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SRI/USEPA-GHG-QAP-34
May, 2005

Test and Quality Assurance Plan

ECR Technologies, Inc.
Earthlinked Ground-Source Heat Pump Water Heating System

Prepared by:

Greenhouse Gas Technology Center
Southern Research Institute

Under a Cooperative Agreement With
U.S. Environmental Protection Agency

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EPA REVIEW NOTICE

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Greenhouse Gas Technology Center

A U.S. EPA Sponsored Environmental Technology Verification (ETV) Organization

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ECR Technologies, Inc.
Earthlinked Ground-Source Heat Pump
Water Heating System

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Test and Quality Assurance Plan
ECR Technologies, Inc.
Earthlinked Ground-Sourced Heat Pump
Water Heating System

This Test and Quality Assurance Plan has been reviewed and approved by the Greenhouse Gas Technology Center Project Manager, Quality Assurance Manager, and Center Director, the U.S. EPA APPCD Project Officer, and the U.S. EPA APPCD Quality Assurance Manager.

Tim Hansen Center Director Greenhouse Gas Technology Center Southern Research Institute	Date	David Kirchgessner APPCD Project Officer U.S. EPA	Date
Bob Richards Project Manager Greenhouse Gas Technology Center Southern Research Institute	Date	Robert Wright APPCD Quality Assurance Manager U.S. EPA	Date
Richard Adamson Quality Assurance Manager Greenhouse Gas Technology Center Southern Research Institute	Date		

Test Plan Final: 04 May 2005

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List of Acronyms and Abbreviations

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
Btu/h	British thermal units per hour
Btu/y	British thermal units per year
CoP	coefficient of performance
DQI	data quality indicator
DQO	data quality objective
DUT	device under test
ETV	Environmental Technology Verification
g/h	grams per hour
gal	gallon
gph	gallons per hour
kW	kilowatt
psia	pounds per square inch, absolute
psig	pounds per square inch, gauge
QA / QC	quality assurance / quality control
SUT	system under test
tpy	tons per year

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1.0 INTRODUCTION

1.1. BACKGROUND

The U.S. Environmental Protection Agency's Office of Research and Development operates the Environmental Technology Verification (ETV) program to facilitate the deployment of innovative technologies. The program's goal is to further environmental protection by accelerating the acceptance and use of these technologies. Primary ETV activities are independent performance verification and information dissemination. Congress funds ETV in response to the belief that many viable environmental technologies exist that are not being used for the lack of credible third-party performance data. With performance data developed under this program, technology buyers, financiers, and permitters will be better equipped to make informed decisions regarding new technology purchases and use.

The Greenhouse Gas Technology Center (GHG Center) is one of several ETV organizations. EPA's ETV partner, Southern Research Institute (Southern), manages the GHG Center. The GHG Center conducts independent verification of promising GHG mitigation and monitoring technologies. It develops verification Test and Quality Assurance Plans (test plans), conducts field tests, collects and interprets field and other data, obtains independent peer-review input, reports findings, and publicizes verifications through numerous outreach efforts. The GHG Center conducts verifications according to the externally reviewed test plans and recognized quality assurance / quality control (QA / QC) protocols.

Volunteer stakeholder groups guide the GHG Center's ETV activities. These stakeholders advise on appropriate technologies for testing, help disseminate results, and review test plans and reports. National and international environmental policy, technology, and regulatory experts participate in the GHG Center's Executive Stakeholder Group. The group includes industry trade organizations, environmental technology finance groups, governmental organizations, and other interested parties. Industry-specific stakeholders provide testing strategy guidance within their expertise and peer-review key documents prepared by the GHG Center.

GHG Center stakeholders are particularly interested in building heating and cooling technologies with the potential to improve efficiency and reduce concomitant GHG and criteria pollutant emissions. The Energy Information Administration reports that in 1999 approximately 3.1 million commercial facilities in the U.S. consumed about 4.8×10^{12} British thermal units per year (Btu/y). The portion of this energy consumption that is attributable to water heating varies significantly by facility type, but it averages about 11 %, or 5.3×10^{11} Btu/y.

ECR Technologies, Inc. (ECR) has addressed this issue with their EarthLinked water heating system. The system incorporates a ground-sourced heat pump into a building's water heating system. ECR states that the EarthLinked system may provide up to 70 % reduction in power consumption when compared to electric water heating systems of equivalent capacity. This reduced energy consumption would also reduce emissions from the electric power system's generators or natural gas combustion in direct-fired systems. Broad utilization of such technologies could have a significant beneficial impact on GHG and pollutant emissions.

This verification is intended to quantify the EarthLinked system's performance as installed in a commercial setting with credible measurement procedures and analysis techniques. It will assess performance parameters of interest to potential water heater purchasers, users, regulatory bodies, the

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public, and other stakeholders. This test plan discusses the EarthLinked heat pump as the device under test (DUT). Its integration into the "real world" host facility is known as the system under test (SUT).

This test plan explicitly describes test equipment and procedures or by reference to existing American National Standards Institute (ANSI) or American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standards. The following sections discuss the verification approach and specify QA / QC procedures approved by independent reviewers.

1.2. EARTHLINKED TECHNOLOGY DESCRIPTION

The EarthLinked system consists of two or more 50- or 100-foot copper refrigerant loops installed in the ground, a compressor, a heat exchanger, refrigerant liquid flow controls, and an active charge control refrigerant reservoir. The EarthLinked system is unique because it circulates non-ozone depleting refrigerant (R-407c, R-134a) through the copper earth loops. Other ground-source heat pumps circulate either water or an antifreeze solution through plastic earth loops and then to a refrigerant heat exchanger. The EarthLinked system's direct heat transfer from the refrigerant to the earth improves efficiency.

The liquid refrigerant absorbs heat from the ground, which is typically at a constant temperature year round (45-80 ºF, depending on location), and vaporizes. A compressor raises the refrigerant pressure and routes it to a heat exchanger. There, the vapor condenses and yields the latent heat of vaporization to domestic water circulating through a heat exchanger. Refrigerant is then returned to the earth loops via a patented refrigerant flow control device.

As installed at the test facility, this system preheats water in a commercial 120-gallon storage tank. The preheated water transfers to a second commercial water heater which brings it to the required 130 ^{o}F temperature.

The EarthLinked system consumes power in the compressor and hot water circulation pump, and has no direct emissions. ECR states that typical EarthLinked heating systems will initially be focused on small commercial applications, such as restaurants and laundries.

1.3. HOST FACILITY DESCRIPTION

The Lake Towers Retirement Community, located in Sun City Center, FL, will serve as the host facility. Tests will occur at the Sun Terrace, a one-story building with two residential wings for assisted living. Each wing has 15 rooms, each with a small vanity sink. Other domestic hot water (DHW) uses include two shower rooms, two utility closets, four nurses' stations, and a kitchen.

The facility's DHW source consists of two 15 kilowatt (kW), 480 V electric water heaters. Valves and piping allow each tank to operate individually or in series. Each tank has sufficient capacity to serve the facility by itself. Tank #1 can be heated either by the EarthLinked system or its electric elements. Cold city water enters Tank #1 for the initial heating cycle. The EarthLinked system operates most efficiently when heating cold water, so this configuration is optimal.

As the facility consumes DHW, the heated water transfers to Tank #2. A recirculation pump cycles hot water from Tank #2 through the building's DHW piping and back to Tank #2. This tank maintains the water temperature with its electric elements and the circulation ensures the immediate availability of hot water at each tap.

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1.4. VERIFICATION PARAMETERS

A series of short-term tests and long-term monitoring will determine the performance of the EarthLinked system as compared to the baseline electric resistance-type hot water heater. Industry-accepted ANSI / ASHRAE heat pump water heater test methods [1] will form the basis for the short-term tests. Short-term test verification parameters are:

- water heating capacity at low and elevated temperatures, British thermal units per hour (Btu/h)
- DUT coefficient of performance (CoP) at low and elevated temperatures, dimensionless
- standby heat loss rate, Btu/h, and standby energy consumption, kW, while operating with EarthLinked system at 120 ± 5 ^{o}F

Long-term monitoring will determine the SUT performance in normal daily use. Long-term verification parameters are:

- difference between SUT electrical power consumption with and without the EarthLinked system, kW
- estimated EarthLinked CO, CO_2, and NO_X emission changes as compared to the baseline electric water heater, grams per hour (g/h) or tons per year (tpy)
- estimated simple cost savings based on the price of electricity saved

1.5. PROJECT ORGANIZATION

Figure 1-1 presents the project organization chart.

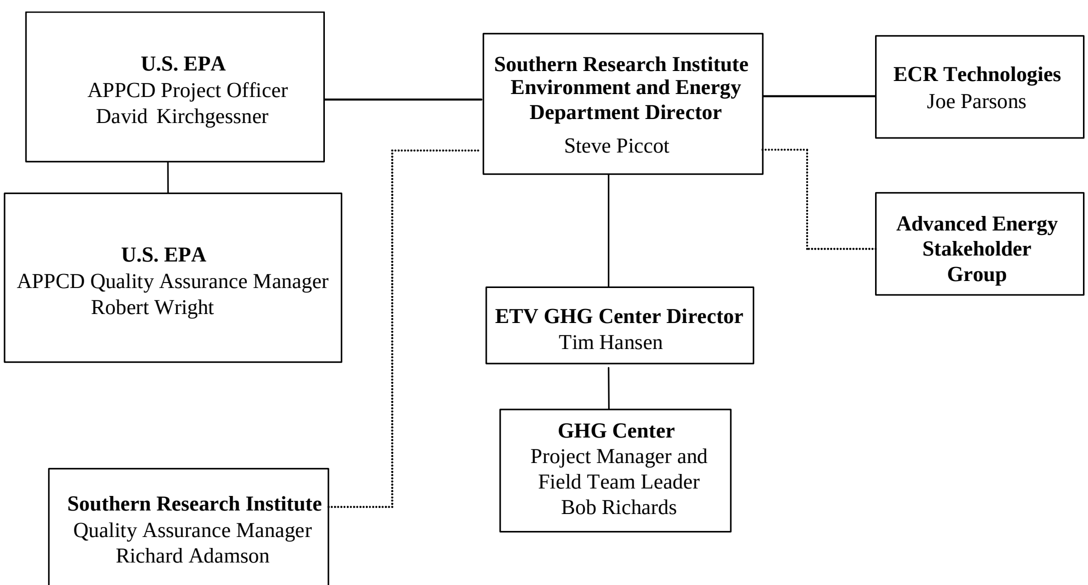

Figure 1-1. Project Organization

The GHG Center has overall verification planning and implementation responsibility. The GHG Center will coordinate all participants' activities; develop, monitor, and manage schedules; and ensure the acquisition and reporting of data consistent with the strategies in this test plan. The GHG Center Director, Mr. Tim Hansen, will:

- review the test plan and report for consistency with ETV operating principles
- allocate appropriate resources for the verification
- oversee GHG Center staff activities

Mr. Joe Parsons of ECR is the technology developer's primary point of contact. He or his designee will:

- review the test plan and report with respect to accuracy in the technology description and its application
- coordinate ECR's installation of the EarthLinked system, plumbing, fittings, or other permanent equipment that will remain at the site
- coordinate weekly operations during the long-term monitoring period

The GHG Center project manager, Mr. Bob Richards, will:

- coordinate the test plan, report, and Verification Statement writing and review process
- oversee the field team leader's activities
- ensure collection, analysis, and reporting of high-quality data and achievement of all data quality objectives (DQO)s
- maintain communications with all test participants
- perform budgetary and scheduling review

The project manager will have authority to suspend testing for health and safety reasons or if the QA/QC goals presented in Section 3.0 are not being met.

Mr. Richards will also serve as the field team leader and will supervise all field operations. He will assess data quality and will have the authority to repeat tests as deemed necessary to ensure achievement of data quality goals. He will:

- coordinate the installation of required plumbing fittings with ECR
- supervise and coordinate subcontractor activities
- install and remove temporary power- and water-metering equipment
- operate the water heater controls during the short-term tests
- collect interim test data for use in consultations with the project manager
- download data during the long term monitoring period
- perform other QA / QC procedures as described in Section 3.0

The field team leader will communicate test results to the project manager for review during the course of testing. The field team leader and project manager will collaborate on all major project decisions including the need for further test runs or corrective actions.

The GHG Center QA manager, Mr. Richard Adamson, or his designee will review this test plan. He will independently reconcile the measurement results with the data quality objectives as part of a planned audit of data quality. He will also review the verification test results, report, and conduct the audit of data quality described in Section 4.0. The QA manager will report all internal audit and corrective action results directly to the GHG Center Director who will provide copies to the project manager for inclusion in the report.

EPA's Office of Research and Development will provide oversight and QA support for this verification. The Air Pollution Prevention and Control Division project officer, Dr. David Kirchgessner, and QA manager, Mr. Robert Wright, will review and approve the test plan and report to ensure that they meet

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EPA QA goals and represent sound scientific principles. Dr. Kirchgessner will be responsible for obtaining final test plan and report approvals.

1.6. SCHEDULE

The tentative schedule of activities for the ECR EarthLinked ground source heat pump water heater verification test is:

Verification Test Plan Milestones	**Dates**
GHG Center internal draft development	20 Dec. 2004 - 15 Apr. 2005
ECR review	18 Apr. 2005 - 27 Apr. 2005
Industry peer review and plan revision	29 Apr. 2005 - 06 May. 2005
EPA review	09 May 2005 - 23 May 2005
Final test plan posted	23 May 2005
Verification Testing and Analysis Milestones	
Short term testing	23 May 2005 - 27 May 2005
Long term testing	28 May 2005 - 24 Jun. 2005
Verification Report Milestones	
GHG Center internal draft development	6 Jul. 2005 - 29 Jul. 2005
ECR review	01 Aug. 2005 - 15 Aug. 2005
Industry peer review and report revision	22 Aug. 2005 - 06 Sep. 2005
EPA review	09 Sep. 2005 - 23 Sep. 2005
Final report posted	30 Sep. 2005

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2.0 VERIFICATION APPROACH

This section describes the GHG Center's verification approach, the test design, data collection, and analytical methods. The testing procedures and nomenclature generally conform to those provided in ANSI / ASHRAE Standard 118.1-2003 [1] for testing "Type V" heat pump water heaters. The following subsections discuss test methods in detail and note any exceptions to the ANSI / ASHRAE specifications.

2.1. TEST DESIGN

The GHG Center will first conduct a series of short-term tests to determine the DUT performance. ECR will install the EarthLinked system on Tank #1, with provisions to operate either the tank's electric heating elements or the EarthLinked system. GHG Center test personnel will isolate Tank #1 from the facility's DHW system during the short-term tests; the building will operate on Tank #2 during this period.

The short-term tests will determine:

- DUT water heating capacity while raising the lowest achievable city water temperature (likely to be approximately 72 ^{o}F in Florida in June) 20 ^{o}F or to whatever temperature can be achieved over a 60-minute period, whichever occurs first, Btu/h
- DUT water heating capacity while raising the water temperature from 110 to 130 ^{o}F or over a 60-minute period (whichever occurs first), Btu/h
- CoP at the lower and elevated temperatures, dimensionless
- DUT standby heat loss rate, Btu/h and standby energy consumption, kW, at 120 ^{o}F

At the conclusion of the short-term series, test personnel will configure the SUT for normal operations such that Tank #1 initially heats incoming city water while Tank #2 maintains the circulating water temperature. Test personnel will install a second power meter on Tank #2 to monitor its power consumption.

Long-term monitoring will begin with the Tank #1 heating elements operating for one week while the EarthLinked system is disabled. The second week, ECR operators will set the controls so that the EarthLinked system provides Tank #1 water heating service. Test personnel will download the data by telephone, and this pattern will be repeated for at least four weeks.

Long-term monitoring results will allow assessment of:

- difference between SUT electrical power consumption with and without the EarthLinked system, kW
- estimated EarthLinked CO, CO_2, and NO_X emission changes as compared to the baseline electric water heater, g/h or tpy
- estimated simple cost savings based on the price of electricity saved

2.2. INSTRUMENTATION

Figure 2-1 shows the water piping schematic diagram and the proposed test instrument locations. Figure 2-2 depicts the electrical wiring schematic and the power meter locations.

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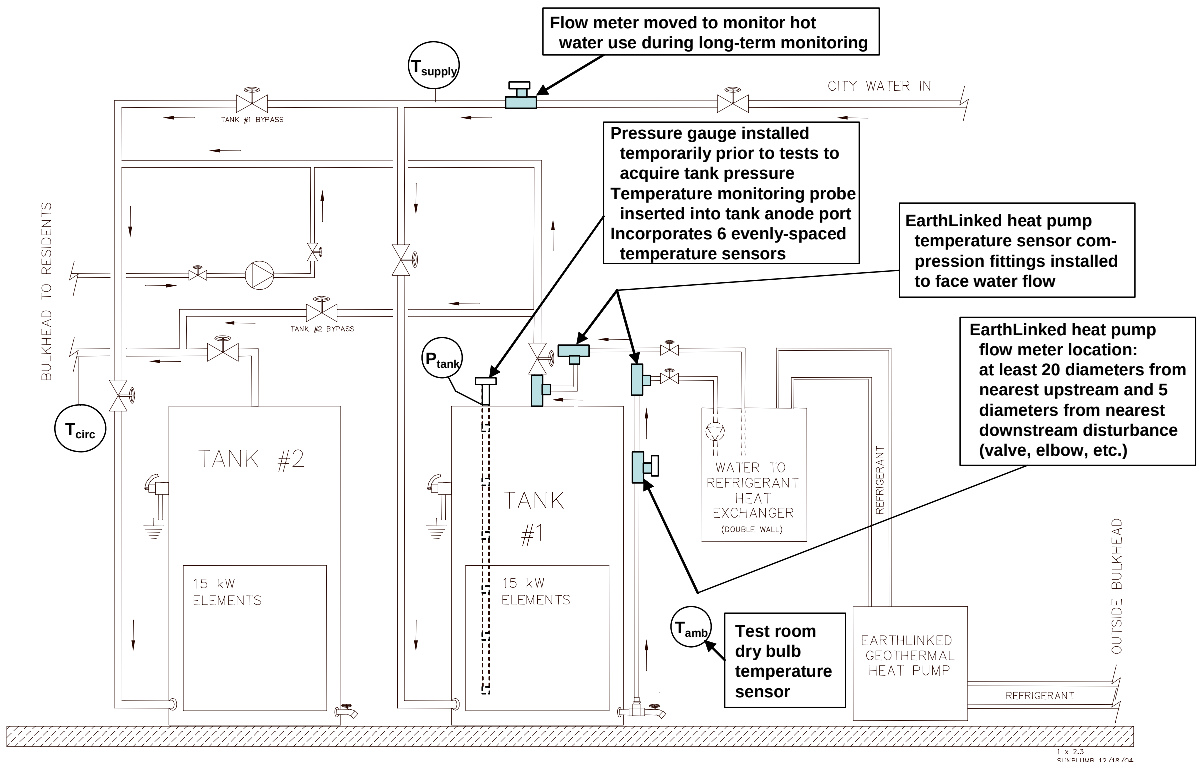

Figure 2-1. Plumbing Schematic and Sensor Locations

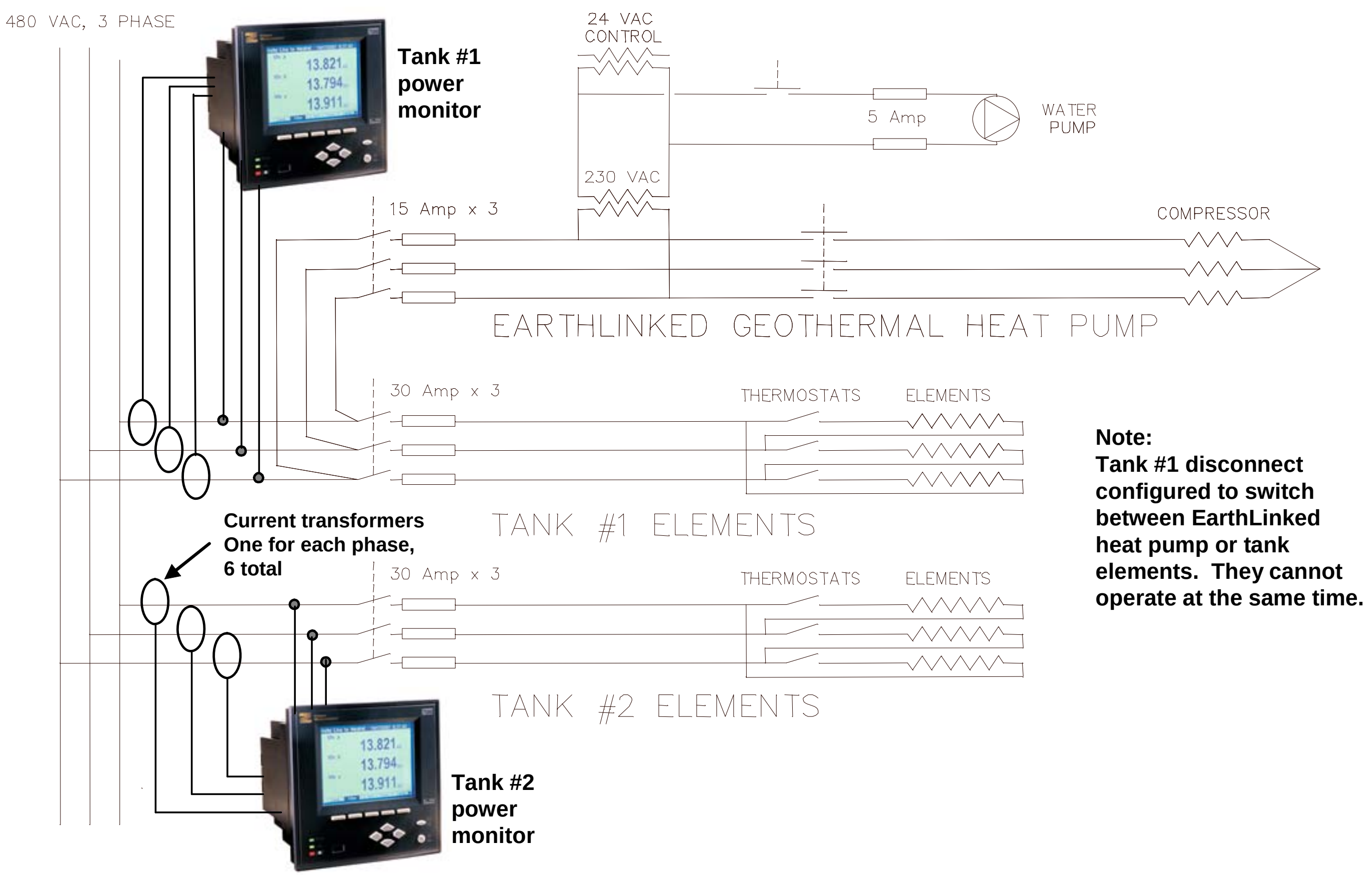

Figure 2-2. Electrical Schematic and Power Meter Locations

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2.2.1. EarthLinked and City Water Flow Meter

Water flow determinations to and from the EarthLinked system, combined with its inlet and outlet temperature difference, will allow an independent calculation of the heating effect (see Section 3.2). The ANSI / ASHRAE accuracy specification for flow rates is ± 1.0 %.

This verification will employ an Omega Model FTB-909 flow meter installed as shown in Figure 2-1. An Omega Model FSLC-64 transmitter will condition the flow meter's pulse output. An Agilent / HP Model 34970A will totalize and log the pulse output. Accuracy of this system will be ± 0.5 % of reading. The nominal K factor for the flow meter is 322 pulses per gallon, but a pretest calibration will document actual average K factor.

Note that test personnel will relocate the flow meter to the city water supply line at the beginning of the long term monitoring period (see Figure 2-1). This will allow normalization of the varying hot water use rates throughout the period (see Section 2.3.5).

2.2.2. EarthLinked Inlet and Outlet Temperature

The Type V (tank incorporated) verses Type IV (tankless) water heater QA / QC crosscheck discussed in Section 3.2 requires EarthLinked inlet and outlet temperatures. The ANSI / ASHRAE accuracy specification for the Type IV heat pump inlet and outlet temperature difference is ± 0.2 ^{o}F. This verification will employ Class A 4-wire platinum resistance temperature detectors (RTD) whose specified accuracy, including the Agilent / HP Model 34970A datalogger, is ± 0.6 ^{o}F. This means that the combined accuracy for temperature difference will be ± 0.8 ^{o}F, based on the specifications. While this combined accuracy does not meet the method specifications for Type IV water heaters, it is sufficient for the QA / QC check. The GHG Center will perform pretest calibrations and it is likely that an RTD pair will be available whose combined accuracy is better than ± 0.8 ^{o}F. Also, analysts will account for and report the achieved accuracy and its potential effects on the results.

Test personnel will install the direct immersion-type RTDs through compression fittings located as shown in Figure 2-1.

2.2.3. Hot Water System Supply and Circulating Water Temperatures

These sensors will contribute to system diagnostics and data normalization during the long term monitoring period. They will consist of externally-mounted Class A 2-wire RTDs wrapped with insulation. Accuracy for the expected operating range is ± 1.4 ^{o}F.

2.2.4. Tank #1 Temperature and System Pressure

The datalogger will record Tank #1 temperatures from a probe inserted through one of the anode fittings located in the tank's top. Test personnel will temporarily remove the anode to allow probe access. The temperature probe will incorporate 6 Class A 4-wire RTDs spaced throughout its length such that the tank is divided into 6 equal portions from top to bottom.

The ANSI / ASHRAE accuracy specification for water temperature is ± 2 ^{o}F. RTD specified accuracy will be ± 0.6 ^{o}F.

Determination of the water specific volume (see Sections 2.3.4, Eqn. 2-4 and 3.2, Eqn. 3-1) requires the water pressure in pounds per square inch, absolute (psia). Test personnel will acquire the system gage pressure, psig, by temporarily installing a Bourdon-type pressure gauge in the tank's anode fitting prior to testing. They will obtain local ambient pressure from a climbing altimeter or the barometric pressure as corrected for altitude. The ANSI / ASHRAE method has no specification for this measurement, but the bourdon gauge will be accurate to ± 3 % or better.

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2.2.5. Test Room Dry Bulb Temperature

The datalogger will record the test room dry bulb temperature from a single Class A 4-wire RTD located at head height. The ANSI / ASHRAE accuracy specification for air temperature is ± 1 ^{o}F. RTD specified accuracy will be ± 0.6 ^{o}F.

2.2.6. Power Consumption

The ANSI / ASHRAE accuracy specification for the power sensor (kW) is ± 1.0 %.

Power Measurements ION 7500 / 7600 power meters will record real power consumption at Tank #1 and Tank #2 Power meter accuracy is ± 0.15 %. Test personnel will install 0.3 % metering accuracy class current transformers (CTs) on each phase conductor. The combined kW accuracy will be ± 0.3 % of reading.

2.3. TEST PROCEDURES AND ANALYSIS

Sections 2.3.1 through 2.3.4 discuss the short-term test procedures and analyses while long term monitoring appears in Section 2.3.5. Note that nomenclature and equation symbols generally conform to those cited in ANSI / ASHRAE Standard 118.1 [1].

2.3.1. Water Heating Capacity and CoP Test Procedures

Test personnel will first perform the ANSI / ASHRAE water heating capacity and CoP tests for Type V heat pump water heaters. Tests will incorporate at least 3 valid test runs at low and elevated temperatures, or 6 total.

1. Adjust supply and bypass valves for building DHW supply from Tank #2 and to isolate Tank #1.
2. Disconnect Tank #1 power, relieve the tank pressure, remove the protective anode on top of the tank, and install the pressure gauge.
3. Restore the system pressure and record the pressure gauge reading as the system pressure.
4. Relieve the tank pressure, remove the gauge, and install the Tank #1 temperature probe.
5. Drain the tank completely, and refill with the coldest possible city water.
6. Enable and verify data logging. The ION power meters will acquire kW data at 1-second intervals; compute and log 1-minute averages. The Agilent datalogger will acquire all temperatures at 5-second intervals; a laptop computer will calculate and log 1-minute averages.

7. Disable Tank #1 heating elements, record the mean tank temperature, T_{mh0} (the average of the 6 internal tank temperatures), and enable the EarthLinked system. Note that all manual field records (except for the system pressure recorded in Step #3) serve as diagnostic tools and start / stop signals only. Analysts will calculate reported test results from the datalogger files after tests are completed.
8. Continue the test until T_{mh} has increased by 20 °F or until 60 minutes have elapsed. Record the final mean tank temperature, T_{mhf}, and actual elapsed time (to the second) for the final T_{mhf} reading.
9. Perform the Type V vs. Type IV water heater cross check as outlined in Appendix A-2.
10. Repeat steps 5 through 8 until three valid test runs are completed.
11. Raise the mean Tank #1 temperature, either with the heat pump or heating elements, to 110 °F.
12. Enable and verify data logging.
13. Disable Tank #1 heating elements, record the initial mean tank temperature, T_{mh0}, and enable the EarthLinked system.
14. Continue the test until T_{mh} has increased by 20 °F or until 60 minutes have elapsed. Record the final mean tank temperature, T_{mhf}, and actual elapsed time (to the second) for the final T_{mhf} reading.
15. Admit cold water into the tank while discharging heated water until T_{mh} is less than 110 °F. Raise the mean tank temperature back to 110 °F.
16. Repeat steps 11 through 14 until three valid test runs are completed at the elevated temperature.
17. Acquire DUT and test facility data as noted in Appendix A-3.
18. Relocate flow meter for long term monitoring.
19. Configure valves and electric power controls for the first long term monitoring cycle. Note the date, start time, and configuration on the form in Appendix A-2.

2.3.2. Water Heating Capacity Data Analysis

Water heating capacity (§ 10.3.2 of [1]) is:

$$Q_h = \frac{V * \left(\frac{C_p}{C_{fg} * v} \right) * \left(T_{mhf} - T_{mh0} \right)}{\left(t_{fh} - t_{0h} \right)} + Q_{hs} \qquad \text{Eqn. 2-1}$$

where:

Q_h = Water heating capacity, Btu/h
V = Storage tank capacity, gal (116.3 for this test series)
C_p = Specific heat of water at the mean of T_{mhf} and T_{mh0} (from [2]), Btu/lb.°F
C_{fg} = Volume conversion factor, 7.48055 gal/ft^3
v = Specific volume of water at the mean system pressure (from [3]), ft^3/lb
T_{mhf} = Final mean tank temperature (as the average of all 6 in-tank sensors), °F
T_{mh0} = Initial mean tank temperature (as the average of all 6 in-tank sensors), °F
t_{fh} = Final time stamp, h
t_{0h} = Initial time stamp, h
Q_{hs} = Mean storage tank heat loss rate as calculated in Section 2.2.4, Btu/h or as estimated from manufacturer's data (341.2 Btu/h for this test series)

Electric power usage is:

$$Q_{he} = \frac{C_{ge} * (Z_h)}{\left(t_{fh} - t_{0h} \right)} \qquad \text{Eqn. 2-2.}$$

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where:

Q_{he} = Electric power consumption as Btu/h
C_{ge} = Power conversion factor, 3412 Btu/kWh
Z_h = Electric energy consumption, kWh

Note that Z_h will consist of the individual 1-minute average kW readings, summed over the test run, and normalized to a 60-minute mean. For example, if each 1-minute average is 0.134 kW, and the test run is 48 minutes long, the summed values would be 6.432 kW over 48 minutes. This is equivalent to 8.04 kWh.

CoP is:

$$CoP_h = \frac{Q_h}{Q_{he}} \qquad \text{Eqn. 2-3.}$$

Analysts will calculate water heating capacity, electric power consumption, and CoP separately for each test run. The report will cite the lower and elevated temperature results as the mean and sample standard deviation for each set of three test runs at the lower and elevated temperatures, respectively.

2.3.3. Standby Heat Loss Test Procedure

Test personnel will conduct 3 standby heat loss test runs immediately following the last water heating capacity test run. Note that the ANSI / ASHRAE method specifies that the test room dry-bulb temperature must be regulated at 75 ± 1 ^oF. This will not be possible at the host facility, but testers will acquire and report test room temperatures and the data analysis will allow for different temperatures.

1. Enable datalogging and adjust the EarthLinked system controls to bring the mean tank temperature to 120 ^oF.
2. Verify that the EarthLinked system cycles off at the selected temperature and that the datalogger is operating properly.
3. Monitor the collected data for one complete cooling and heating cycle. The EarthLinked system must cycle on as the tank cools and off as it achieves its setpoint in accordance with the manufacturer's control algorithm. Continue monitoring for at least three full cooling and heating cycles.

2.3.4. Standby Heat Loss Analysis

The datalogger record will include the 1-minute mean tank temperatures (as the average of all six in-tank temperature sensors), test room temperatures, and power consumption rates. The tank heat loss parameter for each complete cooling / heating cycle is:

$$L_{hs} = \frac{\ln\left(\frac{T_{mhsf} - T_{ahsf}}{T_{mhs0} - T_{ahs0}}\right) * V * \frac{C_p}{C_{fg} * v}}{\left(t_{fhs} - t_{0hs}\right)} \qquad \text{Eqn. 2-4}$$

where:

L_{hs} = Heat loss parameter, Btu/h.^oF

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T_{mhsf} = Final mean tank temperature (as the average of all 6 in-tank sensors), ^oF
T_{ahsf} = Final test room dry bulb temperature, ^oF
T_{mhs0} = Initial mean tank temperature (as the average of all 6 in-tank sensors), ^oF
T_{ahs0} = Initial test room dry bulb temperature, ^oF
V = Storage tank capacity, gal
C_p = Specific heat of water at the mean of T_{mhf} and T_{mh0} (from [2]), Btu/lb.^oF
C_{fg} = Volume conversion factor, 7.48055 gal/ft^3
v = Specific volume of water at the mean of T_{mhf} and T_{mh0} (from [3]), ft^3/lb
t_{fhs} = Final time stamp for the individual cooling / heating cycle, h
t_{0hs} = Initial time stamp for the individual cooling / heating cycle, h

Analysts will calculate the mean heat loss parameter as the average of the 3 individual results from the monitored cooling / heating cycles.

The tank's heat loss rate (used in Eqn. 2-1) is:

$$Q_{hs} = L_{hs,mean} * \frac{(T_{mh0} - T_{ah0}) + (T_{mhf} - T_{ahf})}{2} \qquad \text{Eqn. 2-5}$$

where:

Q_{hs} = Heat loss rate, Btu/h
$L_{hs,mean}$ = Mean heat loss parameter, Btu/h.^oF
T_{mh0} = Initial mean tank temperature (as the average of all 6 in-tank sensors), ^oF
T_{ah0} = Initial test room dry bulb temperature, ^oF
T_{mhf} = Final mean tank temperature (as the average of all 6 in-tank sensors), ^oF
T_{ahf} = Final test room dry bulb temperature, ^oF

2.3.5. Long Term Monitoring Procedures and Analysis

During the long-term monitoring period, the two power meters will monitor electricity consumption for both tanks. System operators will alternate between EarthLinked and resistive element heating at Tank #1 on a weekly schedule for at least 4 weeks.

Analysts will report Tank #1 power consumption separately as overall mean real power consumption while operating from the EarthLinked system and from the heating elements. They will also report Tank #2 power consumption as it maintains the circulating water temperature. This will allow an assessment of the heating power consumed by the Tank #2 circulating flow.

The difference between SUT electrical power consumption with and without the EarthLinked system will be:

$$\Delta Z_{kW} = Z_{kW,EarthLinked} - Z_{kW,elements} \qquad \text{Eqn. 2-6}$$

where:

ΔZ_{kw} = Change in electrical power consumption, kW
$Z_{kW,EarthLinked}$ = Mean power consumption, both tanks, during EarthLinked operations, kW
$Z_{kW,elements}$ = Mean power consumption, both tanks, during resistive element heating, kW

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Mean real power consumption (Z_{kW}) for each tank will be the sum of the one-minute average kW divided by the number of minutes during each monitoring cycle.

Analysts will also calculate power consumption for each tank, normalized to the hot water used and the temperature rise during each long-term cycle. This will be:

$$Q_{normalized} = \frac{\sum_{1}^{n} \frac{Z_{kW}}{FR_{City} * 0.01667 * \Delta T_a}}{n} \qquad \text{Eqn. 2-7}$$

Where:

$Q_{normalized}$ = Normalized power consumption for Tank a, kW/gal.^{o}F
n = Number of minutes in the monitoring period
Z_{kW} = Sum of Tank #1 and Tank #2 mean electric power consumption for each minute, kW
FR_{City} = Mean city water flow rate for each minute, gph
0.01667 = hours per minute
ΔT = Tank #1 temperature rise for each minute, ^{o}F

Note that ΔT is the difference between the mean of the Tank #1 six in-tank temperature sensors and T_{supply} (see Figure 2-1).

Appendix B provides the procedure for estimating emission reductions. The procedure correlates the estimated annual electricity savings in MWh with Florida and nationwide electric power system emission rates in lb/MWh. For this verification, analysts will assume that the EarthLinked system operates continuously throughout the year with the electric power savings as measured during the long-term monitoring period.

Appendix C provides the procedure for estimating simple cost savings based on the Florida and nationwide prices for retail electricity at “commercial” rates. Similar to emissions reductions, analysts will assume that the EarthLinked system operates continuously throughout the year with the electric power savings as measured during the long-term monitoring period. The EarthLinked system does not use auxiliary fuel, nor is it intended as a power source, so their potential costs or revenues need not be considered for this verification.

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3.0 DATA QUALITY

3.1. DATA QUALITY OBJECTIVE

The GHG Center selects test methods and instruments for all verifications to ensure a stated level of data quality in the reported results. The data quality objectives (DQOs) are based on the GHG Center's stakeholder guidelines, measurement accuracies achieved during previous verifications, test method, and instrument specifications. The resulting DQOs for the short-term tests and long-term monitoring are:

- determine EarthLinked water heating capacity and CoP to within ± 5 %
- determine the power consumed by the baseline and EarthLinked systems (during long-term monitoring) to within ± 0.4 %

Each test measurement contributes to the verification parameters according to the equations in Sections 2.3.2 through 2.3.4. Each measurement is linked to accuracy specifications, or data quality indicator (DQI) goals which, if met, ensure achievement of the DQOs. The accuracy specifications quoted below, compounded through the applicable equations according to standard root-mean-square techniques, are the source of the DQOs. Reference [4] provides examples of compounded accuracy derivations.

The project manager will calculate and report the achieved DQO based on the actual instrument and measurement accuracies, as documented by specific instrument calibrations, manufacturer certifications, etc.

3.2. INSTRUMENT SPECIFICATIONS, CALIBRATIONS, AND QA/QC CHECKS

Table 3-1 lists the instruments to be used in this verification test, their expected operating ranges, and accuracies or DQI goals.

Table 3-1. Instrument and Accuracy Specifications

Measurement Variable	Expected Operating Range	Instrument Mfg., Model, Type	Instrument Range	Measurement Frequency	Accuracy Specification[a]	How Verified / Determined
EarthLinked system water flow	10 gpm	Omega FTB-905 turbine	3 - 29 gpm	Every 5 seconds, record 1-minute averages	± 0.5 %	NIST-traceable calibration within 2 years
EarthLinked system water inlet, outlet temperatures	70 - 140 °F	Omega or Controlotron 4-wire RTD	0 - 250 °F		± 0.6 °F	
Tank #1 temperatures						
Test room temperature	60 - 90 °F					
System pressure	20 - 40 psig	Ametek fluid-filled Bourdon gauge	0 - 60 psig	Beginning of tests	± 3 %	
Tank #1 kW	0 - 15 kW	Power Measurements ION 7500	0 - 125 kW	Every second, record 1-minute averages	± 0.15 %	NIST-traceable calibration within 6 years; pretest crosscheck
Tank #2 kW		Power Measurements ION 7600				

Table 3-1. Instrument and Accuracy Specifications						
Measurement Variable	**Expected Operating Range**	**Instrument Mfg., Model, Type**	**Instrument Range**	**Measurement Frequency**	**Accuracy Specifica-tion[a]**	**How Verified / Determined**
Current trans-formers (for kW)	0 - 18 A	Flex-Core Model 191-151 metering class	0 - 150 A		± 0.3 %	Manufacturer's certificate
Tank #1 volume, gal	120, nominal	Note: Tank volume measured during original fabrication			± 3.3 %	Gravimetrically as part of statistical process control
[a]Accuracy is % of reading unless stated as absolute units.						

Table 3-2 summarizes QA / QC checks which the field team leader will perform before and during the short-term tests. These checks are intended only as field diagnostics. This is because, if the instruments function in the field as they did in the laboratory, it is reasonable to expect that calibration and accuracy specifications have not changed.

Table 3-2. QA / QC Checks				
System or Parameter	**QA / QC Check**	**When Performed**	**Expected or Allowable Result**	**Response**
EarthLinked system flow rate	Zero check[a]	Immediately prior to first test run	0 gpm	Troubleshoot and repair sensors
	Full flow check[a]		9 - 11 gpm	Consult with EarthLinked representative
Tank #1 and Tank #2 real power consumption	Voltage and current field reasonableness checks with Fluke 335 clamp meter	Prior to testing	Voltage within ± 2 % Current within ± 3 %	Troubleshoot and repair sensors
	Laboratory cross checks between power meters		kW readings within ± 1 % of each other	
Temperature sensors	Ambient cross check	Prior to installation	All within ± 1.5 °F of each other	
Water heating capacity	Cross check between Type V (tank) and Type IV (flow) test methods[a]	After each short-term test run	Result within ± 6.4 % of each other	Troubleshoot and repeat the test run
[a]Procedure provided in Appendix A-2				

This verification is based on the ANSI / ASHRAE test method for Type V heat pump water heaters which incorporate a storage tank. Testers will, however, collect sufficient data to quantify the water heating performance for Type IV systems, or as if it did not have a storage tank. While the Type IV determination's accuracy will not meet the ANSI / ASHRAE test specifications, the results will serve as a cross check against the Type V determinations. Analysts will calculate the Type IV performance for each minute during the tests as:

$$Q_{hm} = FR_{hn} * 60 * \left(T_{ohn} - T_{ihn}\right) * \frac{C_p}{C_{fg} * v} \qquad \text{Eqn. 3-1}$$

where:

Q_{hm} = Heat capacity for minute m, Btu/h
FR_{hn} = EarthLinked water flow rate during minute m, gpm
T_{ohn} = EarthLinked outlet temperature during minute m, °F
T_{ihn} = EarthLinked inlet temperature during minute m, °F
C_p = Specific heat of water at the mean of T_{ohn} and T_{ihn} (from [2]), Btu/lb.°F
C_{fg} = Volume conversion factor, 7.48055 gal/ft^3

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v = Specific volume of water at the mean system pressure (from [3]), ft^3/lb

The mean water heating capacity for each test run will be:

$$Q_h = \frac{\sum_{1}^{n} Q_{hm}}{n} \qquad \text{Eqn. 3-2}$$

where:

Q_h = Mean water heating capacity, Btu/h
n = number of minutes in the short-term test run under consideration

Analysts will consider the test run results calculated according to Section 2.3.2 to be valid if they are within ± 6.5 % of the results calculated here.

3.3. INSTRUMENT TESTING, INSPECTION, AND MAINTENANCE

Test personnel will assemble and commission all equipment as anticipated to be used in the field prior to departure. They will, for example, assemble the Tank #1 temperature probe and ensure that all temperature sensors provide values within ± 1 ^{o}F prior to departure. Any faulty sub-components will be repaired or replaced before starting the verification tests. Test personnel will maintain a small supply of consumables and frequently needed spare parts at the test facility. The field team leader or project manager will handle major sub-component failures on a case-by-case basis such as by renting replacement equipment or buying replacement parts. In accordance with the GHG Center Quality Management Plan, test personnel will subject all test equipment to the QA / QC checks discussed earlier prior to demobilization.

3.4. INSPECTION AND ACCEPTANCE OF SUPPLIES AND CONSUMABLES

Test personnel will inspect all test equipment and evaluate its conformance to the specifications above prior to acceptance. The field team leader will maintain copies of NIST-traceable calibration certificates, records of QA / QC checks, and other information.

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4.0 DATA ACQUISITION, VALIDATION, AND REPORTING

4.1. DATA ACQUISITION AND DOCUMENTATION

Test personnel will acquire the following electronic data and generate the following documentation during the verification:

Electronic Data

The ION 7500 and 7600 power meters will poll their sensors once per second. They will then calculate and record one-minute averages throughout all tests. The field team leader will download the one-minute data directly to a laptop computer during the short-term tests. GHG Center personnel will download the data by telephone during the long term monitoring period.

An Agilent / HP Model 34970A datalogger will record all temperature and flow meter data once every 5 seconds. The field team leader will download the data directly during short-term tests while GHG Center will download the data by telephone during the long term monitoring period. Analysts will use Excel spreadsheet routines to calculate one-minute averages from the 5-second snapshots.

The electronically-recorded one-minute averages (except for the manually-logged water system pressure data) will be the source data for all calculated results.

Documentation

Printed or written documentation will include:

- Daily test log, including water system pressure data, starting and ending times for test runs, notes, etc.
- Appendix A forms which show the results of QA / QC checks
- Copies of calibrations and manufacturers' certificates
- Corrective action reports, as needed

The GHG Center will archive all electronic data, paper files, analyses, and reports at their Research Triangle Park, NC office in accordance with their quality management plan.

4.1.1. Corrective Action and Assessment Reports

A corrective action will occur if audits or QA / QC checks produce unsatisfactory results or upon major deviations from this test plan. Immediate corrective action will enable quick response to improper procedures, malfunctioning equipment, or suspicious data. The corrective action process involves the field team leader, project manager, and QA Manager. The GHG Center QMP requires that test personnel submit a written corrective action request to document each corrective action.

The field team leader will most frequently identify the need for corrective actions. In such cases, he or she will immediately notify the project manager. The field team leader, project manager, QA Manager and other project personnel, will collaborate to take and document the appropriate actions.

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Note that the project manager is responsible for project activities. He is authorized to halt work upon determining that a serious problem exists. The field team leader is responsible for implementing corrective actions identified by the project manager and is authorized to implement any procedures to prevent a problem's recurrence.

4.2. DATA REVIEW, VALIDATION, AND VERIFICATION

The project manager will initiate the data review, validation, and analysis process. At this stage, analysts will classify all collected data as valid, suspect, or invalid. The GHG Center will employ the QA/QC criteria specified in Section 3.0 and the associated tables. Source materials for data classification include factory and on-site calibrations, maximum calibration and other errors, etc.

In general, valid data results from measurements which:

- meet the specified QA/QC checks,
- were collected when an instrument was verified as being properly calibrated,
- are consistent with reasonable expectations (e.g., manufacturers' specifications, professional judgment).

The report will incorporate all valid data. Analysts may or may not consider suspect data, or it may receive special treatment as will be specifically indicated. If the DQO cannot be met, the project manager will decide to continue the test, collect additional data, or terminate the test and report the data obtained.

Data review and validation will primarily occur at the following stages:

- on site -- by the field team leader
- before writing the draft report -- by the project manager
- during draft report QA review and audits -- by the GHG Center QA Manager

The field team leader's primary on-site functions will be to install and operate the test equipment. He will review, verify, and validate certain data (QA / QC check results, etc.) during testing. The log forms in Appendix A provide the detailed information he will gather.

The QA Manager will use this test plan and documented test methods as references with which to review and validate the data and the draft report. He will review and audit the data in accordance with the GHG Center's quality management plan. For example, the QA Manager will randomly select raw data and independently calculate the verification parameters. The comparison of these calculations with the results presented in the draft report will yield an assessment of the GHG Center's QA/QC procedures.

4.3. DATA QUALITY OBJECTIVES RECONCILIATION

A fundamental component of all verifications is the reconciliation of the collected data with its DQO. In this case, the DQO assessment consists of evaluation of whether the stated methods were followed, DQIs achieved, and overall accuracy is as specified in Section 3.0. As discussed in Section 4.2, the field team leader and project manager will initially review the collected data to ensure that they are valid and are consistent with expectations. They will assess the data's accuracy and completeness as they relate to the stated QA / QC goals. If this review of the test data shows that QA / QC goals were not met, then immediate corrective action may be feasible, and will be considered by the project manager. DQOs will be reconciled after completion of corrective actions. As part of the internal audit of data quality, the GHG Center QA Manager will include an assessment of DQO attainment.

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4.4. ASSESSMENTS AND RESPONSE ACTIONS

The field team leader, project manager, QA Manager, GHG Center Director, and technical peer-reviewers will assess the project and the data's quality as the test campaign proceeds. The project manager and QA Manager will independently oversee the project and assess its quality through project reviews, inspections if needed, and an audit of data quality.

4.4.1. Project Reviews

The project manager will be responsible for conducting the first complete project review and assessment. Although all project personnel are involved with ongoing data review, the project manager must ensure that project activities meet measurement and DQO requirements.

The GHG Center Director will perform the second project review. The director is responsible for ensuring that the project's activities adhere to the ETV program requirements and stakeholder expectations. The GHG Center Director will also ensure that the field team leader has the equipment, personnel, and resources to complete the project and to deliver data of known and defensible quality.

The QA Manager will perform the third review. He is responsible for ensuring that the project's management systems function as required by the quality management plan. The QA Manager is the GHG Center's final reviewer, and he is responsible for ensuring the achievement of all QA requirements.

ECR personnel and selected GHG Center stakeholders and/or peer reviewers will then review the report. Technically competent persons who are familiar with the project's technical aspects, but not involved with project activities, will function as peer reviewers. The peer reviewers will provide written comments to the project manager. ECR will also have the opportunity to insert supplemental unverified information or comments into a dedicated report section.

The GHG Center will submit the draft report to EPA QA personnel, and the project manager will address their comments as needed. Following this review, the report will undergo EPA management reviews, including the GHG Center Director, EPA ORD Laboratory Director, and EPA Technical Editor.

4.4.2. Audit of Data Quality

The audit of data quality is an evaluation of the measurement, processing, and data analysis steps to determine if systematic errors are present. The QA Manager, or designee, will randomly select approximately 10 percent of the data. He will follow the selected data through analysis and data processing. This audit is intended to verify that the data-handling system functions correctly and to assess analysis quality. The QA Manager will also include an assessment of DQO attainment.

The QA Manager will route audit results to the project manager for review, comments, and possible corrective actions. Project records will document the results. The project manager will take any necessary corrective action needed and will respond by addressing the QA Manager's comments in the report.

4.5. VERIFICATION REPORT AND STATEMENT

The report will summarize each verification parameter's results as discussed in Section 2.0 and will contain sufficient raw data to support findings and allow others to assess data trends, completeness, and quality. The report will clearly characterize the verification parameters, their results, and supporting measurements as determined during the test campaign. It will present raw data and/or analyses as tables, charts, or text as is best suited to the data type. The report will contain additional information about the SUT and the host facility such as ground loop installation data, etc. The report will also contain a Verification Statement, which is a 3 to 5 page document summarizing the technology, the test strategy used, and the verification results obtained.

Examples of the reported values include the mean and 95-percent confidence intervals for:

- short-term test verification parameters listed in Section 2.1
- city water supply temperatures during short-term tests
- test room ambient temperatures during the standby heat loss tests

The report will also cite the long-term monitoring results and indicate the range of city water supply and test room ambient temperatures.

The project manager will submit the draft report and Verification Statement to the QA Manager and GHG Center Director for review. A preliminary outline of the report is as follows:

Preliminary Outline
ECR EarthLinked Ground Source Heat Pump Water Heating System Verification Report

Verification Statement

Section 1.0: *Verification Test Design and Description*
Description of the ETV program
EarthLinked System and Host Facility Description
Overview of the Verification Parameters and Evaluation Strategies

Section 2.0: *Results*
Water Heating Capacity
CoP
Long-term Monitoring Results
Estimated Emissions Reductions
Estimated Simple Cost Savings

Section 3.0: *Data Quality*

Section 4.0: *Additional Technical and Performance Data Supplied by ECR (optional)*

Section 5.0: *References*

Appendices: *Raw Verification or Other Data*

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4.6. TRAINING AND QUALIFICATIONS

This test does not require specific training or certification beyond that required internally by the test participants for their own activities. The GHG Center's field team leader is a licensed professional engineer with approximately 15 years experience in field testing of air emissions from many types of sources. He is familiar with the test methods and standard requirements that will be used in the verification test.

The project manager has performed numerous field verifications under the ETV program, and is familiar with EPA and GHG Center quality management plan requirements. The QA Manager is an independently appointed individual whose responsibility is to ensure the GHG Center's conformance with the EPA approved QMP.

4.7. HEALTH AND SAFETY REQUIREMENTS

This section applies to GHG Center personnel only. Other organizations involved in the project have their own health and safety plans which are specific to their roles in the project.

GHG Center staff will comply with all known host, state/local and Federal regulations relating to safety at the test facility. This includes use of personal protective gear (such as safety glasses, hard hats, hearing protection, safety toe shoes) as required by the host and completion of site safety orientation.

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5.0 REFERENCES

[1] *ANSI /ASHRAE Standard 118.1-2003: Method of Testing for Rating Commercial Gas, Electric, and Oil Service Water Heating Equipment*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA. 2003

[2] *Handbook of Chemistry and Physics, 60th Edition*, "Specific Heat of Water", page D-174, CRC Press. Boca Raton, FL. 1980

[3] *Handbook of Chemistry and Physics, 60th Edition*, "Steam Tables—Properties of Saturated Steam and Saturated Water", page E-18, CRC Press. Boca Raton, FL. 1980

[4] *Distributed Generation and Combined Heat and Power Field Testing Protocol—Appendix G: Uncertainty Estimation*, Association of State Energy Research and Technology Transfer Institutions. 2004. Available from <http://www.dgdata.org/pdfs/field_protocol.pdf>.

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Appendix A

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Appendix A-1. Power Meter and RTD QA / QC Checks

Project ID: ______________ Location: ____

Power Meter Sensor Checks

Note: Acquire at least 3 separate readings for each phase. All ION voltage and current readings must be within 2 % or 3 %, respectively, of the corresponding DVM reading.

Tank #1 power meter: Make: ___________ Model:______________ Serial No: _______________

Date: ___________ Signature: ______________________________________

	Phase A			Phase B			Phase C		
	ION	**DVM**	**% diff**	**ION**	**DVM**	**% diff**	**ION**	**DVM**	**% diff**
Voltage									
Current									

Tank #2 power meter: Make: ___________ Model: ______________ Serial No: ______________

Date: ___________ Signature: _____________________________________

	Phase A			Phase B			Phase C		
	ION	**DVM**	**% diff**	**ION**	**DVM**	**% diff**	**ION**	**DVM**	**% diff**
Voltage									
Current									

RTD Ambient Crosschecks

Note: Allow RTDs to equilibrate in ambient conditions for at least ½ hour. All RTD readings must be within ± 1.5 ^{o}F of each other.

Date: ___________ Signature: ____

Ref.	**RTD ID #**	**Description / location**	**^{o}F (at DAS)**
1			
2			
3			
4			
5			
6			
7			
8			
9			
spare			

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Appendix A-2. Flow Meter Checks and Water Heating Performance Crosscheck

Flow Meter Checks

Record at least 3 flow rates each while EarthLinked heat exchanger pump is disconnected and while it is running. Zero flow should be ≤ 2.9 gpm. Full flow should be between 9 and 11 gpm.

Date: ___________ Signature: ____

Make: _________ Model: ______________Serial #: ____________________Mean K (pulses per gallon): ________________

$$Pulse/min = \frac{60(PulseCount)}{T_{elapsed}} \qquad gpm = \frac{Pulse/min}{K}$$

	$T_{elapsed}$, s	PulseCount	Pulse/min	gpm	OK ?
Zero flow					
Full Flow					

Type V vs. Type IV Crosscheck

Type V water heating capacity, Q_{typeV}, Btu/h, should agree with Type IV capacity, Q_{typeIV}, to within 6.4 %.

$$Q_{TypeV} = \frac{116.3*\left(\frac{C_p}{7.48055*v}\right)*(T_{mhf} - T_{mh0})}{(t_{fh} - t_{0h})} + 341.2 \qquad Q_{TypeIV} = FR_{Avg}*60*(T_{ohn} - T_{ihn})*\frac{C_p}{7.48055*v}$$

Where: C_p (specific heat) and v (specific volume) are obtained from the tables below
T_{mhf} and T_{mh0} are the initial and final tank temperatures taken as the mean of all 6 tank temperature sensors during each test run, ^oF
$(t_{fh} - t_{0h})$ = type V test run duration, s
FR_{Avg} = overall mean of one-minute EarthLinked system flow rates for each test run, gpm
T_{ohn}-T_{ihn} = overall mean of one-minute temperature differentials across the EarthLinked system for each test run, ^oF

C_p depends on average tank water temperature over the entire test run, $T_{avg} = \left[\frac{T_{mhf} + T_{mh0}}{2}\right]$. v depends on system pressure. System pressure is the sum of the pressure gauge psig and ambient psia. Ambient psia is the location station pressure, P_{bar}, as recorded by the local weather radio and corrected for altitude or as measured by a climbing altimeter. Note that psia = "Hg * 0.4911541.

Date: ___________ Signature: ____

psig: _________P_{bar}: ___________ P_{system}: ____________

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Appendix A-2, Continued

Acquire specific volume and specific heat from following table. Enter table at P_{system} for specific volume. Enter table at T_{avg} for specific heat. Use linear interpolation for values between those given.

Specific Volume		**Specific Heat**	
P_{system}, psia	**v, ft^3/lb**	**T_{avg}, ^oF**	**C_p, Btu/lb.^oF**
24.08	0.01691	60	0.99963
29.82	0.01701	70	0.99868
34.24	0.01707	80	0.99816
39.18	0.01714	90	0.99797
44.68	0.01721	100	0.99799
49.20	0.01726	110	0.99817
54.08	0.01732	120	0.99847
59.35	0.01738	130	0.99889

Type V Water Heating Performance			
Parameter	**Run 1 Values**	**Run 2 Values**	**Run 3 Values**
C_p			
v			
T_{mhf} (final tank temp)			
T_{mh0} (initial tank temp)			
T_{mhf} - T_{mh0}			
t_{fh} (final time stamp)			
t_{0h} (initial time stamp)			
t_{fh} - t_{0h} (difference, s)			
Q_{typeV}			

Type IV Water Heating Performance			
Parameter	**Run 1 Values**	**Run 2 Values**	**Run 3 Values**
C_p			
v			
FR_{Avg} (overall mean of one-minute flow rates)			
T_{ohn} -T_{ihn} (overall mean of one-minute differential temperatures)			
Q_{typeIV}			
Q_{typeV} vs. Q_{typeIV} % Difference			
Acceptable? (within ± 6.5 %)			

<u>Long Term Monitoring Period</u>

Start date: _______________ Time: _____________ Circle one: {EARTHLINKED} {TANK ELEMENTS}

Signature: ____

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Appendix A-3. SUT and Site Information

Date: ___________________ Signature: ____

SUT Data
Description: ____

Mfg: ___________________________ Model: __________________ Serial No.: ________________

Temperature rise: _________ °F at ________ gph Nominal CoP: _________

Loop Data
Designer: __________________________________ Installer: ______________________________

Tubing material: ___________ Dia: _____ Number of loops / bores: __________________________

Loop length each: _____Total length: _________ Bore diameter: _________ Depth: ____________

Water table encountered? ________ Water table depth _________

Grouting method / material (describe): ____

Soil type / description (from driller's log): ____

Notes (Is installation representative? Problems encountered? Exceptions made?): __________________

____

____

Site Data
Note: record number and type of hot water uses only.

Residence rooms: _____ Fixtures (describe): ____

Utility rooms: ________ Fixtures (describe): ____

Kitchens: ___________ Fixtures (describe): ____

Nurse Stations: ______ Fixtures (describe): ____

Baths / Spa: _________ Fixtures (describe): ____

Other: ______________ Fixtures (describe): ____

Daytime staff (function / number): ____

Nighttime staff (function / number): ____

Number of residents at start of tests: ________

Number of residents at end of long-term monitoring: _________

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Appendix B
Electric Power System Emissions Reduction Estimates

The verification report will provide estimated emissions reductions (or increases) as compared to aggregated electric power system (EPS) emission rates for the state in which the apparatus is located (Florida for this verification). The report will also include estimated reductions based on aggregated nationwide emission rates. Analysts will employ the methods described in this Appendix.

A DG asset or power-saving device, when connected to the EPS, will change the overall EPS emissions signature. As an example, a zero-emission generator, such as a hydroelectric power plant, will decrease EPS CO_2 emissions on a lb/MWh basis. The potential emissions reduction (or increase) for DG is the difference between the EPS and DG emission rates, multiplied by the expected power generation or savings rate:

$$Reduction_i = (ER_{EPS,i} - ER_{DG,i}) * MWh_{DG,Ann} \qquad \text{Eqn. B1}$$

Where:

$Reduction_i$ = annual reduction for pollutant i, pounds per year (lb/y)
$ER_{EPS,i}$ = EPS emission rate for pollutant i (see below), pounds per megawatt-hour (lb/MWh)
$ER_{DG,i}$ = DG emissions rate for pollutant i, lb/MWh
$MWh_{DG,Ann}$ = annual estimated DG power production or device-based power savings, megawatt-hours per year (MWh/y)

The potential emissions reduction for a power savings device is simply:

$$Reduction_i = ER_{EPS,i} * MWh_{Device,Ann} \qquad \text{Eqn. B2}$$

Values for $ER_{DG,i}$ are available from the performance verification results. Estimated $MWh_{DG,Ann}$ or $MWh_{Device,Ann}$ should also be available from the verification results. This estimate depends on the specific verification strategy and its derivation should be clearly described in the test plan and verification results. A simple example is the power production or power savings multiplied by the annual availability or capacity factor. For example, a 200 kW fuel cell which operates at full capacity 75 percent of the time can be expected to generate 1314 MWh annually.

$ER_{EPS,i}$ for specific pollutants can vary widely because the EPS may obtain its power from many different generators. The generation mix can change dramatically from hour to hour, depending on market forces, system operations, wheeling practices, emergencies, maintenance, and other factors. Many different approaches have been suggested for estimating $ER_{EPS,i}$, but no consensus has been achieved.

The following estimation methodology is simple, it uses peer-reviewed carbon dioxide (CO_2), nitrogen oxide (NO_X), mercury (Hg), and sulfur dioxide (SO_2) data available from the US Environmental Protection Agency's "EGRID" database, and it provides some analysis flexibility.

EGRID is available from www.epa.gov/cleanenergy/egrid/download.htm. At this writing, data is available through 2000. Data through 2003 will likely be available in late 2005. Figure B-1 shows the introductory screen prompts which provide year 2000 emission rates for Florida.

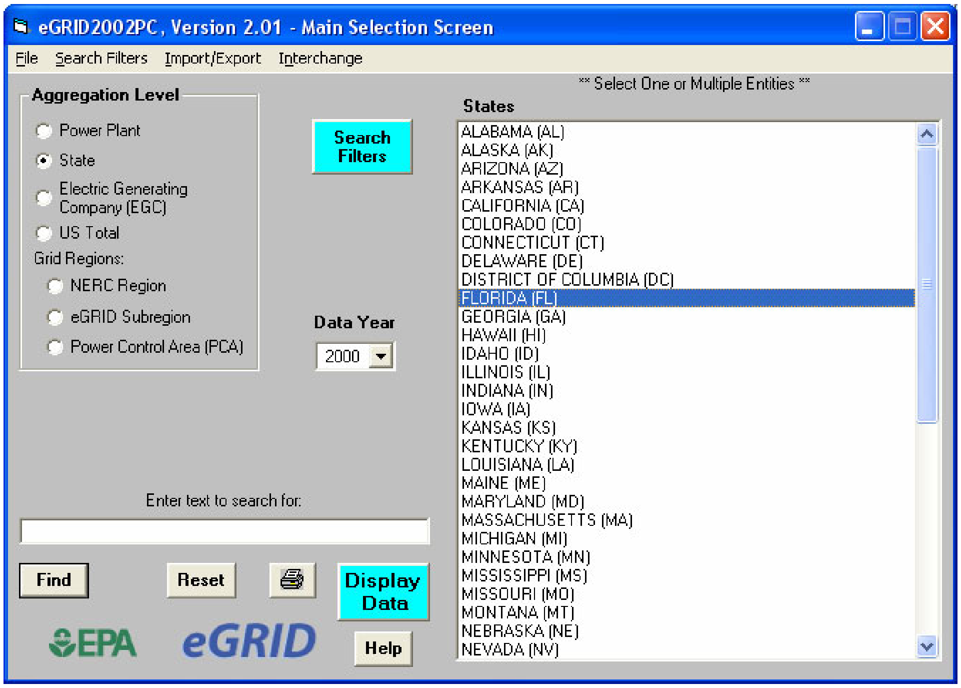

Figure B-1. Florida Aggregated Emissions Introductory Screen

Double-clicking the state of interest brings up the emissions data, as shown in Figure B-2.

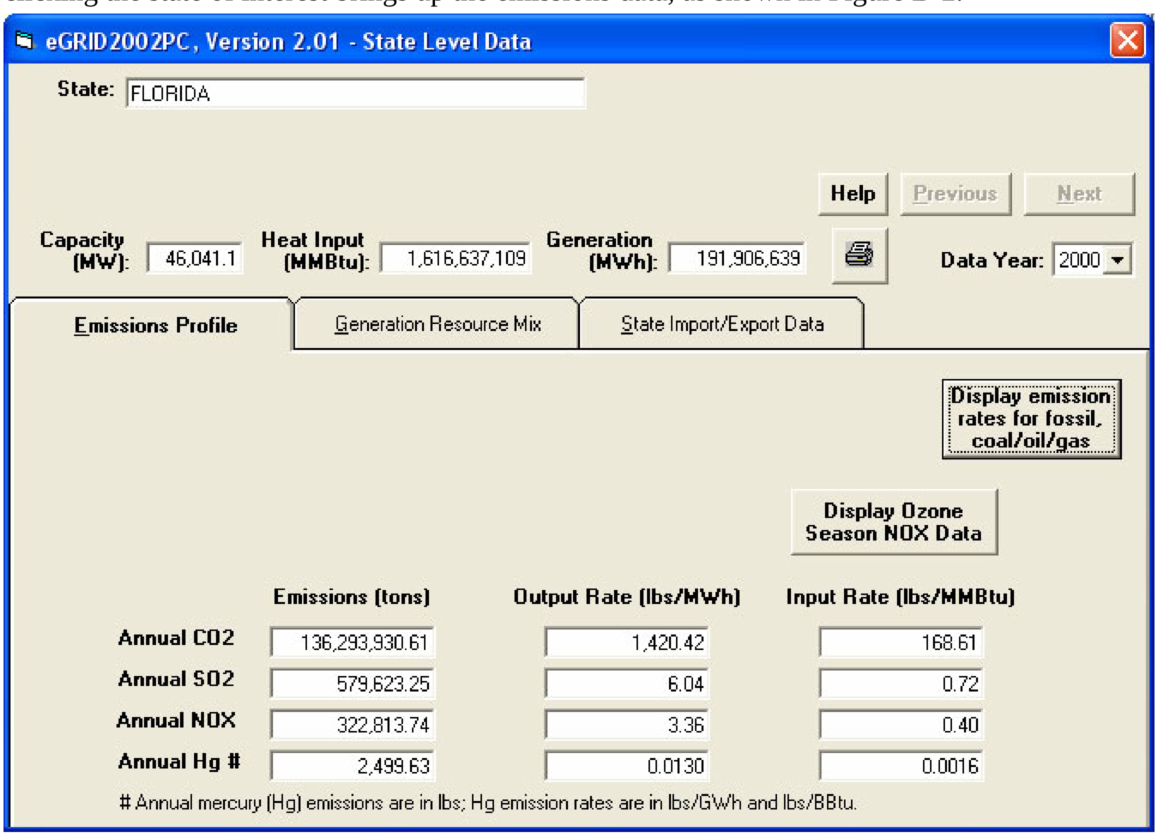

Figure X-2. Florida EPS Emission Rates for 2000

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Figure B-3 provides the nationwide emission rates for 2000.

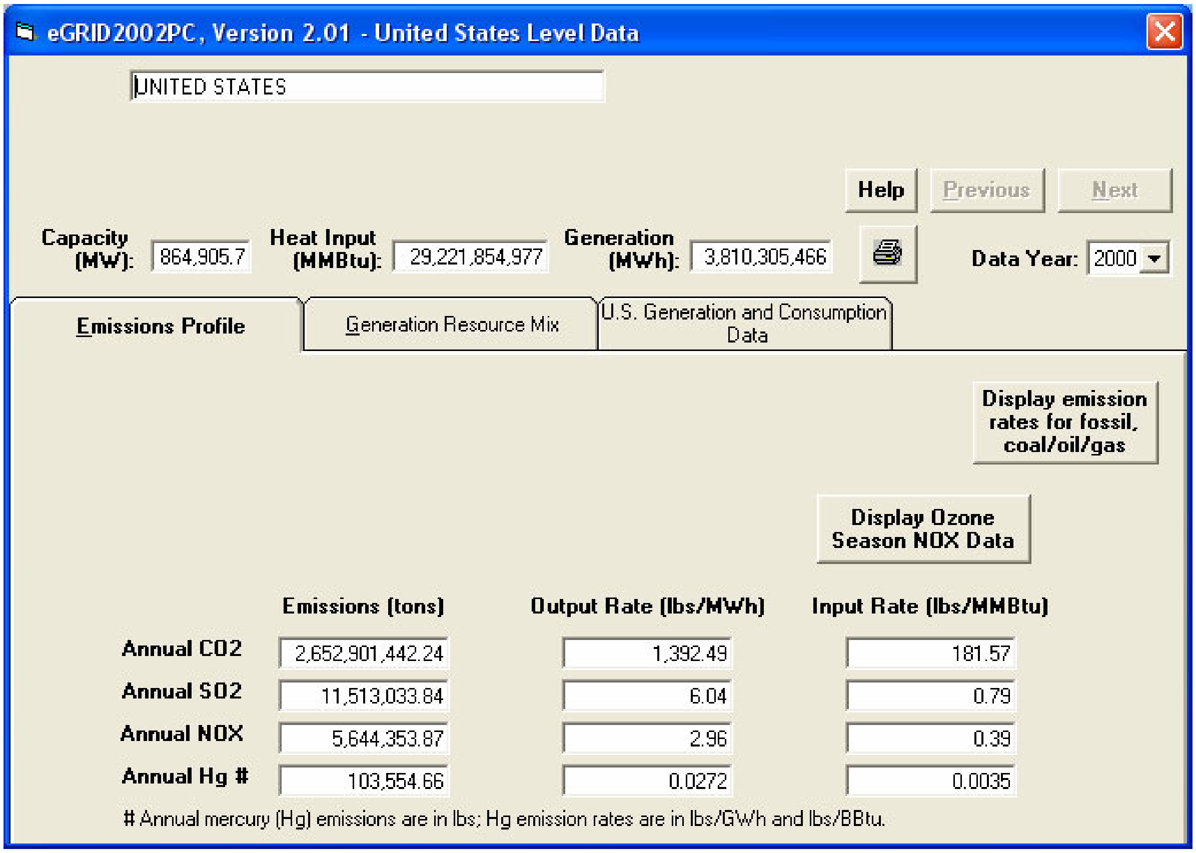

Figure B-3. Nationwide Emission Rates

These results form the basis for comparison. Table B-1 provides emissions offsets estimates for a hypothetical 200 kW fuel cell located in Florida.

Table B-1. Example Fuel Cell Emissions Offsets Estimates

	Florida		Nationwide	
Pollutant	CO_2	NO_X	CO_2	NO_X
ER_{EPS} (from EGRID), lb/MWh	1420	3.36	1392	2.96
ER_{DG} (from verification tests), lb/MWh	1437	0.13	1437	0.13
ER_{EPS} - ER_{DG}, lb/MWh	-17[a]	3.23	-45[a]	2.83
DG capacity, kW	200		200	
Estimated availability or capacity factor	75 %		75 %	
$MWh_{DG, Ann}$	1314		1314	
Emission offset, lb/y	-22400	4250	-59130	3720
[a]Negative numbers represent an increase over the EPS emission rate				

Note that this fuel cell increases the overall EPS CO_2 emission rate if electricity generation alone is considered. The increased CO_2 emissions in this example would be balanced by the fuel cell's heat or chilling power production if it is in combined chilling / heat and power (CHP) service. Each verification test plan must provide a specific accounting methodology for electricity production and CHP utilization

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because it is impossible to consider all the permutations here. The simplest case, that the unit really operates at a constant power output, predictable availability (or capacity factor), and that all the heat produced is actually used, is not necessarily true for every installation. Also, the CHP application may displace units fired by various fuels (electricity, heating oil, natural gas, etc.) with their own efficiencies and emission factors. Each verification strategy should explicitly discuss these considerations as part of the specific emissions offset calculation.

It is useful, however, to continue this example. Assume that the fuel cell provides a constant 800,000 British thermal units per hour (Btu/h) to a domestic hot water system, thus displacing an electric-powered boiler. This heat production is equivalent to 234 kW, which would require approximately 239 kW of electricity from the EPS at 0.98 water heating efficiency (source: ASHRAE Standard 118.1-2003, § 9.1). The fuel cell would therefore save approximately 15700 MWh annually at 75 percent capacity factor. Table B-2 shows the resulting emissions offsets estimates.

Table B-2. Example CHP Emissions Offsets Estimates

	Florida		Nationwide	
Pollutant	CO_2	NO_X	CO_2	NO_X
ER_{EPS} (from EGRID), lb/MWh	1420	3.36	1392	2.96
ER_{DG} (from verification tests), lb/MWh	0^a	0^a	0^a	0^a
ER_{EPS} - ER_{DG}, lb/MWh	1420	3.36	1392	2.96
DG capacity, kW	239^b		239^b	
Estimated availability or capacity factor	75 %		75 %	
$MWh_{DG, Ann}$	15700		15700	
Emission offset, lb/y	2.23×10^7 (11100 tons)	52800 (26.4 tons)	2.19×10^7 (10900 tons)	46500 (23.2 tons)

[a]Emissions are zero here because the electricity production offset estimate included them.
[b]Based on the power required to run an electric-fired boiler at 98 % water heating efficiency.

In this CHP application, the fuel cell represents a considerable net annual CO_2 emissions reduction for Florida of 2.23×10^7 lb/y.

This approach is generally conservative because it does not include transmission and distribution (T&D) losses. T&D losses vary between approximately 3 to 8 percent depending on dispatch practices, the unit's location with respect to the EPS generator actually being displaced, and other factors. This means that 100 kW of energy at the DG unit's terminals will actually displace between 103 and 109 kW (and the associated emissions) at the EPS generator.

EGRID provides numerous other aggregation options, and the reader may wish to conduct other comparisons, such as for a particular utility, North American Electric Reliability Council (NERC) region, or control area.

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Appendix C.
Electric Power Simple Cost Savings Estimates

The performance verification report will provide estimated simple cost savings as compared to the average retail price of electricity for the state in which the device under test (DUT) is located (Florida, for this verification). Simple cost savings will also be based on the average nationwide retail price. Analysts will employ the methods described in this Appendix.

The simple cost savings is the annual estimated device-based power savings multiplied by the average retail price of electricity:

$$\text{Simple Cost Savings} = \frac{MWh_{DUT,Ann} * RP_{elec} * 10^3}{100} \qquad \text{Eqn. C1}$$

where:

Simple Cost Savings = estimated annual device-based cost savings, dollars
$MWh_{DUT,Ann}$ = annual estimated device-based power savings, MWh
RP_{elec} = average retail price of electricity, cents/kWh
10^3 = conversion factor from MWh to kWh
100 = conversion factor from cents to dollars

The value for estimated $MWh_{DUT,Ann}$ should be available from the verification results. This estimate depends on the specific verification strategy and its derivation should be clearly described in the test plan and verification results. A simple example is the power production or power savings multiplied by the annual availability or capacity factor. For example, a 200 kW fuel cell which operates at full capacity 75 percent of the time can be expected to generate 1314 MWh annually.

Varying values for RP_{elec} can be found in many resources. This methodology of estimating economic payback uses the Energy Information Agency's (EIA) *Table 5.6.A. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State* to find RP_{elec}. This table is available from http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html. Table C-1 provides data for 2004.

Table C-1. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector[a]

Census Division and State	Residential	Commercial	Industrial	Transportation	All Sectors
New England	**11.78**	**10.57**	**8.08**	**5.2**	**10.61**
Connecticut	10.24	8.48	7.47	5.46	9.12
Maine	12.51	12.99	4.57	--	10.6
Massachusetts	12.29	10.9	8.89	5.08	11.08
New Hampshire	11.95	10.79	10.31	--	11.19
Rhode Island	13.36	11.89	9.71	--	12.12
Vermont	12.68	11.33	8.1	--	11.02
Middle Atlantic	**11.22**	**9.94**	**6.23**	**7.1**	**9.6**
New Jersey	10.03	8.34	8.11	10.92	8.96
New York	14.44	11.67	6.31	6.8	11.75
Pennsylvania	9.21	8.46	5.82	7.08	7.91
East North Central	**7.94**	**7.17**	**4.65**	**5.51**	**6.55**
Illinois	7.7	6.94	4.75	4.94	6.49
Indiana	7.03	6.23	4.13	8.45	5.54
Michigan	8.47	7.88	5.25	8.92	7.29

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Table C-1. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector[a]					
Census Division and State	**Residential**	**Commercial**	**Industrial**	**Transportation**	**All Sectors**
Ohio	7.94	7.37	4.6	8.26	6.62
Wisconsin	8.91	6.95	4.79	--	6.86
West North Central	**7.09**	**5.79**	**4.35**	**5.36**	**5.85**
Iowa	8.79	6.46	4.25	--	6.29
Kansas	7.16	6.24	4.42	--	6.03
Minnesota	7.91	5.92	4.93	6.72	6.28
Missouri	6.22	5.23	3.79	3.87	5.37
Nebraska	6.07	5.48	3.99	--	5.24
North Dakota	6.26	5.82	4.12	--	5.53
South Dakota	7.2	6.46	4.32	--	6.33
South Atlantic	**7.87**	**7.15**	**4.58**	**5.25**	**6.9**
Delaware	8.45	7.23	5.06	--	7.08
District of Columbia	7.06	6.55	1.01	2.57	6.4
Florida	8.76	7.8	5.76	7.53	8.07
Georgia	7.07	7.15	4.77	5.05	6.48
Maryland	7.57	9.18	4.28	5.83	6.93
North Carolina	8.07	6.77	4.74	--	6.87
South Carolina	7.73	7.09	4.13	--	6.17
Virginia	7.42	5.85	4.3	7.07	6.27
West Virginia	6.01	5.39	3.78	5.7	5.09
East South Central	**6.88**	**6.86**	**3.71**	**13.95**	**5.59**
Alabama	7.04	6.98	3.72	--	5.65
Kentucky	6.15	5.7	3.13	--	4.55
Mississippi	7.96	8.03	4.65	--	6.78
Tennessee	6.86	7.05	4.09	13.95	6.02
West South Central	**8.68**	**7.5**	**5.49**	**7.23**	**7.23**
Arkansas	7.09	5.68	4.01	--	5.5
Louisiana	8.07	7.93	6.06	7.9	7.24
Oklahoma	6.82	6.28	4.54	--	6.01
Texas	9.34	7.79	5.7	7.11	7.65
Mountain	**7.74**	**7.12**	**4.82**	**5.31**	**6.66**
Arizona	7.88	7.39	5.24	--	7.21
Colorado	7.64	7.31	5.73	5.29	7.05
Idaho	5.83	5.14	3.41	--	4.91
Montana	7.7	7.21	4.06	--	6.14
Nevada	10.11	9.7	6.29	--	8.44
New Mexico	8.27	7.39	4.78	--	6.87
Utah	7	5.51	3.6	5.43	5.3
Wyoming	6.7	5.66	3.89	--	4.93
Pacific Contiguous	**9.86**	**8.49**	**6.19**	**6.55**	**8.54**
California	11.92	9.27	7.79	6.56	9.9
Oregon	7.15	6.38	4.05	6.08	6.16
Washington	6.37	6.19	3.79	6.46	5.68
Pacific Noncontiguous	**16.5**	**14.7**	**14.1**	**--**	**15.15**
Alaska	12.22	10.74	7.47	--	10.88
Hawaii	20.01	17.93	15.66	--	17.72
U.S. Total	**8.58**	**7.81**	**5.01**	**6.51**	**7.32**

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Census Division and State	Residential	Commercial	Industrial	Transportation	All Sectors

Table C-1. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector[a]

[a] Source: Energy Information Administration, Form EIA-826, "Monthly Electric Sales and Revenue Report with State Distributions Report."

Continuing the example from above, Table C-2 provides the estimated simple cost savings for a hypothetical 200 kW fuel cell located in Florida. This example uses the average retail price listed for all sectors. Individual verification test plans may opt to use the average price for the sector (residential, commercial, industrial, or transportation) that is most applicable to the DUT. This should be specified in the test plan.

Table C-2. Fuel Cell Estimated Economic Payback

	Florida	Nationwide
DUT capacity, kW	200	200
Estimated availability or capacity factor	75 %	75 %
$MWh_{DUT, Ann}$	1314	1314
RP_{elec}, cents/kWh	8.07	7.32
Estimated Economic Payback, dollars	$106,040	$96,185

This approach is generally conservative because the actual prices are often the result of negotiation and subject to local regulation or market forces.

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