possible.

What to include in the M&V Plan and Report: In the M&V Plan, describe the inspection and monitoring that will occur after you have installed the new heating system. After the inspection occurs, use the information in your M&V Plan to document findings in the M&V Report or in a separate post-installation report; see Section 4.7 for more information about M&V Reports. Provide adequate reporting and documentation on the post-installation inspection(s), including installed equipment. Include illustrations where appropriate. If you conducted more than one post-installation inspection, make sure to discuss each one.

4.5.2 Conduct Monitoring

Description: After the biomass heating system is installed, monitoring of both the new plant and the supplemental oil boilers are conducted for the entire M&V period.

How to implement this task: Monitoring is conducted using the data points listed in Section 5.1. Many meters log at 5- to 15-minute intervals, though data are often downloaded only weekly (or monthly) and then validated and stored. Make at least two site visits during the M&V period during a time when the system is operating to ensure the M&V implementation is going according to plan and to provide Cx oversight. Additional site visits may be needed for research and demonstration projects. Quality assurance and quality controls measures are discussed in Section 4.6. Box 15 provides additional information.

Troubleshooting: In the event that there is a significant gap in the data due to a meter failure, the process to replace the missing data with interpolated or averaged data must be clearly documented.

Box 14. What is the Standard Time Period for M&V for Biomass Projects?

The standard is at least one year, but can be two years or more. Longer M&V periods provide better means for examining savings and fuel displacement, and also enable ongoing commissioning, especially during the first year of operation. In addition, longer M&V durations also support billing and heat sale agreements and may be needed for certain complex projects involving district heating systems.

4.6 Quality Control (QC) and Quality Assurance (QA) Procedures

It is important to develop a plan that describes your process for ensuring the quality of all data that you collect and to identify a means for speedy intervention when data issues are identified. Report any deviations from this plan (e.g., a change in data collection procedures) in the annual M&V report.

Recommendations to control for and assure quality include verifying:

- The accuracy of each sensor location.
- That each sensor was installed in a suitable location.
- That the sensors were installed properly.
- Sensor calibration and data quality.
- Sensor communication and download capabilities.
- That sensor and loggers are adequately protected and labeled.
- The sensors' and data acquisition system's ability for data archiving, retrieval, storage, backup, remote access, and prevention of data loss.
- EMCS or SCADA (System Control and Data Acquisition) programming for system controls, integration, and data acquisition.
- The existence of automatic and manual range and relational (R&R) checks.

When addressing QC, especially with ultrasonic type flow meters, deploy flow sensors with the proper equivalent pipe diameters upstream and downstream from bends and fittings. Be sure to follow manufacturer specifications to get accurate readings and to avoid turbulent or non-laminar flows caused by valves, fittings, and bends. Also, observe recommendations regarding meter installations on vertical versus horizontal pipes. Read the instruction manual carefully for other tips and tricks such as applying the proper adhesive/conducting gel between the ultrasonic flow sensor and the pipe, or cleaning the pipe properly to get a good contact/reading. Use a battery backup or uninterruptable power supply to avoid data loss.

Box 15 presents numerous examples of the specific measures that you might include in your QA/QC plan. In some cases, notes are provided to further explain the sample measure.

Box 15. Potential QA/QC Measures

- [NAME] will check the data logger, boiler control panel, or the Energy Management System (EMS) trend log data weekly (or monthly) to make sure the readings are within reason and to ensure high levels of data capture. Data will be downloaded weekly (or monthly) to separate storage media. Data will be stored in two locations, locally on a computer and also to a network-attached storage device to ensure data redundancy. (Note: For systems >300,000 Btu/h, collect key performance data at 5- to 15-minute intervals with greater than 90% data capture through the use of flow meters, temperature sensors, and data loggers. For systems \leq 300,000 Btu/h, use the on-board central processing unit (CPU) to provide bin-hour analysis by load in 5% full load increments. Despite the > 90% data capture requirement, you may be able to obtain much higher values through a reliable and well commissioned EMS and data acquisition systems.)
- [NAME] will take spot xyz measurements with a xyz meter calibrated at xyz the factory to \pm 2 percent of reading.
- [NAME] will perform range and relational (R&R) checks where feasible to trigger and generate automatic data QC alarms.
- We will calibrate temperature and flow measurements from designated meters at the time of installation and will check for calibration once or twice every year.
- For projects that are likely to have an electrical impact, we will monitor electrical energy and demand using an [insert brand] kilowatt-hour meter. CTs (current transducers) and voltage clips will be deployed on the A, B and C phases of the 460-volt service that supplies the new pumping assembly. Placement of the kWh meter will attempt to isolate the system components to the furthest extent possible. (Note: Explain if other devices draw power from these breakers and if anything is shared.)
- The xyz meter will record electrical consumption at xyz-minute intervals for the duration of the monitoring period. This meter is capable of continuously storing the interval metered energy consumption from the in-service date. Data will be downloaded and stored on the first working day of each month to ensure that the meter is working properly. The meter will not be reset to zero until all M&V activities are completed.
- We will archive data electronically when feasible. Portable meters or standalone controllers may be used rather than a permanent EMCS. Despite portability benefits, portable meters increase manual labor for downloads unless a reliable Ethernet or cell service is used to facilitate the data downloads remotely (the preferred approach).
- XYZ data will be prescreened to verify completeness and to identify anomalies which may bias the analysis (or regression analysis). Baseline and post-installation building regression models must have (or target) an R^2 greater than 75% to be considered accurate.

Box 15 continued

- We will investigate abnormal data and if explainable, treat abnormal data as outliers, (e.g., a one-month plant shut down). (Note: If anomalous data cannot be explained, include it in the analysis if you believe it was representative of plant operations. Include in the M&V Report a list of all outliers and their explanations with the analysis and regression results. When eliminating outliers from the analysis or regression, substitute via interpolation or average data from other years for the same time period and document such substitutions.)
- [NAME] will document the actual implementation of the M&V Plan, including verification of the proper installation of all in-scope items, and any deviation from the original M&V Plan such as type of metering equipment, monitoring data points, the monitoring schedule, the data collection and archival procedures.
- We will document missing data as well as data substitutions, if any, and the method used. (Note: Replace missing data either by interpolation, extrapolation, average values, supported calculations, or a reasonable combination of the above approaches. Clearly identify data replacements in the legend of the piping and instrumentation diagram, as applicable.)
- [NAME] will check the recorded data on a weekly (or monthly) basis. (Note: Investigate any anomalies in the data in a timely manner and address any data reporting problems. Maintain a log book of all data reporting problems and subsequent corrections and include the log in the annual M&V report, as appropriate.)
- Automatic R&R checks should be performed where feasible to trigger and generate automatic data QC alarms; however, this may not be feasible with basic data collection systems or individual controllers. Companies specializing in data collecting use monitoring centers and advanced programming algorithms to continuously perform data verifications. Some even use metadata to perform QC checks where one group of data points is used to check another group and vice versa. Regardless of the capabilities of the customer and/or the firm doing the M&V, indicate how the data will be routinely checked for quality.
- For example, if you have multiple Btu meters in one plant and there is a plan to include a totalizer meter to sum the flow meters from each individual boiler, include this check meter as an integral part of your R&R checks. Although the total should equal the sum of individual meters, if it does not, then recalibrate, check each meter, and revisit the equations.
- If you plan to include a totalizer meter to sum the flow meters from several individual boilers, make sure checking the totalizer meter is an integral part of your R&R checks. The totalizer meter reading should equal the sum of individual meters; if it does not then recalibrate, check each meter, and revisit the equations.

4.7 M&V Reporting

In this part of the M&V Plan, describe the content and schedule for your M&V reports.

Once the biomass project is complete, monitoring data should be recorded and inspections of the M&V and heating equipment should be written up in an M&V report that documents whether the biomass heating system and M&V equipment were properly installed and are functioning as designed. Address and correct issues promptly; do not wait until the end of the heating season.

M&V reports should be prepared annually for the duration of the M&V period following completion of the first year (or first heating season) of data collection activities. Information and collected data in the M&V report should be presented in tables or graphics, and accompanied by a narrative description and analysis. Raw M&V data alone are not acceptable. Submit M&V reports in electronic format to relevant entities, including the heating system owner, technical consultants, or other parties monitoring system performance. Also ensure that all the data logger, boiler controls, and energy management control system (EMCS) monitoring data are available in electronic format.

The M&V report components should follow the M&V Plan, but focus on reporting and explaining results. The report can include measured fuel displacements and savings estimates (in dollars and Btu), including explanations for deviations from predicted savings or fuel displacements along with corrective actions and next steps.

It is important to have a well-documented M&V report because in some cases, if savings shortfalls are reported, someone may be financially responsible. Other shortfalls may delay payments. Some customers may wish to obtain an independent and experienced third-party M&V contractor.

5 Resources for Data Collection and Analysis

Refer to this section for more detailed support on how to identify, collect, measure, and analyze the data described in Section 4. Section 5.1 provides specific information about how to collect the data that you will need for pre-installation baseline development and post-installation activities. Section 5.2 provides specific information on methods for analyzing these data. Additional information on resources for data collection is provided in the appendices. Appendix B discusses fuel types and alternative heating systems. Appendix C covers thermal energy storage (TES) and buffer tank issues. Appendix D describes boiler protection issues (thermal, chemical, water level, and high temperature/high pressure). Appendix E provides information on stack placement and code compliance.

5.1 Resources for Data Collection

As described in Section 4.2, throughout the M&V process, it is possible to collect a significant amount of data. Consequently, it is important to be conscientious about how and what kind of data you collect, and to provide a clear definition of all data points. A complete and carefully planned list of data points is needed before sensors and controls equipment are ordered or deployed. Improper M&V equipment can result in extremely inaccurate readings. Figure 2 presents an example of a data point list spreadsheet.

Section 5.1.1 presents information on data collection related to a biomass heating system. Section 5.1.2 describes data collection related to a building and its systems.

Figure 2. Data Points List

| Data Point List Specification | | | | | | | | | | | |
|--|--|----------------------|----------------------------------|--|---|----------------------------------|--|---|---|---|---|
| Project Title: | | | | | | | | | | | |
| Building Location: | | | | | | | | | | | |
| Phone & Email Numbers: | | | | | | | | | | | |
| Monitoring Duration: | | | | | | | | | | | |
| <<----- List of Data Points ----->> | | | | | | | | | | | |
| 1. Data Point Name, or Parameter Monitored; 2. Data Point Number; 3. Data point Abbreviation, Designation, or Symbol | Data Point General Category (Temp, Fuel, Flow, Elec, Emissions, Efficiency, Volume, Safety, Other, Misc) | 4. Engineering Units | 5. Data Point or Sensor Location | 6. Metering Interval; 7. Monitoring Duration (or Duration of Measurement) | 8. Metering Instrument Used; 9. Make/Model of the Metering Instrument; 10. Specification of the metering instrument | 11. Comments &/or Relevant Notes | 1. <u>Common</u> between Baseline and Future | 2. <u>Baseline</u> Development, Pre-Conditions Evaluation, or Pre-Installation Metering or Monitoring | 3. <u>Future</u> Biomass Boiler Plant, Post-Conditions Evaluation, Post-Installation Metering or Monitoring | << Insert new columns here as needed >> | |
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| << Insert new rows above as needed >> | | | | | | | | | | | |

5.1.1 Data Collection for Biomass Heating System Projects

This section describes common, baseline, and future data points related to your biomass heating system project. Data points to collect during the M&V process include, but are not limited to:

- *Date and time Stamps.*
- *Outdoor-air dry bulb temperature (OAT).* Obtain the dry bulb temperature from the closest weather station. The dry bulb temperature is key to M&V analysis and must be reliable. Check that sensors are shaded and placed away from any sources of heating or cooling from the building, including exhaust air grills (e.g., general, kitchen, restroom), or sources of heat from a mechanical room exhaust or stacks, or near overhead doors in loading docks. Procure sensors from reputable manufacturers, follow manufacture recommendations, and periodically verify the sensor calibration. You may average readings between two sensors.

Note: There is no pressing need for secondary weather variables such as outdoor air wet bulb temperature (OA WBT), relative humidity (% RH), wind speed, wind direction, and solar radiation unless a cooling analysis is to be completed as part of a large energy audit. Other weather variables, such as solar radiation and wind speed, can impact heating but these generally have minimal impact compared to OAT. Solar radiation can impact heating if the building has a lot of glazing and/or skylights. Wind speed and direction can have an impact in leaking buildings. Additional data points may be used to fit your specific building needs.

- *Zone Temperatures (Indoor).* In addition to logging the outdoor air dry bulb temperature, include zone thermostat setpoint and setback temperature settings (target temperatures) as well as actual measured space temperatures. This data is used to determine whether the heating system (primary or secondary) is capable of maintaining desired space conditions. Explain deviations in the M&V Plan, as discussed in Section 4.2.
- *Fuel usage.* Record the dates and amounts of fuel and pellet deliveries, and fuel oil tank level readings (if any) in order to track baseline and proposed fuel use over the M&V period. Shorter periodic readings (daily, hourly, or 15-minute) provide a better baseline resolution that is sensitive to weather and can generate improved regression analysis and fuel usage correlations with outdoor air dry bulb temperature readings. However, short intervals may present reliability challenges. Types of fuel data points include:
 - *Baseline usage of petroleum or other fuels⁴.* This usage primarily includes but is not limited to fuel oil #2, #4, and #6 kerosene or propane deliveries. It may also include other solid fuels such as wood chips, cordwood, coal, other agricultural biomass, or other non-woody biomass.
 - *Tons of pellets delivered during M&V data collection period.*

⁴ This is a typical example of a common data point. The same point is used for measuring displaced fuel usage by subtracting post-retrofit fuel usage from the original baseline fuel usage.

- *Tons of fuel used post-installation.* Include secondary or supplemental fuels in the post-installation case, as appropriate.
- *Boiler room voltage.* The fixed speed of the auger motor can be impacted by voltage fluctuations. Addressing this may require adjustment to the feed rate.

Note: Small pipe diameters and relatively low fuel oil flow rates to the burners can cause positive ultrasonic flow measurements to read inaccurately. In systems greater than 300,000 Btu/h, in-line displacement meters are recommended. This insertion type flow meter requires cutting existing fuel oil lines. Although it may concern some customers, accurate flow data is critical to properly assess loading, efficiency, operation, runtime, the number of hours the existing fuel oil boiler spends in standby mode, its on/off cycle rates, and how it is integrating with the new biomass boiler at varying load conditions. As an alternative, oil consumption can be measured daily by recording changes in oil storage tank volume. Regression of the daily fuel oil tank level readings tends to underestimate the regressed peak heating load extrapolations (despite a reasonable regression R^2 value), therefore, in this situation we also recommend deploying Btu and GPM meters on the boilers.

Observations related to how the fuel oil boilers operate after the addition of the biomass boilers are very important, especially because some fuel oil boilers lack the necessary turndown capabilities and may experience operational difficulties and even increased cycling after integration. Inadequate turndown capabilities may also cause an oil boiler to take precedence over the biomass boiler in meeting the heating loads, which would result in smaller fuel displacement than originally targeted.

- *Thermal efficiency.* Thermal efficiency, based on higher heating value of fuels, may differ between the original baseline boilers and the new ones. Although fuel displacement drives the majority of the energy and cost savings in biomass projects, changes to overall thermal efficiency may also occur when both the biomass boiler and existing plant work together properly. See Section 5.2 for examples of equations to calculate thermal efficiency.
- *Combustion Efficiency Monitoring.* Combustion efficiency differs from the calculated overall thermal efficiency previously explained. It includes numerous parameters such as stack temperatures, and levels of O₂, CO, and hydrocarbon in stack exhaust. Requirements depend on the project type and complexity. Some boilers have their own built-in monitoring for 15-minute or shorter intervals. Others must be monitored externally. Typically, combustion efficiency measurements are taken using handheld instruments during periodic boiler tests once or twice a year; however, that is inadequate for measuring a wide range of varying load conditions. Continuous combustion efficiency monitoring is preferred, but may not be required if adequate thermal efficiency monitoring measurements and calculations are performed (because high thermal efficiency is an indicator of good combustion efficiency).

Note: Stack gas CO and hydrocarbon measurements are desired, but some manufacturers do not log them. In that case, combustion efficiency is computed using O₂ and the difference in temperature between the stack gas and the boiler room temperature, as measured at the inlet to the boiler for combustion air.

- *Carbon Monoxide (CO) Monitoring and Alarms.* Elevated CO levels are a serious health and safety concern. Sensors with audible alarms are necessary in the boiler room and where pellets are stored, in addition to the CO monitors used for combustion efficiency or stack gas emissions monitoring. All safety and Occupational Safety & Health Administration (OSHA) regulations must be followed.
- *Runtime and cycle rate.* Collect runtime data for all of the boilers at regular intervals (15-minute or shorter) over the monitoring period. Runtime and cycle rate can be obtained by deploying split-core CTs on the electric wiring serving the forced draft fan and/or the fuel oil pump; a high amperage reading indicates high fire while a low amperage reading indicates low fire. Similarly, any reading indicates the pump is on while no reading indicates the pump is off. Ensure you specify the right CT for the high and low fan amperage values as well as on/off pump amperage values. Additional readings are strongly recommended or required depending on the project scope and complexity. For example, *burner runtime* can be useful, especially with linkage oil boilers that have oil nozzles with fixed flow for high and low firing rates (as opposed to fully modulating linkage-less oil boilers). Many older buildings have linkage boilers.
- *Thermal Metering.* Thermal metering (also called Btu metering) can be measured using a Btu meter or heat meter, which is a device that measures thermal energy provided by a source or delivered to a sink. It does so by measuring the flow rate of the heat transfer fluid and the change in its temperature between the outflow and return legs of the system. It is typically used for measuring the output from an individual boiler and/or the entire boiler plant. It can be used to measure the heat delivered to district heating consumers). Similarly, it can be used to measure the cooling output from an individual chiller and/or an entire chilled water plant. Btu meters are extremely valuable because they measure in real time the actual amount of heating energy that is produced by the boilers (oil and/or biomass) to meet the load. They also measure the amount of heat stored in the buffer/TES tank and later released, and indicate the rate at which the heat was released. This Btu thermal energy is simply calculated by the well-known equation: $GPM \times \Delta T \times \text{fixed factor}$. The fixed factor depends on the properties of the fluid used. Documentation of BTU readings must detail where individual flow and temperature sensors are located; solely reporting the Btu results is not acceptable and is not adequate to analyze M&V or perform system diagnostics and trouble shooting. The combination of the two items listed below represent the data needed for thermal metering.
 - *Supply and return temperatures* at hourly (or shorter) intervals for the individual boilers and the overall system, as appropriate. Temperatures may be measured using Resistance Temperature Devices (RTDs) that are strapped on to the piping, thermocouples, thermistors, or thermal wells. For your application, select the appropriate temperature range and needed accuracy levels.

- *Hot water flow readings* at hourly (or shorter) intervals over the monitoring period to calculate thermal output and efficiency. Hot water (or antifreeze) flow can be measured using ultrasonic flow meters, electromagnetic flow meters, or different types of insertion flow meters (turbine or positive displacement). Meter selection depends on pipe diameter, fluid flow volume, fluid velocity, fluid properties like density and thermal conductivity, pipe material, and required accuracy level. Specifying and installing the proper flow meter can be more challenging than it is with temperature sensors. See Section 4.6 for tips on QC for flow metering.

Note: Insertion meters are more accurate than ultrasonic meters that are strapped on to the outside of the pipe, but they have higher upfront material and installation costs. Regardless of what type of meter is installed, include a budget for meter commissioning and calibration to ensure accurate readings are obtained.

Note: Mathematically dividing the boiler's (or the plant's) measured thermal output from the Btu meter by the fuel input to the boiler (or plant) over the same metering interval calculates the measured thermal efficiency of the individual oil or biomass boiler (or the entire plant) as appropriate. More detailed equations are provided in Section 5.2.

Note: Do not deploy flow metering devices that reduce pipe diameter. This action increases the system/pump head and constricts fluid flow. For example, if flow measurements are taken on an existing 3-inch pipe, a 2-inch Btu meter should not be installed by cutting through the existing 3-inch pipe and using a pipe reducer.

- *Fluid Type.* Set the BTU meter parameters for the specific fluid type (e.g. water or ethylene glycol). Additional information is provided in Section 5.2.
- *Wood pellet auger runtime and/or speed.* Auger runtimes are often monitored automatically at the boiler control panel. Given that auger motors usually run at a single speed with simple on/off controls and low RPM, if the feedstock is homogeneous (such as wood pellets), an on/off status reading suffices to measure fuel usage because the rotation speed is fixed whenever it is operating. The status reading can be obtained from the boiler onboard control panel or by using a split core CT for auger motor runtime.

Note: Revisit the auger calibration after each new load of pellet fuel is delivered. Fuel input to the boiler may be calculated based on actual historic auger run times and measured pellet consumption, but be aware there can be slight variations in auger calibration based on pellet density, texture and moisture content. Accurate auger calibration leads to an accurate fuel input, which supports an accurate thermal efficiency calculation.

Note: It is important to use certified pellets that adhere to size and other specifications. Despite the preceding guidance, there may continue to be issues with accurate pellet feed. Use caution.

- *TES tank temperatures.* Take tank temperatures in multiple locations to assess stratification. Use at least three temperature sensors in a vertically stratified tank: one at the top, one at the middle, and one at the bottom. Although three is typically the minimum, taking readings from five sensors will better assess the true stratification and thermocline, especially when there are difficult tank geometries or aspect ratios. Temperature sensors can be installed between the tank shell and tank insulation, but inserting them in thermowells using thermal grease is more accurate and gives more representative measurements.
- *TES tank inlet and exit water temperatures.* In a four-pipe tank, take the temperature of the water at the two inlet and the two exit ports. The Btu meters at the top and bottom of the tank measure both flows and temperatures. In a two-pipe tank, log temperature at the inlet and exit, but also log flow direction, which tracks tank charging and discharging.
- *TES tank inlet and exit water velocity.* Measure the velocity of the water at the two tank inlet and two tank exit ports. Hot water enters and leaves horizontally from the top of the tank while return water enters and leaves horizontally from the bottom of the same tank. Although velocity is not directly measured at these inlet and exit ports, it can be calculated using the flow data from the Btu meters and the tank specifications (the cross-sectional area of the entering and exit pipe or diffuser). The velocity of the flow in the pipe can be calculated using the following equation: velocity = flow/cross sectional area, for instance velocity (in feet/second) = flow (ft³/second)/ area (ft²).

Note: The standard four-port configuration on the TES tank has two inlets and two exit ports; however, some modern designs use only two ports. This setup requires bypasses to reduce velocities. A conscious effort should be made during system design to reduce velocities at all four ports by proper port placement and other techniques. This is crucial to achieving thermal stratification. For more information about TES and techniques for maintaining stratification, refer to Appendix C.

- *Three-way Valve Position for Verification of Boiler Thermal Protection.* Record the position of the three-way valve in the log. The valve exists to achieve adequate mixing of supply and return water into the boiler to achieve proper temperature modulation for protecting the biomass boiler from thermal shock. A three-way valve is included in the design of many recent biomass boilers. It may be set by the manufacturer to either self-modulate internally and thermostatically (using bellows) or be externally actuated by the boiler controller. If the valve position cannot be recorded, verify that it is operating by showing that the return water temperature stays above the setpoint the biomass boiler manufacturer requires (usually 130 or 140°F), regardless of the water temperature coming back from the load, which can be as low as 60°F, especially right at startup after a long shut down.

Note: Pay attention to the controls and boiler protection for both the biomass boiler and the existing oil and propane boilers. (A truly modulating condensing propane boiler may need less attention than an oil boiler). Old oil boilers cannot handle low return water temperatures; therefore, verify the original piping and protection in addition to the way the system will be piped and protected after adding the biomass boiler. Piping, pumping, and valving modifications can cause unintended damage. Oil boiler protection should be at least as good as it was before, if not better.

Note: Besides piping, ensure the controls sequence of operation reflects the necessary boiler protection sequence for both boilers regardless if the site used an EMCS or just a set of individual controllers. For more information about boiler protection, refer to Appendix D.

- *Savings.* Calculate and present potential savings to the customer: heating cost savings, net savings, fuel displacements, or other energy savings. Although many customers may be most interested in the net financial savings, others may be interested in the details and steps that led to the net energy and cost savings. Although it is helpful to the customer to summarize the savings as succinctly as possible in the M&V Plan, all steps that have been performed to arrive at the conclusion should also be included. See Section 5.2 for an example of equations that will support potential savings calculations for the M&V Plan that can later be compared to savings shown in the M&V Report.
- *Stack Gas Monitors or Emissions Analyzers.* If net emission impacts are to be evaluated, include them in the M&V Report, including particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NO_x), and sulfate (SO₂). Some emission impacts may be directly measured while others are calculated. This is especially important for research projects, especially those with post-combustion emission control technologies such as an Electrostatic Precipitator (ESP), or condensing units (See Appendix A, Slide 21 for details).
- *Electrical Equipment Used with the Biomass Heating System.* Measure biomass boiler parasitics, feedwater pumps, and other circulators, current (amps), and power (kW). The M&V plan should measure electrical savings (or penalties). Measure pump and other circulators' status as "on" or "off." Measure current amperage using a CT. Measure boiler plant voltage frequency to verify there are no outages. Power measurements are complex, especially in variable speed systems. Boiler plants can have primary and secondary pumps; select the pump(s) for measurement relevant to your biomass project. For example, if alterations took place only to the primary pump (and valve) during the biomass system conversion with absolutely no change to the secondary and distribution pumping, there is no need for power measurements on the secondary pumps.

Note: If you need a more accurate reading of true power measured in kW that measures three-phase power and reactive power components, you will also need to measure voltage and power factor (PF) in addition to amperage. If fixed speed pumps or fans are used, a one-time amp, volt, and PF measurement is generally adequate as long as you measure the on/off status of the pump or fan. Combining the monitored on time with the one-time power measurement yields the total power consumption (kWh). However, if variable speed pumps are used, amp, volt, and PF will actually vary as frequency varies and you will need to take continual measurements of true power.⁵ Besides good thermal data (flow rates and temperatures), good power data (on/off status and true power) will indicate whether the pump is cycling on and off, or if it exhibits true variable speed controls. A true variable frequency drive (VFD) would benefit from the near square (or ideally, near cubic) relationship between power draw and fluid flow fraction. On/Off systems do not enjoy such electricity savings benefits. Pumping and three-way valve combinations can be single speed, multiple speed, or variable speed; this detail must be clarified as part of the detailed design stage.

Note: Some VFDs display ongoing and real-time true power measurements while others only present frequency in hertz. Some present true power while others present calculated power.

Note: If power measurements using true power meters are too expensive, VFD frequency can be logged instead. This gives a reasonable indication of percent flow.

Note: Use your judgement and apply any or all of the preceding techniques as appropriate to measure the electricity consumption (electrical penalty) from the biomass boiler automatic ignition air guns, primary/secondary (maybe tertiary) combustion fan motors, cyclone/emission controls fan motors, turbulator motors (for automatic boiler cleaning systems), power exhaust fan motors, auger⁶ conveyance motors, and pumping. Although such electrical parasitic loads are relatively small⁷ compared to the project's savings, they must be accounted for to properly assess the project net benefits. Depending on the boiler manufacturer, most of this information can come from the boiler control panel, though some needs to be logged separately.

⁵ Note that modern biomass plants employ a balanced combination of VFD pumps or 3-way valves to optimize their hydraulics design with TES and attain better boiler thermal protection.

⁶ There can be multiple augers in a biomass heating system.

⁷ Additional electrical parasitics may include controls/sensors, LED display screen, the very small motor used for the pellet sliding gate, etc. Discuss with the boiler manufacturer how such information can be gathered and/or make a reasonable estimate based on logger runtime from the boiler control panel, operating wattage and whether it varies. Parasitics use a small amount of electricity, but including their electrical usage ensures a complete assessment of the electrical impacts.

5.1.1.1 Simplified Approaches to Data Collection

In limited-budget situations, a simplified M&V process may be necessary. The following two examples show how simplifying the measurements can reduce costs.

Fuel Input Flow Measurements. Split-core CTs (forced draft fan or fuel oil pump⁸) can be used on the burner of an existing oil or propane boiler to measure cycling and the number of hours spent in standby mode during pre- and post-retrofit conditions. Split-core CTs can log high-fire, low-fire, and no-fire modes based on the fan amperage reading. Insertion type flow meters replace 1- to 15-minute fuel oil flow readings. Carefully review both the boiler and the burner nameplate data to determine the fuel oil flow rates at high and low fire. In addition, measure the rate and compare it with the nameplate flow ratings as they may vary over time, especially if burner nozzles were recently replaced.

Boiler Output Btu Measurement. Keep the supply and return water temperature readings to complete the loop on Btu metering at the loop closest to the oil or propane boilers to assess its Btu output. Divide the output by fuel input to calculate the delivered efficiency of these boilers. However, given that the most expensive part of the Btu meter is the flow transducer (not the temperature sensor), the following simplification can be offered on a case-by-case basis. To eliminate the hot water flow transducer, use CT surrogates to log the on/off status of fixed speed primary boiler pumps. With this method, a reliable one-time flow measurement must be taken when the pump is on. Unfortunately, some fixed speed pumps may experience a slight variability in flow due to system head changes caused by downstream controls, other pumps on the same header, and valve position modulations in the system. Therefore, use CTs in this application with caution.

Note: Some boilers have a built-in Microprocessor Control Panel that records useful data points such as these.

- Boiler firing (on/off) status and stage.
- Status of the primary and secondary combustion air fans as a clear indicator of real firing. They can be simple on/off, multiple speed or variable speed.
- Exhaust fan readings (similar to the above).
- Hot air gun blower status.
- Stack temperatures.

⁸ Most likely, it will be easier to measure the forced draft fan operation rather than the fuel oil pump. The fan CT amperage measurement gives a clear indication of high or low fire. In contrast, the fuel oil pump amperage can be very confusing in cases where fuel oil is provided using an oil loop to the burner instead of a direct feed to the burner.

- Leaving and entering hot water temperatures. (Fluid flows are not typically included as part of the boiler built in controls and thus must be obtained externally. See BTU meter discussion for more information).
- Pellet auger status.
- Combustion air inlet temperature.
- Power feed to the boiler (voltage and frequency).
- Other parameters such as O₂ readings, CO, combustion efficiency.
- Percent load. Because this can be a misleading parameter, it is important to verify if and how it is measured or calculated and what assumptions and stipulations are used by the manufacturer. Some knowledge of boiler manufacturer controls may be necessary to ensure the control panel data is accurately interpreted and used during the M&V process.
- Depending on the manufacturer, other beneficial readings may be obtained using the boiler control panel.

5.1.2 Data Collection for the Building and Building Systems

This section provides a list of information required for analyzing data related to the building and building systems. Some of this information may not be easily available for the baseline system, but try to obtain as much as is available. Additionally, some details may not yet be available for the proposed system, especially before the design and specifications are completed.

Building and system background information might include:

- *Existing building operation information.* Include information about the condition of the existing building operation such as the controls, space comfort, boiler water treatment, existing boiler protection, availability of plant logs to establish a baseline, and current efficiency levels.
- *Boiler information.* Including specifications such as the capacity, brand, model, serial number, cost at the date of purchase (note the date), manufacturing location, if it is certified by the American Society of Mechanical Engineers (ASME), and other specifications for the:
 - Thermal storage tank, including brand, model, insulation type and level, size and dimensions.
 - Pellet storage silo.⁹
 - Pellet conveyance system.
 - Circulator system.

⁹ Because oil is denser than pellets, liquid fuels require less storage volume than solid fuels. Therefore, a pellet silo is larger in volume (and heavier) than an oil tank for an equivalent amount of stored BTUs. Wood chips require an even larger (and heavier) bunker than a pellet silo. Familiarity with the BTU value of various fuels helps in estimating storage volumes, the number of fills needed per year, and how that may impact the cost. A 30-ton pellet silo has a higher upfront cost than a 15-ton pellet silo, but requires fewer deliveries, so the negotiated cost of delivered pellets may be less. Estimate storage and delivery costs during project planning.

- Piping, circulator, or hydronics system.
- Boiler protection and system controls.
- Expansion tank.
- Sensors and controls.
- Breaching and venting system.
- *TES tank information.* Including the volume, height, diameter as well as inlet and leaving pipe or diffuser cross sectional areas to calculate flow velocities.
- *Information on old technologies that will be replaced.* Including the fuel type, manufacturer, model, vintage, size, past fuel usage, removal cost if applicable.
- *Installer, design team, and construction management information.* Include information about other key participants in the project. Note details such as the company name, contact information, and name of the contact person in the organization. If possible, also include other details such as the number of years working with similar systems and the total number of completed projects.
- *Progress and tracking information.* Include dates for project milestones, funding approvals, permits, and installation. Because many funding agreements are milestone-based – sometimes go/no-go decisions are based on satisfactory submission of milestones – accurate and clear tracking is key to task approvals (see Section 3.3).

5.2 Resources for Planning and Conducting Data Analysis

Your M&V Plan should describe how you intend to analyze the data collected during the pre-installation and post-installation phases of your project. Include as many equations as necessary to substantiate items, such as savings, fuel displacement, system efficiency, and valuation. Equations connect the dots by explaining how the data will be used to generate beneficial results.

Data analysis tips include:

- Present equations in text boxes or a table and give each a unique identifier (e.g., Box 16).
- Make sure each equation is referenced and explained in writing.
- Delineate each parameter in the equation and its engineering units as applicable. For example:
 - Explicitly list the specific heat (C_p) of water at 1.00 Btu/lb/°F because load calculation errors will result when using non-water fluids with different specific heats. If a site uses a glycol mix, C_p will be less than 1.00 Btu/lb/°F and must be adjusted for ethylene glycol or propylene glycol, which have different C_p values.
 - Use the proper antifreeze-water ratio and the proper fluid densities. Errors can mistakenly overestimate the calculated building load and heating plant efficiency.

5.2.1 Basic Equations and Conversions

This section describes several key equations and conversion factors that are used when conducting M&V for biomass projects. To keep this section brief, it is not possible to list every equation for every biomass project situation.¹⁰ Nevertheless, getting the right data can be a real challenge.

Basic equations. The basic M&V equations used in calculations for biomass projects are similar to related conventional technologies. For example, heating load can be calculated as displayed in Box 16, regardless of the type of system being evaluated.

Box 16. Example of Calculating Heating Load

Load (Btu/h) = 500 x GPM x Delta T (across varying equipment)

Note that 500 = 1.00 Btu/lb/F x 8.34 lb/Gal x 60 Min/hr (The 500 factor is okay for water, but use a lower C_p & higher density for Glycol-water mix)

Delta T varies depending on entering and leaving temperature sensor locations; however, ensure that you report actual temperatures, not only the delta.

GPM is simply Gallon per Minute for hot water, but you can use whatever units you are comfortable with as far as you accurately depict the flow.

Conversions. Conversion equations may also be necessary to make comparisons among fuel types when evaluating the cost implications and other impacts of different fuels used in the project. Box 17 presents an example of how to document the cost comparison of certified wood pellets and baseline #2 fuel oil. Ensure that all conversions are documented in this way. Similar simple conversions apply to all baseline and renewable fuels.

¹⁰ For example, although we used the generic equation, “Load (Btu/h) = 500 × GPM × Delta T (across varying equipment),” the M&V contractor should have clear plan of where to deploy the Btu meters (flow and temperatures) covering the boilers, TES, and the hot water common header.

Box 17. Cost Comparison of Certified Wood Pellets versus Baseline #2 fuel oil (per MMBtu)

Certified wood pellets

$8,200 \text{ Btu/lb} \times 2,000 \text{ lb/ton} = 16.4 \text{ million Btu/ton}$

$\$200/\text{ton} / 16.4 \text{ million Btu/ton} = \$12.20/\text{MMBtu}$

Note: Certified wood pellets contain 8,200 Btu/lb and may cost \$200/ton

Baseline #2 fuel oil

$1,000,000 / 138,690 \text{ Btu/Gallon} \times \$3.50/\text{gallon} = \$25.25/\text{MMBtu}$

Note: Baseline #2 fuel oil contains 138,690 Btu/Gallon and costs about \$3.50/gallon

The energy content of liquid fuels like oil is not presented per ton; it is presented per gallon. There can be up to 37.5 million Btu/ton at a fuel oil density of approximately 7.9 lb/gallon (depending on temperature). $35.1 = 2,000 \text{ lb/ton} / 7.9 \text{ lb/gallon} \times 138,690 \text{ Btu/gallon} / 1,000,000$. Oil is 2.14 times ($35.1 / 16.4$) more Btu dense than pellets on a weight basis.

5.2.2 Calculating Energy and Cost Savings

This section describes how to calculate cost, energy, and thermal efficiency savings.

Cost equations. As discussed in Section 5.1, it is important to calculate net savings to the customer.

Several examples of equations from a feasibility study that identifies all cost components are presented in Box 18. Measured results are compared to feasibility study projections and any differences are discussed.

Box 18. Cost Calculations

Based on a multiyear utility billing analysis, the annual baseline fuel oil bills were approximately \$44,100 per year (or \$1.23/sqft/year) for the 36,000 sqft buildings ($44,100 = 12,600 \text{ gallons} \times \$3.50/\text{gallon}$).

The net energy cost savings is estimated to be \$18,226 per year (\$0.51/sqft/year), which is a net reduction after accounting for (1) the future wood pellets cost, (2) additional annual operation and maintenance costs, and (3) parasitic electrical usage costs of the biomass boiler system (the auger).

This analysis proposes displacing 80% to 93% of the baseline fuel oil usage (insert actual measured value after M&V), and realizing a 41.3% net annual energy cost savings (\$18,226 net savings per year out of a \$44,100 baseline). This calculation reflects a net reduction in the baseline fuel and heating costs from \$44,100/year to \$25,874/year.

The \$25,874 estimated future annual heating bill is comprised of:

- \$19,819 (99.1 tons at \$200/ton) for premium wood pellets as the replacement fuel.
- \$2,500 for pellet boiler maintenance.
- \$3,087 for the remaining oil costs.
- \$468 for additional electrical parasitic loads.

Note that the \$3,087 remaining fuel oil cost represents only 7% of the \$44,100 baseline fuel usage. It is anticipated that pellets will displace well over 80% (up to 93%) of the baseline fuel using a pellet boiler that is sized at approximately 50% to 60% of peak building heating demand and most importantly with a properly sized and well insulated buffering/thermal energy storage tank and proper controls.

Energy Savings. In general, and in traditional energy projects: Energy Savings =

(Baseline or Pre-Installation Energy Usage) - (Post Installation Energy Usage)

Given that the objectives of biomass projects are primarily to attain fuel displacement while potentially including some energy and cost savings, the impact evaluation equations should account for each of these factors:¹¹

- Measure the pre- and post-installation fuel oil usage (after the data regressions) and compare them to the heating load to compute fuel oil displacement and fuel oil savings.
- Measure pellet usage in the biomass heating system to identify displaced oil.
- Conduct a 5- to 15-minute interval analysis to serve as the basis for computing seasonal values for system operation at varying load conditions (including diurnal responses).
- Note that energy cost savings generally result when displacing oil (estimated to be \$25/MMBtu) with pellets (estimated to be \$12/MMBtu) to meet the same building heating load.

Thermal efficiency. To calculate overall thermal efficiency, divide the output by the input (see Box 19). (See the “thermal efficiency” bullet in Section 5.1 for further discussion). Measure the delivered output-based thermal efficiency rather than the combustion efficiency using the stack loss method. To do this, obtain data across a wide spectrum of load conditions and generate regression plots for the boiler and system efficiency as a function of numerous independent variables such as boiler load, building load, and OAT. The least expensive method of taking measurements, by penetrating the boiler stack, is only suitable for short term combustion efficiency measurements and does not capture other system losses such as boiler skin loss, seasonal losses, and standby losses, which can be significant.

Box 19. Calculation for overall thermal efficiency

Overall Thermal Efficiency = Output / Input

Combustion Efficiency should be calculated from stack temperature and other readings like O₂

¹¹ Use proper regressions, baseline adjustments and compute the parasitic electrical penalty from additional automatic ignition air guns, primary/secondary combustion fan motors, power exhaust fan motors, turbulator motors, auger conveyance motors, and pumping in biomass heating projects. Although such electrical parasitic loads are relatively small compared to the project’s savings, they must be accounted for to properly assess the project’s net benefits.

Thermal efficiency calculations support the evaluation of standby loss impacts on seasonal efficiency and idle boilers. Valving off unnecessary boilers is recommended. Combustion efficiencies under ideal conditions can be more than 80% but seasonal thermal efficiencies that include system and standby energy losses can be less than 60%. For this reason, the entire heating system must be evaluated, not just the individual components.

Ideally, you should bin the boiler and plant efficiency at varying load conditions to get diurnal and other load profiles. Combustion analysis via onetime handheld measurements during a site visit is no substitute for continuous measurements during the heating season.

Thermal efficiency calculations depend on the scope of the project, the baseline energy usage, and the energy usage and load profiles for the proposed system. Although HELE biomass projects target fuel displacement, there can also be net Btu savings if system efficiency, sizing, or control is improved. Determining savings can be tricky because savings can be from central heating plant operational efficiency or from envelope load reduction and HVAC controls-related EEMs. Make this distinction where possible. Use data points from other locations in the building (not necessarily the heating plant) to verify space comfort or system savings such as reducing excessive amounts of outdoor air via demand controlled ventilation. EMS can monitor ventilation through damper positions, OA flow rates and space CO₂ levels.

Other considerations. Include equations to evaluate the skin loss of tanks and pipes. Some designers suggest bypassing thermal storage during peak heat load conditions and/or suggest super insulating storage tanks to reduce thermal loss. In district heating situations with long piping runs, evaluate pipe insulation by measuring the temperatures at the beginning and end of the pipes. District heating systems line losses must not be ignored. Any new piping must have adequate insulation. In addition:

- Include fuel input equations for oil (or propane) in terms of gallons or auger run time, both converted to Btu.
- In general, the equations and data spreadsheet analysis should account for boiler operation with and without storage for a complete assessment of not only the boiler, but also the thermal energy storage impacts on enhancing boiler and system efficiency.

- Although the focus of the equations is on thermal energy, some M&V plans also examine cash flow (especially those with complex energy savings performance contracts or those with heat sale agreements).
- Include any other questions needed to support the M&V process, both thermally and electrically.
- Include a comments section with the equations as applicable to document any special conditions.

5.2.3 Peak Heat Load Determination

For proper sizing of a biomass heating system, a peak heat load determination must be calculated. This amount of heat must be provided during the coldest winter conditions. A properly-designed system is sized at no more than 60% of peak heating load. This sizing reduces system cycling and increases efficiency by increasing the amount of time the system operates at full load. For additional information about peak heating load determination, refer to Slides 163 to 180 in Appendix A.

The major categories of tools for proper system sizing include:

1. Computer simulations.
2. Calculations.
3. Plant logs.
4. Baseline data logging and analysis.
5. Hybrids of the above.

Using a hybrid of items 3, 4 and 5, you can use the data points and equations described in Section 5.1, to perform heating load calculations from available plant logs using:

- BTU meters for GPM delta T interval measurements
- Fuel oil tank level readings (hardcopy printouts or electronic)
- Fuel oil flow measurements into the boilers (if it can be accurately metered using insertion type positive displacement meters)
- Other general boiler plant logs (hardcopy and/or electronic)
- Regression against OAT, heating degree days (HDD), and other independent variables such as building schedules, setpoints and setbacks (like occupancy and vacant), other multi-variable regressions in industrial and process sites
- Observe appropriate metering intervals (see Section 4.2.1) as you apply the preceding analyses.

A hybrid approach is strongly suggested. For example, a combination of the first three items uses a careful data-based sizing process, but also measures and calculates system efficiency at varying load conditions including generating diurnal load profiles. Although some information may seem redundant, it is used as a check for consistency and accuracy.

5.2.4 Operation and Maintenance (O&M) Costs

Address the annual O&M costs and the ability of the customer to provide ongoing O&M. Biomass projects can have higher O&M costs than oil systems; this cost should be deducted from savings. Be sure to budget for building operator training.

6 Wrap-Up

For M&V data to be used effectively, the biomass heating system must be designed and built properly. Each heating system should be properly sized and have adequate amounts of thermal energy storage/buffer tank, system protection, system integration, controls and controls integration as well other energy efficiency measures. Conversions of heating systems to biomass are best performed in conjunction with an energy audit to enhance reliability, address existing controls and comfort issues (if any), and maintain acceptable levels of redundancy to the existing heating systems.

Following these suggested steps along with tips in Box 20 can ensure successful integration of M&V into a biomass heating project:

1. Begin with an Energy Audit, with a focus on heating load reduction EEMs as well as the necessary integration between the proposed biomass and existing heating systems.
2. Establish a reliable energy baseline through an energy bill baseline analysis. Take measurements of existing boilers and heating systems to support careful sizing of future biomass boilers. At a minimum, gather fuel oil tank readings and deploy burner runtime data loggers. Chart data against OAT to evaluate excessive on-off cycling, if any. Follow the recommendations in the guide to fit specific project needs.
3. Properly size biomass boilers and couple them with TES or buffer tanks. This ensures longer runtimes at higher loads and reduced cycling. Follow sizing guidelines (60% or less of design heat load) and use tandem boilers where possible.
4. Properly stratify the TES buffer tank to reduce boiler cycling, displace more fossil fuel, and attain faster biomass system response time, higher efficiencies, and longer service life.
5. Use the existing fuel oil boiler to (1) back up the proposed biomass heating system and (2) meet peak building heating loads that exceed the baseloaded (and undersized) biomass plant output capacity.
6. Write, implement, and commission a good sequence of operation for the controls for system optimization and integration. This responsibility should be assigned early in the process to either the design engineer of record and/or the controls firm.
7. Use piping and instrumentation diagrams (PIDs) to clearly indicate sensor and logger locations for both M&V planning/execution and control sequences.
8. Commission (Cx), measure and verify (M&V), and have an independent review to ensure proper biomass system integration with existing heating systems, energy management systems, and heat distribution systems.
9. If the project is to receive external funding, comply with any applicable project-specific eligibility requirements.
10. Carefully review Section 3 and Section 4 before writing the M&V Plan. Apply the sections that best suit how your project will gather the right quantity and quality of M&V data to substantiate the evaluation of your project performance.
11. Follow the detailed information on how to conduct M&V data collection and analysis presented in Section 5.

Box 20. 10 Tips for a Successful M&V Project

- Regardless of what technologies are being evaluated, M&V must be performed properly. Therefore, plan carefully, take your time, do not shy away from asking questions, and request help or expert advice when needed.
- Share your lessons learned and learn from others. Correct errors in a timely manner.
- Include M&V equipment as an integral part of all of your biomass heating system designs and when possible, leave it on the system for the life of the equipment.
- Archive and backup data and ensure sensors are well placed, well protected, and well calibrated.
- Review data during the heating season, not at the end. Return to the site in a timely manner to address any observed issues.
- Label your work properly and leave clear instructions for others.
- Apply recommendations from this guidance document as appropriate and insert your own thoughts to customize M&V to your specific project. This will improve your likelihood of attaining the desired outcome, provide well demonstrated energy cost savings, meet fuel displacement targets, and generate valuable data and lessons to share with others.
- Biomass heating systems require proper design installation, oversight, commissioning, maintenance, and troubleshooting in order to get you the outcome you desire and deserve out of them, especially considering the cost of the system.
- Being expensive does not mean the equipment will do the job. It is your job to ensure that whatever system you select is appropriate.
- Do it right the first time, or you will pay to fix problems that could have been avoided.
- Transparency, clarity, professionalism, diligence, and good documentation are required throughout all stages of the M&V process.

Appendix A: Resources

More detail on M&V can be found in the slides prepared by this report's author and provided as part of a full-day training course entitled, "*Biomass System Training for Proper Sizing, M&V, Cx, Controls Integration, Feasibility Analysis, Energy Audits, Load Reduction EEMs, Lessons from the Trenches, and Other Relevant Energy Efficiency Topics.*"

This slide presentation is available at <http://www.pyramidees.com/publications/>

Appendix B: Fuel Types and Alternative Heating Systems

B.1 Fuel Types

B.1.1 Cordwood vs. Pellet projects

In general, cordwood boilers are used in smaller commercial projects or residential applications (sometimes replacing outdoor wood boilers). Many pellet-based M&V requirements apply to cordwood projects. For example, in pellet projects, measure the auger runtime (after calibration); in cordwood projects, however, keep a log of the weight and time of when the cordwood was fed on the boiler (every 8 to 12 hours for example). Cordwood specs like moisture content and ash content should also be recorded.

Both cordwood and pellet projects may use Btu meters to measure the heat load to the building and storage. Cordwood systems usually have much larger thermal energy storage tanks than pellet systems.

Cordwood projects are usually small and have limited budgets; however, make a conscious effort to incorporate Btu meters, if possible.

B.1.2 Wood Chips

Low-moisture wood chips are preferable to green chips because they have a higher Btu content per ton, require slightly less bunker volume to store, are less sensitive to freezing, and allow boilers to operate at higher efficiencies and lower emissions than green chips do.

Despite numerous benefits from low-moisture, low-ash and no-bark wood chips, they are not yet available in large volumes in the marketplace.¹² Nonetheless, there are many commonalities with wood pellets. For example, undersizing and thermal storage provide similar benefits. Regardless of whether you are using

¹² This guide does not offer specific details regarding wood chip projects; however, many of the recommendations apply to wood chip and other solid fuel projects.

pellets or chips, boilers should be properly protected using three way valves and water treatment. Also, they need the same sort of integration with supplemental fuel oil boilers, including proper sequences of operation for the controls.

B.1.3 Non-Woody Biomass

Many of the recommendations included herein would also benefit non-woody biomass and other solid fuel projects.

B.2 Alternative Heating Systems

B.2.1 District Heating

District heating systems can be hot water or steam. Pay attention to the larger number of Btu meters needed and how the delivered heat to individual buildings is assessed, metered, and billed. Also, expansion to future buildings may be important and may need to be included in the baseline development.

B.2.2 Steam Systems

Many M&V requirements apply directly to a steam system; developers of steam systems may benefit from the recommendations in this guide. However, there are a few major differences between steam systems and hot water systems, and M&V for steam systems is not the subject of this guide. See Appendix D for more information.

B.2.3 Radiant Slabs

Radiant slab systems offer a completely different storage method than traditional hot-water storage tanks (4-pipe or 2-pipe tanks). Although Btu meters are still deployed on the fluid side of both systems, radiant slabs may require additional sensors inserted into the slab and a different means of assessing the amount of energy stored in the slab using the density and specific heat of concrete, which are very different from those of water or glycol. Some radiant slab systems may deploy both radiant slabs and thermal storage tanks. Both the slab and the tank should be valved in a manner to allow separate assessment of each of them.

B.3 Pellet Furnaces

Because the heat distribution and delivery in a furnace with an air system varies significantly from a boiler with a hydronic hot water system, Btu meters are not used, rather an air monitoring station measures flow and temperatures. Although it is fairly easy to log the temperature returning and leaving from an advanced furnace's built-in control panel, measuring airflow is a challenge, but it is necessary for calculating overall system efficiency using the output/input method.

Due to the potential high cost and large size of an air flow monitoring station, the following simplification is offered. CT surrogates can be used to log the on/off status of a fixed-speed furnace fan. A reliable one-time air flow measurement can be taken to verify the air flow during fan operation. A similar approach would be used if a two-speed fan motor is in place. Although this solution may be acceptable, it should be used with caution. Some of the fixed-speed or two-speed fans may experience slight variability in air flow due to system head changes caused by downstream damper controls even if they have bypass systems. If the furnace uses VFD fans, the frequency and/or fan speed from the boiler control panel can be logged and correlated to air flow. You may also use a short term and/or temperature air flow monitoring station and take measurements in increments of 5% speed variation to validate the measured relationship between air flow and fan speed.

Appendix C: Thermal Energy Storage (TES) / Buffer Tank Reminders

Thermal storage tanks help optimize system response time and minimize boiler short-cycling and overheating upon unexpected shutdown. The following list provides considerations to keep in mind while designing a system:

- A minimum storage capacity is recommended of 2.0 gallons for each 1,000 Btu/h (MBtu/h) of boiler thermal output capacity (based on the output capacity of one boiler in a tandem system).
- Use vertically stratified tanks with a high aspect ratio because the taller and slimmer the tank, the better the vertical thermal stratification will be. If taller and slimmer tanks cannot easily fit under lower ceilings, choose multiple slim tanks instead of one short and fat tank even though piping, valving, and controls may become more costly. There is a maximum height limit, however, beyond which the surface area to volume ratio is too high and heat loss becomes unacceptable. A height to diameter ratio higher than 5:1 should be avoided. A 3:1 ratio is common and should be considered a minimum.
- Insulate tanks. You may consider removable custom-made blanket insulation (as opposed to permanent spray foam) to aid in inspection and repairs of the tank shell, or allow access to the tank stratification temperature sensors. Foam insulation is also a good option. R-24 is suggested, which equates to 4 inches of sprayed polyurethane foam. If used it should be covered with an intumescent coating to act as a fire barrier as per local code requirements.
- Present a PID showing the location of the buffer tank (at beginning or end of loop) and explain the rationale for the location. Reduction of unnecessary flow into the tank is preferable.
- In general, tanks maybe bypassed in standby mode to reduce thermal losses; this can be specified with the sequence of operation for the controls.
- Indicate bypass valving and piping on the PID, especially if you have multiple buffer/storage tanks. If each tank has its own bypass, system owners may experiment with the effectiveness of varying storage volumes. If each tank is isolated, designers should plan piping and valving so removal is possible without disturbing the other tanks.
- Although it is obvious that hot water enters and leaves horizontally from the top of the tank while return water enters and leaves horizontally from the bottom of the same tank, you must make a conscious effort to reduce the inlet and exit water velocities at all four ports. Proper stratification is what actually separates return water from the supply water. Therefore, you should make every effort to not interrupt the stratification (also called the thermocline). This can be done by several methods including:
 - Use oversized diffusers to reduce velocities and turbulence to ensure gentle entry and exit at all four ports. This may be the simplest method presented here.
 - Use horizontal baffles inside the tank to reduce mixing between supply and return water.
 - Use a horizontal moving diaphragm inside the vertical tank. Note: the reliability of such a system is questionable and may add maintenance concerns, but may be considered if the tank manufacturer is experienced with thermoclines.

The design engineer responsible for the hydronics and boiler protection should understand the different functions expected from a buffer tank, a thermal energy storage tank and a hydraulic separator.

It is much better to unify the concepts of buffering, protection, hydraulic separation, and thermal storage than treat them as separate functions. Without proper temperature sensing and mixing at the boiler inlet, no tank can protect a boiler from thermal shock or sustained flue gas condensation. Thermal shock protection and protection against sustained flue gas condensation can both be accomplished with the right mixing assembly and temperature control at the boiler inlet. Theoretically, they can be accomplished without thermal storage or buffer tanks, but these tanks provide numerous other benefits such as reduction of boiler cycling and use as a heat sink during power outages.

Appendix D: Boiler Protection Reminders (Thermal, Chemical, Water Level, and High Temperature/High Pressure)

Both the new biomass boilers and the existing supplemental oil or propane fired boilers and systems must be protected thermally and chemically to ensure they do not corrode, fail catastrophically, crack from shocking, or experience sustained flue gas condensation conditions.

Low water levels can cause boiler cracking and/or even explosions.¹³ Protection measures are an integral part of the boiler warranty; however, not all warranties are explicit about all protection requirements. Therefore, it becomes the full responsibility of the design engineer and Cx contractor to ensure full boiler plant and systems protection. A few boiler protection reminders:

- Attain Boiler Thermal Protection against low entering hot water temperatures for both Biomass and Existing Fuel Oil or Propane Boilers. This is a MUST in terms of hydronics, controls, and system integration. Three-way valve protection and/or variable speed¹⁴ boiler primary pumps are used for thermal protection; there may be other methods as well. This protects against firetube cracking caused by thermal shock when the return water is too cold (lower than 130 °F).
- Ensure Boiler Thermal Protection against overheating during power failure by Syphoning extra heat to heat dump radiators or buffer/TES tanks. Chip and cordwood boilers may have more strict requirements than pellet boilers.
- Proper water treatment is sometimes overlooked. Have a clear and continuous water treatment program¹⁵ as opposed to just one basic and minimum treatment per year. Lack of proper water treatment can lead to corrosion and scale of the system internals and premature failure of the heating system. Though less stringent than steam systems, which require a lot of fresh make up water due to boiler blow downs, hot water boiler treatment is also necessary. Staff training is suggested if this task is not outsourced.
- In steam systems, use the commercially-known Hartford Loop for protection against firing with low water levels and to avoid catastrophic failures. Also ensure the proper relief valves and alarms for protection against higher steam pressures are provided.
- In hot water systems, ensure you have both the low water level cut off controls as well as a high exiting water temperature limit controller. Some are equipped with a reset button to be pushed after an alarm.

¹³ This is more symptomatic of steam boilers than hot water boilers.

¹⁴ Sometime VFD pumps are referred to as injection pumps.

¹⁵ Water treatment requirements in steam systems are a lot stricter than in hot water systems.

Proper systems protect the boiler fire tubes from both the inside (fire side against flue gas condensation) and the outside (against the water side thermal shock) and reduces corrosion/oxidization caused by untreated water and unremoved O₂. This protects the boiler feed water as well as the rest of the existing hot water (and/or steam) radiators and distribution pipes.

Consult with the design engineer to ensure the entire plant is protected.

Though such heating system improvements and protection measures may not have an economic (energy) payback, they are necessary for reliable building and system operation and longevity.

D.1 Special Note Pertaining to Steam Boilers

The preceding suggestions assume that biomass boilers are actually firetube hot-water type (i.e., the fire is inside the tube, while the water is surrounding the outside of tubes (heat exchanges) in the water box).

There are additional precautions for hot-water watertube (and/or steam boilers). For example:

- There is the need to avoid water tube burnout simply if the boiler water level falls too low causing tube burnout and causing an explosion. That can happen more with steam boilers.
- Additional precautions against water carryover in steam systems if boiler water level in the steam drum goes too high causing water droplets carryover damaging downstream steam equipment.

Covering both extremes to protect both the boiler and downstream equipment (caused by both low and high boiler water level extremes) was just briefly mentioned -- make sure all precautions are taken during system design and commissioning.

Appendix E: Additional Stack Placement Precautions and Code Compliance Reminders

Stack heights should be consistent with good engineering practice to minimize the wake effects caused by buildings or terrain on emissions. The design of the exhaust stack and location should be done carefully to prevent exposure to building occupants and visitors or to people in frequently occupied outdoor areas such as playgrounds. The boiler's stack height must be sufficient to adequately disperse emissions from the immediate vicinity and prevent entrainment of exhaust gases and particles into the building air intakes and to minimize exposure at ground level adjacent to the building on which the stack is being located. Poor dispersion characteristics are generally associated with short stacks that have little plume rise. This happens when stacks are too short relative to the building height or the exhaust flow is not sufficient, resulting in the plume not escaping the building's aerodynamic effects and becoming entrained in or near the building.¹⁶

The stack should not be placed in close proximity to an air intake or operable window. Stack design should also minimize horizontal piping and bends.

The bottom line is to use good engineering practices and meet all code requirements regarding stack design and placement.

¹⁶ From Cleaner, Greener Communities Program: Commercial Biomass Heating System Program Requirements (<http://www.nyserda.ny.gov/-/media/Files/About/Statewide-Initiatives/CGC-Plans/Guidance/Biomass-CGC-Commercial-Program-Requirements.pdf>).

Appendix F: Energy Audits

F.1 Energy Audit Walkthroughs and Benefits

As part of a successful biomass heating project, it is strongly recommended that an ASHRAE Level-II Energy Audit Walkthrough is completed to estimate the existing building heating loads as well as examine the current building and heating system condition prior to recommending a biomass conversion or other HVAC solutions. Besides auditing the heating plants, the energy audit should include the entire building and secondary systems served by the existing and future heating plants.

Biomass conversion projects should not be developed in isolation; they must be well integrated with other existing systems to provide a holistic solution to the facility under study.

What is an energy audit/assessment and what are an energy auditor's responsibilities?

- An energy audit is a systematic review and inspection of an existing facility to understand its operation, existing systems, baseline energy usage for all fuels (electric, nonelectric [natural gas, oil, kerosene, or propane], biomass, landfill gas, purchased steam, site-generated steam, purchased hot water, purchased chilled-water, etc.), understand utility tariffs, and to identify existing problems.
- Select buildings and/or systems with higher energy use intensities (and therefore higher energy savings potential) as a first priority within an existing complex.
- Propose energy efficiency measures (EEM) that provide short term, medium term, long term and master plan solutions that are appropriate for the facility under inspection to improve its energy efficiency, reduce maintenance, and facilitate the integration with proposed biomass boilers.
- Complete a sequential/interacted analysis of EEMs using a variety of analytical tools as appropriate, compute energy economic feasibility, and present the proper level report to the customer.
- Define and prioritize specific EEMs and energy management strategies that can be integrated into the site's on-going practices and future projects/programs.
- Advance the customer into the next steps starting with EEM design, implementation approaches/schedules, commissioning, documentation, M&V, training, project funding options, potential financial subsidies, etc.
- Adapt a goal oriented approach to ensure you reach the energy audit objectives.

Energy audit specifics to biomass projects include:

- Focus on heating load reduction EEMs to support smaller biomass system sizing, reduce project first cost and O&M costs, and reduce biomass boiler cycling.
- Identification of comfort improvement and controls measures to address existing issues with overheated and/or overcooled spaces. Such issues shall be addressed as an integral part of an energy audit. Note that comfort and controls enhancements do not necessarily reduce energy usage, but can result in enhanced employee productivity and financial benefits such as increased customer traffic.
- Assessment of the operation, reliability, and protection measures for the existing heating system and identifying precautions that must be addressed before considering adding a second boiler, regardless of it is oil or biomass fired.
- Estimation of the existing building heating loads to support the sizing of any future boilers, and accompanying system components (balance of plant).
- Enhancement of the communication between the building owner, owners' consultants (architects or engineers), vendors of varying equipment and balance-of-plant systems (boiler and others).
- Carefully examining the integration, communication and controls between the proposed and existing boilers. Carefully size and interconnect the biomass boiler and TES tank to efficiently work with the existing oil boiler.

Site inspections and discussions with facilities staff are expected to identify recommendations and challenges that must be addressed during design and development.

Auditors are encouraged to follow the provided audit checklist (but they can also use their own based on their past audit experience). A professional energy auditor is recommended:

- General.
- Envelope.
- Lighting and Other Internal Gains.
- Heating Plant.
- Cooling & Central Plant.
- EMCS.
- Unit Ventilators, AHUs, HX.
- Kitchen.
- Domestic Hot Water.
- New Additions, if any.
- Compressed Air, if any.
- Thermostats.
- Elevator, Escalators, and Conveying.
- Water Conservation Opportunities.
- Status of Utility Meters.

Energy audit results should start with a general building description/summary, building floor plans and finally a listing of the EEM recommendations. An energy audit walkthrough differs from a full energy audit. A walkthrough identifies EEMs and presents them in a simple format, whereas a full audit includes a report write-up with full EEM descriptions and energy analysis.

Sections F.2 to F.7 include topics to support energy audit walkthroughs, write-ups, recommendations in support of biomass projects. They also include example write-ups that you may use and/or modify as needed to fit your project specific needs.

Section F.8 is optional but provides many valuable, relevant and practical notes. It is relevant to energy audits and controls and is included right after that section.

F.2 Example for Use in Project Summary, Building Introduction, and General Information

- Built in 19xx as the original xx,xxx sqft bldg.
- A x,xxx sqft addition was built in 19xx.
- Xx floors and a basement.
- Sporadic DX cooling (windows, split, small unitary).
- Envelope Improvements:
 - new roof in added in 19xx &
 - Storm windows added in 19xx.
 - Total area of all = xx,xxx sqft.
 - xx kW of PV array reduced elec usage in 20xx compared to 20xx,
 - Several Lighting EEMs identified for additional electricity savings planned for 20xx implementation.
- ~ xx Full Time Employees, xx Part Time Employees, xx Total (estimated low occupancy).
- xxx sqft/employee.
- 5 day/week schedule, except the library and other social functions.
- x,xxx gallon fuel oil #2 Tank installed in 19xx.
- One #2 fuel oil boiler (Output hi/lo fire x.x & x.x MMBtu/h, refurbished 20xx).
- Backup Generators not used, but desired in the future; look into EDRP and ISO programs.



F.3 Sample Text for Building Floor Plans Indicating Planned Biomass Plant Location

The xyz building floor plans are shown next. This includes the basement, first and second floors. The double dashed lines reflect the suggested pipe locations as discussed with facility staff during the facility walkthroughs. The solid line reflects the suggested biomass boiler location. Detailed design drawings for the biomass heating systems were not available during this feasibility stage, but the energy auditor and the owner had engaged in productive discussions with the owner's design engineering firm of record for the next steps in this project after the feasibility results are reviewed by the board and the project is brought to a vote.

F.4 EEMs List

Identify EEMs, and use photographs as much as possible for clarity. EEMs can be presented into logical groupings including but not limited to:

- Envelope EEMs.
- Lighting EEMs.
- HVAC and controls EEMs.
- Other Controls and miscellaneous EEMs.
- Boiler EEMs,
- Boiler Plant BOP EEMs,
- Boiler Protection Measures and Precautions.
- DHW EEMs.
- Misc EEMs.

F.5 EEM Detailed Section

EEM details are presented in this section. The following sections are needed if a full ASHRAE Level-II energy audit is performed:

- Measure description with baseline photos of building and equipment.
- Estimated EEM capital cost.
- Analysis methodology.
- Energy and demand savings and energy cost savings.
- Effect on operations and maintenance.
- Impacts on building occupants (if any).
- Simple payback period (in years).
- Estimated equipment life (in years).

- Equipment cut sheets indicating which specific equipment is proposed, in case several sizes are included on the same cut sheet.
- Life-cycle cost analysis/parameters.
- Utility tariff impacts.
- M&V plan and instrumentation, if needed.
- Other comments, such as specific training requirements and/or maintenance contracts with specialty measures such as CHP, advanced controls, wind turbines, etc. Explain that lack of training, maintenance and proper operation may impact/reduce the projected savings. If any of the above items necessitate a long description, please provide a brief or reasonable length description in the report and move the details to an appendix. Appendices may also be needed for other long sections such as the analysis, detailed cost estimates, equipment cut sheets, detailed utility tariffs, etc.

F.6 Report Writing and Layout

In the case of a full energy audit, before writing the audit report, know the audience, what the report objectives are, and determine what stays in the body of the report and what goes into the appendix. Some large customers have their own report requirements. The report should be scaled to the cost of the audit.

A three-part training presentation titled *“Introduction to Energy Audits and Relevant Energy Efficiency Topics; what to do before, during and after the energy audit”* is available by contacting the author Khaled Yousef for this guidance document.

F.7 Additional Notes on Energy Audits, Controls, M&V, and Cx

F.7.1 Energy Audits and Controls Related Notes

Performing energy audits at facilities considering biomass heating projects attains multiple benefits. Additional controls and controls integration suggestions are provided below to address numerous issues identified in previous energy audits:

- Control systems are either pneumatic (operated using pressurized air/gas to produce mechanical action) or direct digital controls (DDC) using low voltage electric signals to actuate control devices). Many old/existing buildings still use pneumatics, while most new buildings are primarily DDC. Some of the old facilities have undergone a pneumatic to DDC conversion, sometimes only partially. Although our intention is not to compare overall benefits and drawbacks of the two system types, DDC systems are more accurate than pneumatics. Collecting and storing data from DDC systems is also easier than pneumatics. Therefore, biomass projects are encouraged to adapt DDC controls as much as feasibly possible.

- Buildings with hybrid controls systems comprised of both older pneumatic systems and newer DDC systems use the EP or PE switches (Electric to pneumatic or pneumatic to electric). Switches tend to be unreliable and inaccurate and the mean time between failures tends to decrease with more components, decreasing overall reliability. Reduce intermediate switches or convert to a complete DDC system.
- A full pneumatic to DDC conversion is expensive. Consider converting only the biomass systems, or apportion the cost of the rest of the DDC system separately from the biomass project.
- Despite the above cost concern, it is advisable and less expensive to adapt a comprehensive controls plan than to do it piecemeal. Control specifications should call for oversized control panels that are flexible and expandable so more control points can be easily added as funds become available.
- It is strongly advisable to go with one controls vendor for the entire facility even though most vendors claim to be BACnet or Modbus compatible and capable of communication among controls platforms by different vendors. Programming costs for communication among systems can be high, as can the cost of additional black boxes. One competent controls vendor will maintain consistency and ease of service.
- Budget for operator training covering the EMS controls, operation of the biomass heating system, basic maintenance like ash removal, basic hydronics, and boiler protection training, boiler water treatment, etc.
- M&V Enabled Controls are recommended to control the system from one EMCS.
- Smaller buildings may not even have a pneumatic or DDC system, nor may they have the budget for it. Collect as much data as possible from the boilers' built in microprocessor control package. Couple this data with data from simple wired or wireless loggers for metering flows. Define additional data points as needed for M&V.
- It does not make sense to put in a new boiler (biomass or not) in a building with poor insulation, poor envelope air tightness, poor controls or many system balancing and comfort problems. Fix the building first, then you will end up with a much better, smaller and less expensive boiler. Cut heating loads through low tech improvements such as insulation, air tightness, windows, controls enhancements, etc.
- At times, designers put water circulation pumps on the hot side (leaving the boiler). If possible hydraulically, put the pump on the return side to reduce its exposure to high temperatures. This usually requires a PID review. The return side supports pump longevity and reduced maintenance costs.

F.7.2 Relevant M&V and Cx Notes

- The person in this picture is a lot more important than the computer. No matter how elaborate the EMCS is, it needs capable operators who understand not only the controls, but also the HVAC systems. An EMS that is out of control can cause more damage than manually operated systems,
- Ongoing Cx is important to operation and integration. Review data from an EMS to identify anomalies and update programming to address issues as needed,
- Automated fault diagnosis (ADF) is a semi-automated or fully automated ongoing Cx process. It ensures that success continues. ADF is a new field with M&V.



F.7.3 EMS in Perspective - Scope and Limitations Notes

- EMS systems were originally designed to manage and control the energy systems in a building. They were not necessarily intended for M&V; however, M&V functions can be added.
- Antiquated EMS systems may not have adequate data storage capabilities (e.g. they may only store a week worth of data). If so, add automated external storage capabilities (like a protected hard drive) or consider an interface box that uploads data daily (via cell signal or internet) to a central secure server.
- Losing valuable data and time is a painful and costly experience; ensure a reliable data collection and storage process. Data capture of 95% or greater is desired.

F.7.4 Systems Integration Notes

- Integrating the biomass boiler with the rest of the heating plant ensures that the controls company can be used as a systems integrator. This should be clearly stated in their scope of work, including supervision from the design engineer of record. This will be most successful if the controls company is not promoting one particular product. The controls company must be open to interfacing with other vendors,
- When integrating multiple facilities in a district system, a single controls company is strongly recommended to ease campus wide communication, reduce black boxes, and reduce service call expenditures (because more can be done during one service call),
- Proper system integration paves the way for writing and implementing good sequences of operation for the controls.

F.7.5 Control Sequence of Operation Notes

- One of the most important and often missed elements is a good sequence of operation for the controls. Responsibilities must be clearly defined between the (1) MEP engineer of record, (2) the Project Manager, (3) Chief Architect, (4) the controls vendor/systems integrator, (5) the General Contractor, (6) the Construction Manager, (7) or the Owner who may be distant from the project and/or nontechnical.
- One entity should be responsible for the entire sequence of operations document and full system integration. The owner should require their design team to ensure the controls sequences are written, implemented and commissioned well by the controls vendor/systems integrator. The owner or owner's technical advisor (MEP team or E/A team, or energy engineer) should lead this responsibility.
- Proper sequences of operation for the controls should also be requested in the design documents. They should be planned for, budgeted for properly, maintained well during the course of the project, and during building operation.
- We also recommend proper training to ensure the control system and sequences remain well maintained and updated as the building and system may undergo any changes over the years.
- Suggestion - Bring an engineer with experience writing good sequences of operation. Some say that the good sequences are the original job of the original design engineer, but it is often not done then it becomes shifted to the controls firm and also does not get done.

F.7.6 Putting EMCS vs. Stand-alone Controllers in Perspective - Relevant Reference Notes, Terminology, and Explanations

Applicants have varying levels of controls background and M&V capabilities. Therefore, listed below are a few notes to highlight differences between the following four options:

1. Elaborate energy management and control systems (EMCS).
2. Group of stand-alone microprocessor-based controllers.
3. Using boiler's on-board central processing unit (CPU) to provide some level of data logging.
4. Communication and Interoperability Terminology.

EMCS (Option 1)

In Option 1, using an elaborate EMCS¹⁷ is obviously the ultimate in controls and M&V enabled controls. However, a full blown EMCS presents financial and technical challenges to small buildings and customers with tight budgets, thus stand-alone controller Option 2 becomes more affordable.

Most modern EMCS have built-in monitoring and storage; activating such features must be requested as part of a controls spec. Setting up the trend logging requires some software (and maybe some hardware) to fully benefit from monitoring features.

Stand-alone microprocessor-based controllers (Option 2)

Simpler stand-alone controllers still need to be programmed, interconnected, and commissioned. Here are some comments:

- If you use “**stand-alone microprocessor-based controller**” instead of full blown EMCS systems, ensure they have trend logging capability and/or interconnectivity and interoperability and preferably data archival and remote access capabilities. A higher level of control system may be needed for additional monitoring of more complex control applications.
- Some have LonWorks or BACnet interface to building automation systems through Modbus or Ethernet communication; some have wireless communication capabilities as well.
- Certain specs may mention that the Local Control Interface XYZ is the master controller for the 123 product series. In one single device, it provides an integrated control center for all the HVAC controls and metering on a network. It has a touch screen for onsite configuration and can be remotely accessed and configured over the Internet as well. Controller XYZ is what all of the stand-alone controllers communicate with. Below is a brief description of a master controller and what is expected from it:
 - The XYZ Master Controller is a backlit LCD (or LED) touch screen interface and system configuration tool used to communicate with the individual stand-alone controllers over a LonWorks or BACnet network (or similar). All individual controllers can be completely configured and commissioned through the operator interface.

¹⁷ Recap of common acronyms:

- EMS - Energy Management System,
- EMCS - Energy Management and Control System,
- SCADA - System Control and Data Acquisition,
- EMMCS - Energy Management, Monitoring, and Control System,
- EMS and EMCS acronyms usually used for commercial building applications. SCADA used for industrial, power generation or large central chilled water or heating plant applications. Large industrial/mission critical applications require higher levels of scrutiny, thus data acquisition is an inherent to industrial SCADA.

- The XYZ Master controller fully integrates the HVAC system's individual controllers (this is a very important integration feature). The XYZ Master Controller enables an administrator to add and configure devices on the 123 system and then send the information to the devices over the LonWorks or BACnet network.
- The entire 123 system can be commissioned and modified using the Master Controller touch screen interface. The Master Controller software runs within a Windows CE.net (or similar) operating system and is fully upgradable.
- Such controllers have many features, but ensure you select some that can support your M&V activities, provide remote access, and maintain your system security. Some come with a touch screen interface, some are self-configuring upon connection to the network, or have configurable user interface options, or can view and configure up to 63 controllers (64 - 1 channel reserved for the Master). Other features include Administrator and user level access, Password protection (at multiple levels), Ethernet communications for PC-based configuration, and storage of user configuration data in non-volatile memory (Flash memory) in case of power loss.
- Despite controllers' low voltage, DC and AC power options of 28 to 36 Vdc, or 24 Vac +/- are available. Ensure your selection has battery backup or a UPS to ensure continuity during a power failure. This prevents data loss and eases startup after a power outage.
- Most simple systems use Ethernet (RJ45) connections which are easily commercially available, unless you go completely wireless, which is another option.

Boiler's on-board central processing unit (CPU) (Option 3)

This is briefly discussed in Section 5.1.1 as a simplified means of data collection in small systems < 300,000 Btu/h.

Communication and Interoperability Terminology (Support Option 4)

Some may wonder about the meaning of many of the acronyms like 0-10V, 4-20 MA, LonWorks, BACnet, Modbus, Ethernet, etc. Although we do not intend to cover all controls terminology, below are a few common ones:

- Ensure whichever controls vendor you use is flexible in picking the data points and ensure their controller can take a variety of signals, including but not limited to:
 - 0-10 Volt DC Signal, and/or

- 4-20 Milliamp (MA) Signal.
 - For example, a variable speed drive (or variable frequency drive) should accept a 0-10 V DC or 4-20 MA modulating control signal to control the speed of the circulator motor based on feedback from elsewhere in the heating system loop.
 - Such signal can be used for temperature measurements, pressure transducers, measure status or position of any equipment, etc.
 - For example, a transmitter measures a variable then converts it to a 0-10 VDC or a 4 to 20 MA of proportional output. The range varies in each application. This is applicable to many measurements but is mentioned here in a generic sense in support of building controls and M&V enabled controls.
 - Note that if you use standalone controllers and you need to bring an external data point that is not part of the master controller, you can add it using simple 0-10 V dc or 4-20 MA modulating signals.
 - Additionally, you may also upload any 0-10 V dc or 4-20 MA data to modern biomass boiler control panels. This integrates between external measurements and an existing boiler control panel that can also be used as a data logging and sending unit.
 - As you become more knowledgeable about your control and M&V systems, you may use certain devices as data loggers (boiler controls or master controller) to simplify and streamline your data collection process if the external readings were coming from 0-10 V DC or 4-20 MA signals.
- **Modbus Serial Communication Protocol RS232** (3 wire simple point to point arrangement to connect one device to another less than 50 feet away). However, if you need to connect more than 2 devices on one line with distances exceeding 50 feet up to 4,000 feet, use RS485 (2 wire differential line continuous messages 2-way communication between a single master and multiple slave devices), or RS 422 for **RTU (Remote Terminal Unit)** or communicate using **TCP (Transmission Control Protocol)/IP (Internet Protocol)**.
 - Modbus History: Developed in 1979 to serve industrial systems. Today it is an open protocol, baud rate from 9,600 to 19,600 bps (bits per second). Can have one master and up to 247 slaves on a network each with a unique slave ID from 1 to 247. Repeaters required with > 32 nodes. Daisy Chain connections required and not Star connections. Modbus devices operate over Ethernet cable and switches to communicate with each other. **Modbus TCP/IP devices** use client and server relationships instead of master and slave relationships, must know device IP address, subnet mask and gateway value, all loop like IP addresses and your network administrator can support you in knowing those addresses.
- **BACnet** (A Data Communication Protocol for Building Automation and Control Networks), to provide a method for interoperability among different vendors' equipment and building systems. Offers a common operator interface, reduces training needs and provides flexibility when the system must be expanded.¹⁸

¹⁸ Also frees the building owner from being dependent on one vendor for system expansion. Facilitates that buildings are controlled by one operating system as opposed to three systems.

- BACnet History: Started in 1987 by a group of professionals who wanted controllers and equipment to interoperate and be presented in a network visible way using Ethernet and LAN technologies. ASHRAE's BACnet standard was adapted in 2001 as ISO Standard 16484-5. Maintained by ASHRAE SSPC 135 latest revision entitled ANSI/ASHRAE 135-2010. Makes internal functions of devices network visible, it has 50 predefined devices and it is growing,
- BACnet network supports several network types such as Local Area Networks such as Ethernet, MSTP, LonTalk, ZigBee, etc. Can communicate between different networks for BACnet devices using BACnet routers and BACnet networks. **Gateways** needed to mix BACnet systems with non-compliant protocol like Modbus. **BIBB** (BACnet Interoperability Building Blocks). Who-Is and I-Am relationships:
 - 5 categories of BIBB and interoperability sharing: 1-data sharing, 2-Alarm and event management, 3-scheduling, 4-trending and 5-device and network management.
 - 6 Object Types (1-analog input, 2-analog outputs, 3-analog values, 4-binary inputs, 5-binary outputs and 6-devices).
 - 8 Standard Device Profiles (1 - BACnet Operator Workstation (B-OWS); 2 - BACnet Advanced Operator Workstation (B-AWS); 3 - BACnet Operator Display (B-OD); 4 - BACnet Building Controller (B-BC); 5 - BACnet Advanced Application Controller (B-AAC); 6 - BACnet Application Specific Controller (B-ASC); 7 - BACnet Smart Sensor (B-SS); and 8 - BACnet Smart Actuator (B-SA)).
 - BACnet testing labs needed for compliance and interoperability testing to get BTL labels of the product trademarks.
 - Other terminology 16-bit Registers (inputs and holding), 1-bit coils (input and status), bits and bytes.
 - LonWorks Networking Technology: This is likely the oldest and using the older Ethernet RJ45 connections for interconnectivity and interoperability between smaller and stand-alone microprocessor based controllers as they all interconnect with the master controller. This included digital outputs (DO), analog outputs (AO) as well as analog inputs (AI) and digital inputs (DI). LonWorks (local operating network) is a networking platform specifically created to address the needs of control applications. The platform is built on a protocol created by Echelon Corporation for networking devices over media such as twisted pair, power lines, or fiber optics.

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