That is, based on observing a sample of 12 months, we estimate average monthly consumption to be 4,000 kWh. There is a 95 percent confidence that the *true* mean monthly consumption lies between 2,778 and 5,222 kWh. It can be said with 95 percent confidence that the *true* mean value is 4,000 ±30 percent.

D.4 Mitigating Random/Sampling Error

In most evaluations, we do not have access to an entire population of interest (e.g., all small commercial customers participating in a program), either because the population is too large or the measurement process is too expensive or time-consuming to allow more than a small segment of the population to be observed. As a result, we make decisions about a population on the basis of a small amount of sample data.

For example, suppose an evaluator is interested in the proportion of program participants installing a particular measure. The fairly large program has a population of about 15,000 participants. The parameter of interest is the proportion of participants actually installing the measure (called π).

The evaluator conducts a survey using a random sample of participants. Each participant is asked whether or not they installed the measure. The number (call it n) of participants surveyed will be quite small relative to the population's size. Once these participants have been surveyed, the proportion installing the measure will be computed. This proportion is called a statistic (in this case, it is called p). We can reasonably assume p will not equal π (an exact match would be extremely unlikely). At a minimum, our statistic p involves random sampling error or "the luck of the draw." The difference between the observed p and unobserved π is the sampling error. As long as sampling is used, there will be sampling error.

The most direct way to reduce sampling error is to increase the sample's size. Most research consumers are familiar with this underlying principle. For any given population and confidence level, the larger the sample, the more precise estimates will be.

Evaluation research adopts conventions about sample sizes for particular types of projects. Prior research (or in some cases, requirements set by a regulatory authority) should be the first place to turn for appropriate sample sizes. The next question is whether relationships in prior studies seem likely to exist but have not been borne out by research. This might point toward the need to invest in a larger-than-conventional sample size.

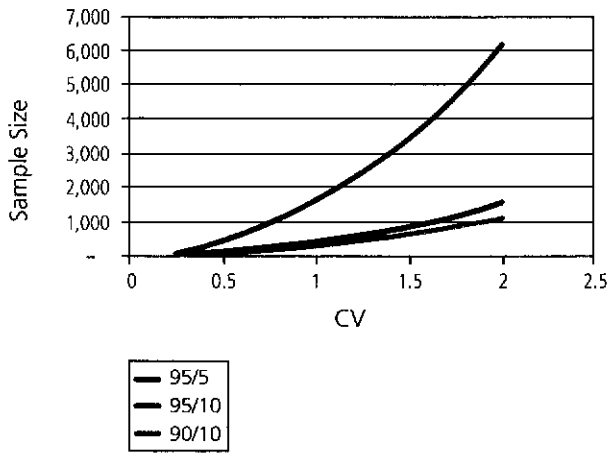
The other way to reduce sampling error is to improve the sampling design. In general, the design with the smallest random error is a simple random sample in which each population element has an equal probability of being selected. There are important reasons why a deviation from this design represents an overall improvement in results. For example, using a stratified sampling design (rather than treating all lighting areas as if they were all part of the same "population") divides populations into homogenous strata prior to sampling, greatly reducing overall sampling error. Researchers should justify stratification or clustering of the sample and address the impact on sampling error.

As noted, sampling error can be minimized by increasing the fraction of the population sampled, obviously at an increased cost. Several issues are critical in optimizing sample sizes. The following steps should be followed in setting the sample size.

1. **Select a homogeneous population.** For sampling to be cost-effective, measured "units" should be expected to be the same for the entire population. If there are two different types of units in the population, they should be grouped and sampled separately. For example, when designing a sampling program to measure the operating periods of room lighting controlled by occupancy sensors, rooms occupied more or less continuously (e.g., multiple-person offices) should be sampled separately from those that are only occasionally occupied (e.g., meeting rooms). The size of the sample needed to achieve a certain level of precision and confidence is sensitive to the amount of variability. Figure D.1 presents a hypothetical case. The horizontal axis shows an estimate of variability (in this case, the cv). The vertical axis shows the sample size needed to achieve different levels of

confidence and precision. Each of the lines shows the relationship between variability and sample size. The higher the confidence and precision requirement, the steeper the line, indicating higher sensitivity to the measure of variability. This clearly displays the need for homogeneous groups. A homogeneous group is defined as a group with low variability in whatever is being measured (e.g., hours of use).

Figure D-1. Sample size selection for different levels of confidence and precision.



In addition to placing the population in homogenous groups, the evaluator needs to set the acceptable levels of precision and confidence. A conventional approach (for example, as defined for certain California energy efficiency evaluations) is to design sampling to achieve a 90 percent *confidence* level and ±10 percent *precision*. Figure D.1 illustrates the impact of selecting confidence and precision levels. For example, in the hypothetical situation illustrated, the sample size needed for a cv of 1.0 varies from 270 for 90/10 to over 1,500 for 95/5. This may translate to a difference of thousands of dollars in sampling costs: improving *precision* from ±20 to ±10 percent would require a fourfold increase in sample size, while improving it to ±2 percent would require a hundredfold increase in sample size. This is due to a sample error inversely proportional to $\sqrt{n}$. Thus, selecting the appropriate sampling criteria requires balancing accuracy requirements and the risk of higher uncertainty with costs associated with less uncertainty.

2. **Decide on the level of disaggregation.** It is necessary to establish whether the *confidence* and *precision* level criteria should be applied to the measurement of all components or to various subgroups of components. If a project includes several measures installed in different building types, the evaluator must decide whether the confidence and precision apply at the project level, measures level, end-use level, and so on. Going from measure-level criteria to overall project-level criteria requires larger samples. However, one large sample covering an entire project may still be smaller than several smaller samples at the measure level. As there are no hard and fast rules, different sampling designs need to be examined, and those optimally balancing the precision and cost should be selected. Whatever that final selection, it should be clearly defined in an evaluation plan along with the rationale behind the selection.

3. **Calculate initial sample size.** Based on the information above, an initial estimate of the overall sample size required to meet the research goals can be determined using the following equation:

$$n_o = \frac{n_o N}{n_o + N}$$

where:

n_o is the initial estimate of the required sample size before sampling begins.

cv is the *coefficient of variance*, defined as the *standard deviation* of the readings divided by the *mean*. Until the actual *mean* and *standard deviation* of the population can be estimated from actual samples, 0.5 is often accepted as an initial estimate for cv. The more homogenous the population, the smaller the cv.

e is the desired level of *precision*.

z is the standard normal distribution value for the desired *confidence* level. For example, z is 1.96 for a 95 percent *confidence* level (1.64 for 90 percent, 1.28 for 80 percent, and 0.67 for 50 percent *confidence*).

For 90 percent *confidence* with 10 percent *precision* and a cv of 0.5, the initial estimate of required sample size (n_0) is

$$n_o = \frac{1.64^2 \times 0.5^2}{0.1^2} = 67$$

Values from previous cv studies may be used if available. It may also be desirable to conduct a study with a small sample for the sole purpose of estimating cv.

4. **Adjust initial sample size estimate for small populations.** The necessary sample size can be reduced if the entire population being sampled is no more than 20 times the size of the sample. For the initial sample size example above (no = 67), if the population (N) from which it is sampled is only 200, the population is only 3 times the size of the sample. Therefore the "finite population adjustment" can be applied. This adjustment reduces the sample size *(n)* as follows:

$$n_o = \frac{n_o N}{n_o + N}$$

Applying this finite population adjustment to the above example reduces the sample size (n) required to meet the 90 percent/±10 percent criterion to 50.

D.5 Mitigating Systematic Error

Many evaluation studies do not report any uncertainty measures besides a sampling error–based confidence interval for estimated energy or demand savings values. This is misleading because it suggests the confidence interval describes the total of all uncertainty sources (which is incorrect) or that these other sources of uncertainty are not important relative to sampling error. Sometimes uncertainty due to measurement and other systematic sources of error can be significant.

Measurement error can result from inaccurate mechanical devices, such as meters or recorders, as well as from inaccurate recording of observations by researchers or inaccurate responses to questions by study participants. Of course, basic human error occurs in taking physical measurements or conducting analyses, surveys, or documentation activities. For mechanical devices such as meters or recorders, it is theoretically possible to perform tests with multiple meters or recorders of the same make and model to indicate the variability in measuring the same value. However, for meters and most devices regularly used in energy efficiency evaluations, it is more practical to either use manufacturer and industry study information on the likely amount of error for any single piece of equipment or use calibration data.

Assessing the level of measurement error for data obtained from researchers' observations or respondents' reports is usually a subjective exercise, based on a qualitative analysis. The design of recording forms or questionnaires, the training and assessment of observers and interviewers, and the process of collecting data from study participants are all difficult to quantify. It is possible, however, to conduct special studies of a participant subsample to validate each of these processes. For example, it is possible to have more than one researcher rate the same set of objects, or to conduct short-term metering of specific appliances for a subsample to verify information about appliance use. Participants can also be reinterviewed to test the answer to the same question at two different times, and pretests or debriefing interviews can be conducted with participants to determine how they interpreted specific questions and constructed their responses. Such special studies can be used to provide an assessment of the uncertainty potential in evaluation study results.

Another challenge lies in estimating the effect of excluding a portion of the population from a sample (sample non-coverage) or of the failure to obtain data from a certain portion of the sample (non-response). Data needed to assess these error sources are typically the same as those needed to resolve errors in the first place—but these data are usually unavailable. However, for both non-coverage and non-response, it is possible to design special studies to estimate the uncertainty level introduced. For studies whose sample design did not include a particular portion of the population (such as a geographical area or respondents living in a certain type of housing), it is possible to conduct a small-scale study on a sample of the excluded group to determine

the magnitude and direction of differences in calculated values for this portion of the population. In some situations, such as a survey, it is also possible to conduct a follow-up study of a sample of members for whom data were not obtained. This follow-up would also provide data to determine if non-respondents were different from respondents, as well as an estimate of the magnitude and direction of the difference.

Determining steps needed to mitigate systematic error is a more complex problem than mitigating random error as various sources of systematic error are often specific to individual studies and procedures. To mitigate systematic error, evaluators typically need to invest in additional procedures (such as meter calibration, a pretest of measurement or survey protocols, a validation study, or a follow-up study) to collect additional data to assess differences between participants who provided data and those who did not.

To determine how rigorously and effectively an evaluator has attempted to mitigate sources of systematic error, the following should be examined:

1. Were measurement procedures, such as the use of observational forms or surveys, pretested to determine if sources of measurement error could be corrected before the full-scale study was fielded?

2. Were validation measures, such as repeated measurements, inter-rater reliability, or additional subsample metering, used to validate measurements?

3. Was the sample frame carefully evaluated to determine what portions of the population, if any, were excluded in the sample and, if so, what steps were taken to estimate the impact of excluding this portion of the population from the final results?

4. Were steps taken to minimize the effect of non-response in surveys or other data collection efforts? If non-response appears to be an issue, were steps taken to evaluate the magnitude and direction of potential non-response bias?

5. Has the selection of formulas, models, and adjustments been conceptually justified? Has the evaluator tested the sensitivity of estimates to key assumptions required by the models?

6. Did trained and experienced professionals conduct the work, and was it checked and verified by a professional other than the one conducting the initial work?

D.6 Addressing More Complex Uncertainty

Our discussion has assumed that uncertainty arises from variation in one variable (e.g., hours of use or level of consumption). Often, uncertainty is caused by variability in several components in a savings estimation equation. For example, total savings may be the sum of savings from different components:

$$savings = savings_1 + savings_2 + \ldots + savings_p$$

Where total savings are the result of lighting, cooling, and so on. Each savings component is likely to have some variability of its own. Combining savings into the total requires the evaluator to also combine the variability associated with the different estimates. Components must be *independent* to use the suggested methods for combining uncertainties. Independence means whatever random errors affect one component are unrelated to the affecting other components. The standard error of reported savings can be estimated by:

$$SE(savings) = \sqrt{SE(savings_1)^2 + SE(savings_2)^2 + \ldots\ldots + SE(savings_p)^2}$$

Savings can also be estimated as the difference between baseline and post-installation energy use. The *standard error* of the difference (*savings*) is computed as:

$$SE(savings) = \sqrt{SE(adjusted\ baseline)^2 + SE(reporting\ period\ energy)^2}$$

At times, the savings estimate is a *product* of several independently determined components (i.e., $savings = C_1 x C_2 x \ldots x C_p$); in that case, the *relative* standard error of the *savings* is given approximately by:

$$\frac{SE(savings)}{savings} \approx \sqrt{\left(\frac{SE(C_1)}{C_1}\right)^2 + \left(\frac{SE(C_2)}{C_2}\right)^2 + \ldots\ldots + \left(\frac{SE(C_p)}{C_p}\right)^2}$$

A good example of this is the determination of lighting savings as:

$savings = \Delta \text{ Watts} \times \text{Hours}$

The relative standard error of savings will be computed using the above formula as follows:

$$\frac{SE(savings)}{savings} = \sqrt{\left(\frac{SE(\Delta\ watts)}{\Delta\ watts}\right)^2 + \left(\frac{SE(hours)}{hours}\right)^2}$$

If savings at a particular hour are what is needed, the affected end-use must be metered hourly. The estimated average is energy use in that particular hour. The variability measure is the usage observed at that hour, and the sampling unit is the number of hours to be metered. Metering periods must account for weather and other seasonal variations, and metered hours must include a sample of different use patterns. In other words, sampling becomes more complex as an evaluator needs to estimate a sample size in number of hours per usage pattern as well as the number of impacted end-uses to be metered.

In many cases, the estimate of uncertainty attributable to systematic errors will have to be stated in qualitative terms. However, it is important to recognize these error sources may be significant. As a result, relying only on confidence intervals and standard errors to express uncertainty may be very misleading.

D.7 Monte Carlo Methods

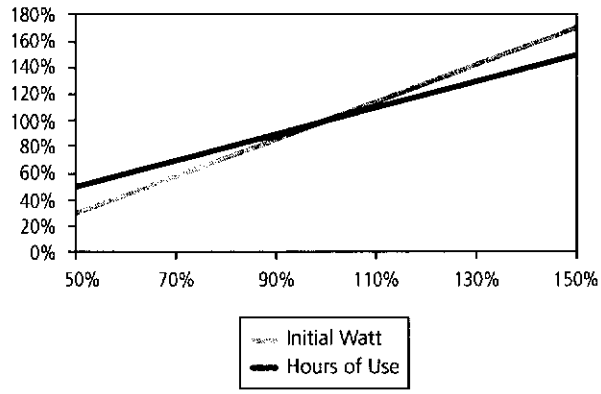
We have discussed uncertainty as a range of values surrounding a point value that has been arrived at directly through a measurement process. Monte Carlo methods arrive at uncertainty in a different way: by simulating reality using chance (hence the gambling reference) and a model of factors contributing uncertainty to the outcome we are examining.

A "Monte Carlo" method can refer to any technique using random numbers and probability to develop a simulation to solve a problem. Monte Carlo methods are used in many fields, such as chemistry and physics, as well as in studying how to best regulate the flow of traffic on highways or in risk management for businesses and organizations. They are used when a large number of uncertainty sources exist in the inputs, and direct measurements of outcomes are not possible. In this case, we refer to Monte Carlo simulation to estimate a population distribution.

Monte Carlo techniques are perfectly viable alternatives when problems are too complex (i.e., too many factors are involved in computing savings). Assessing the importance of individual components is often the best first step in assessing uncertainty.

For example, the Monte Carlo method could be applied for a simple lighting retrofit. Simply stated, such analysis begins by allowing these factors (e.g., hours of use) to vary from plausible lows to plausible highs. The impact on final savings values are observed, then the impact of initial wattage is investigated by allowing its value to vary between plausible lows and highs. The factor that has a higher impact on final savings may be the one worthy of further research. Figure D.2 shows a hypothetical case in which the initial wattage level and hours of use are allowed to vary independently from 50 percent of assumed or most likely values to 150 percent. Savings are estimated for all these variations. The vertical axis shows the change in savings as percentage terms. In this example, the initial wattage has a steeper curve, indicating higher sensitivity of final savings estimates.

Figure D-2. Hypothetical analysis lighting project.



Some commercially available software (e.g., Crystal Ball™) uses a Monte Carlo simulation to perform this type of analysis. These models are usually built using spreadsheets and are organized so ranges can be entered by the evaluator for each input variable needed to perform the sensitivity analysis shown above. Monte Carlo simulation is a very flexible technique, widely used for assessment of risk analysis in various fields.

In the example, hours of use and initial wattage levels were allowed to vary independently one at a time. Using Monte Carlo tools, the evaluator can allow factors to vary concurrently. Thus, Monte Carlo simulation can be as simple or complex as the user requires.

An extended example provides the best explanation of how this approach might be used in evaluating an energy efficiency program. Suppose energy savings from a residential air conditioning upgrade program are assumed to be a function of the net number of participants (subtracting free riders), multiplied by the average savings from each installed air conditioner. The savings from each installed air conditioner is a function of the average difference in SEER, relative to the old unit and a behavioral component related to thermostat settings also incorporated in the program.

Given these assumptions:

- There is uncertainty about the number of free riders. We estimate a 25 percent probability that 10 percent of participants are free riders, a 50 percent probability that 20 percent of participants are free riders, and a 25 percent probability that 30 percent of participants are free riders.
- There is also uncertainty regarding the average difference in SEER. We have not directly measured this through surveys, but we know the distribution of SEER values for qualifying air conditioners and the average SEER of currently installed air conditioners. We do not know whether program participants are different than the general population. We estimate a 25 percent probability that the average difference in SEER values is SEER 1.5, a 50 percent probability that the average difference is SEER 2.0, and a 25 percent probability that the average difference is SEER 2.5.
- Finally, uncertainty exists regarding the behavioral component. We believe there is a 50 percent probability that the average effect of the campaign has no change in thermostat settings, a 40 percent probability that the average effect reduces settings by 0.5 degrees, and a 10 percent probability that the average effect reduces settings by 1.0 degree.

We are modeling 27 possible scenarios (all possible combinations of the three factors, i.e., 33) and can calculate a savings for each state. Using the probability of each state, we can estimate a probability distribution for program savings, including a mean, standard deviation, and confidence intervals. For instance, the probability that actual savings are at the peak estimate (where free ridership is low, SEER difference is high, and thermostat setting is reduced by 1.0 degree) is $0.25 \times 0.25 \times 0.10 = 0.00625$, or 0.625 percent.

So far this does not involve chance because the example has only 27 possible scenarios. As the number of factors or states increases, it becomes impossible to calculate savings for every possible combination. If there are 10 uncertainty factors, with each having 10 possible states, there are 1010 or 10 billion possible combinations. To estimate uncertainty, we can simulate the population of scenarios using random number generators and draw multiple samples of a reasonable size; for instance, we could draw 1,000 samples of 1,000 scenarios. For each sample, we could calculate a mean program savings. Using the laws of probability, we know the average of the 1,000 samples (i.e., the average of the averages) is a good point estimate of energy savings, and the distribution around that estimate is normally distributed and provides a good estimate of uncertainty surrounding the estimate.

The key caution about Monte Carlo analysis is that, as with all simulations, poor assumptions built into the model can yield inaccurate estimates of the true uncertainty surrounding an estimate. Nevertheless, in fields where interrelations are very complex or direct measurements impossible, Monte Carlo analysis can yield useful uncertainty estimates.

D.8 Notes

1. This appendix was prepared by Dr. M. Sami Khawaja, President, Quantec, LLC, and Dr. Bob Baumgartner, Principal, PA Consulting.

Ameren Ex 7.2

Appendix E: Resources

The information in this document is a summary of definitions, approaches, and issues that have developed over the last 30 years of energy efficiency program implementation and evaluation. This experience and expertise is documented in numerous guides, protocols, papers, and reports. From a historical perspective, many of the basic references on energy and energy efficiency impact evaluations were written in the 1980s and 1990s. There are two reference documents in the public domain that provide a historical perspective and solid fundamentals:

- Violette, D.M. (1995). *Evaluation, Verification, and Performance Measurement of Energy Efficiency Programmes*. Prepared for International Energy Agency.
- Hirst, E., and J. Reed, eds. (1991). *Handbook of Evaluation of Utility DSM Programs*. Prepared for Oak Ridge National Laboratory ORNL/CON-336.

However, most of the early reference documents are not easily available to the general public (i.e., they are not posted on the Web).

E.1 Primary Impact Evaluation Resources

The key documents used in the development of this Guide are available via the Web and are presented in this section; they can be considered the current primary resources for efficiency program evaluation and project M&V. These documents are well-established *project* M&V guides and *program* evaluation protocols. They constitute the core M&V guidance documents used for energy efficiency projects in the United States and many other countries.

- **2007 International Performance Measurement and Verification Protocol (IPMVP).** The IPMVP provides an overview of current best practices for verifying results of energy efficiency, water, and renewable energy projects in commercial and industrial facilities. Internationally, it is the most recognized M&V protocol for demand-side energy activities. The IPMVP was developed with DOE sponsorship and is currently managed by a nonprofit organization[1] that continually maintains and updates it.

  The IPMVP provides a framework and definitions that can help practitioners develop M&V plans for their projects. It includes guidance on best practices for determining savings from efficiency projects. It is not a "cookbook" of how to perform specific project evaluations; rather, it provides guidance and key concepts that are used in the United States and internationally. The IPMVP is probably best known for defining four M&V Options for energy efficiency projects. These Options (A, B, C and D) differentiate the most common approaches for M&V and are presented in Chapter 5.

  Reference: Efficiency Valuation Organization (2007). *International Performance Measurement and Verification Protocol*. <http://www.evo-world.org>

- **2000 FEMP M&V Guidelines.**[2] The purpose of this document is to provide guidelines and methods for measuring and verifying the savings associated with federal agency performance contracts. It contains procedures and guidelines for quantifying the savings resulting from energy efficiency equipment, water conservation, improved operation and maintenance, renewable energy, and cogeneration projects.

  References: U.S. Department of Energy (2000). *M&V Guidelines: Measurement and Verification for Federal Energy Projects*. Version 2.2. <http://ateam.lbl.gov/mv/docs/26265.pdf>

U.S. Department of Energy (2002). *Detailed Guidelines for FEMP M&V Option A*. <http://ateam.lbl.gov/mv/docs/OptionADetailedGuidelines.pdf>

- **2002 ASHRAE Guideline 14 Measurement of Energy and Demand Savings.**[3] ASHRAE is the professional engineering society that has been the most involved in writing guidelines and standards associated with energy efficiency. Compared to the FEMP M&V Guidelines and the IPMVP, Guideline 14 is a more detailed technical document that addresses the analyses, statistics, and physical measurement of energy use for determining energy savings.

  Reference: American Society of Heating, Refrigerating, and Air-Conditioning Engineers (2002). *Guideline 14 on Measurement of Demand and Energy Savings*.

In addition, in terms of energy efficiency *program* protocols, two documents are often cited as standards in the United States for energy efficiency evaluation:

- California Public Utilities Commission (2006). *California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals*. <http://www.calmac.org/publications/EvaluatorsProtocols_Final_AdoptedviaRuling_06-19-2006.pdf>

- California Public Utilities Commission (2004). The California Evaluation Framework. <http://www.calmac.org/publications/California_Evaluation_Framework_June_2004.pdf>

These documents provide a great deal of information on evaluation options and principles for impact, process, and market evaluations of a wide variety of energy efficiency program types. In many respects, they are a more detailed version of this Guide. Along with many other evaluation reports and guidance documents, they can be found at two Web-accessible databases:

- CALifornia Measurement Advisory Council (CALMAC): http://www.calmac.org.

- The Consortium for Energy Efficiency's Market Assessment and Program Evaluation (MAPE) Clearinghouse: http://www.cee1.org/eval/clearinghouse.php3.

Readers can also look at the Proceedings of the IEPEC Conference (http://www.iepec.org) and ACEEE Summer Studies (http://www.aceee.org), where there are shorter (10- to 12-page) examples of evaluations (versus the 100+ pages for a typical evaluation study).

Three other important program guides are:

- International Energy Agency (2006). *Evaluating Energy Efficiency Policy Measures & DSM Programmes*. <http://dsm.iea.org>

- U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (2003). EERE Program Analysis and Evaluation. In *Program Management Guide: A Reference Manual for Program Management*. <http://www1.eere.energy.gov/ba/pdfs/pm_guide_chapter_7.pdf>

- U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (2007). *Impact Evaluation Framework for Technology Deployment Programs*. Prepared by J. Reed, G. Jordan, and E. Vine. <http://www.eere.energy.gov/ba/pba/km_portal/docs/pdf/2007/impact_framework_tech_deploy_2007_main.pdf>

Another important resource is the Database for Energy Efficient Resources (DEER). Sponsored by the California Energy Commission and CPUC, DEER provides estimates of energy and peak demand savings values, measure costs, and effective useful life. CPUC has designated DEER its source for deemed and impact costs for program planning. The current version (October 2005) has more than 130,000 unique records representing over 360 unique measures within the DEER dataset. The data are presented as a Web-based searchable data set: http://www.energy.ca.gov/deer/index.html.

For calculating avoided emissions, several publications prepared as part of the Greenhouse Gas Protocol Initiative were consulted. The Initiative is a multi-stakeholder partnership of businesses, non-government organizations (NGOs), governments, and others convened by the WRI and the WBCSD. The Initiative's mission is to develop internationally accepted accounting and reporting protocols for corporate emissions inventories and

greenhouse gas mitigation projects and to promote their use by businesses, policy makers, NGOs, and other organizations. It consists of three GHG accounting modules, as well as outreach activities. The accounting modules are:

- **Corporate Accounting and Reporting Standard.** Standards, guidance, and Web-based calculation tools to help companies, regulators and others develop an organization-wide greenhouse gas emissions inventory.
- **GHG Project Accounting and Reporting Protocol.** Requirements and guidance for quantifying reductions from greenhouse gas mitigation projects, such as those used to offset emissions or to generate credits in trading programs.
- **Guidelines for Quantifying GHG Reductions from Grid-Connected Electricity Projects.**

These documents are available at http://www.wri.org/climate/.

Another series of greenhouse gas guides is the International Organization for Standardization (ISO) 14064 series. There are three parts to the ISO 14064 standards:

- **ISO 14064-1,** which specifies principles and requirements at the organization level for the design, development, management, maintenance, and verification of an organization's GHG inventory.
- **ISO 14064-2,** which specifies principles and requirements and provides guidance at the project level for quantifying and reporting activities intended to cause GHG emission reductions or removal enhancements.
- **ISO 14064-3,** which specifies principles and requirements and provides guidance for those conducting or managing the validation and/or verification of GHG assertions, such as the validation or verification of an organization's GHG inventory emissions claim or a project's GHG emission reduction claim.

These can be downloaded for a fee at http://www.iso.org/.

An additional source of general reporting requirements for greenhouse gases is the California Climate Action Registry (CCAR). CCAR has published several widely used general reporting and project reporting protocols. These can be found at http://www.climateregistry.org.

E.2 Additional Resources

Berlinkski, M.P. (2006). *Quantifying Emissions Reductions from New England Offshore Wind Energy Resources.* Thesis.

California Public Utilities Commission (1998). *Protocols and Procedures for the Verification of Costs, Benefits, and Shareholder Earnings from Demand-Side Management Programs*. Prepared by the California Demand Side Management Advisory Committee. <http://www.calmac.org/cadmac-protocols.asp#>

California Public Utilities Commission (2006). *Protocols for Estimating the Load Impacts from DR Program.* Draft Version 1. Prepared by Summit Blue Consulting, LLC, and Quantum Consulting, Inc. <http://www.cpuc.ca.gov/static/HotTopics/1energy/draftdrloadimpact protocols.doc>

California State Governor's Office (2001). *California Standard Practice Manual: Economic Analysis of Demand-Side Management Programs.* <http://www.energy.ca.gov/greenbuilding/documents/background/07-J_CPUC_STANDARD_PRACTICE_MANUAL.pdf>

Chambers, A., D.M. Kline, L. Vimmerstedt, A. Diem, D. Dismukes, and D. Mesyanzhinov, D. (2005). *Comparison of Methods for Estimating the NO_X Emission Impacts of Energy Efficiency and Renewable Energy Projects: Shreveport, Louisiana Case Study.* NREL/TP-710-37721.

Con Edison (2007). *Demand Side Bidding Guidelines.* <http://www.coned.com/sales/business/targetedRFP 2007.asp>

Connecticut Department of Public Utility Control (2004). *Program Savings Documentation (PSD).* Prepared as part of The Connecticut Light and Power Company's and The United Illuminating Company's Conservation and Load Management (C&LM) Plan for Year 2005, Docket 04-11-01. <http://www.state.ct.us/dpuc/ecmb/index.html>

Efficiency Vermont (2002). *Technical Reference User Manual (TRM)*. <http://www.efficiencyvermont.com>

Electric Power Research Institute (1991). *Impact Evaluation of Demand-Side Management Programs: Volume 1: A Guide to Current Practice*. <http://www.epri.com>

Electric Power Research Institute (1992). *DSM Evaluation—Six Steps for Assessing Programs*. <http://www.epri.com>

Electric Power Research Institute (2001). *Market Transformation: A Practical Guide to Designing and Evaluating Energy Efficient Programs*. <http://www.epri.com>

High, C., and K. Hathaway (2006). *Estimation of Avoided Emission Rates for Nitrogen Oxide Resulting from Renewable Electric Power Generation in the New England, New York and PJM Interconnection Power Market Areas*. Systems Group Inc.

International Petroleum Industry Environmental Conservation Association Climate Change Working Group and American Petroleum Institute (2007). *Oil and Natural Gas Industry Guidelines for Greenhouse Gas Reduction Projects*. <http://www.ipieca.org/activities/climate_change/climate_publications.php#17>

ISO New England (2004). *NEPOOL Marginal Emission Rate Analysis for the NEPOOL Environmental Planning Committee*.

Keith, G., D. White, and B. Biewald (2002). *The OTC Emission Reduction Workbook 2.1: Description and Users' Manual—Prepared for The Ozone Transport Commission*. Synapse Energy Economics.

Keith, G., and B. Biewald (2005). *Methods for Estimating Emissions Avoided by Renewable Energy and Energy Efficiency*. Prepared for the U.S. Environmental Protection Agency. Synapse Energy Economics

La Capra Associates and MSB Energy Associates (2003). *Electric Sector Emissions Displaced Due to Renewable Energy Projects in New England. February 2003 Analysis*. Prepared for Massachusetts Technology Collaborative.

Lawrence Berkeley National Laboratory (1999). *Guidelines for the Monitoring, Evaluation, Reporting, Verification, and Certification of Energy efficiency Projects for Climate Change Mitigation*. LBNL-41877. <http://ies.lbl.gov/iespubs/41877.pdf>

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E.3 Program and Organization Web Sites

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California's Appliance Efficiency Program (including California Title 20 Appliance Standards): http://www.energy.ca.gov/appliances/index.html

California Climate Action Registry: http://www.climateregistry.org

California Demand Response Programs: http://www.energy.ca.gov/demandresponse/index.html

California Energy Commission Efficiency Programs: http://www.energy.ca.gov/efficiency/

California Green Building Initiative: http://www.energy.ca.gov/greenbuilding/index.html

California Investor-Owned Utility Energy efficiency Programs: http://www.californiaenergyefficiency.com/

California Municipal Utilities Association: http://www.cmua.org

California Solar Initiative: http://www.cpuc.ca.gov/static/energy/solar/index.htm

The Climate Trust: http://www.climatetrust.org

Efficiency Vermont: http://www.efficiencyvermont.com/pages/

Efficiency Valuation Organization: http://www.evo-world.org

European Union Energy Efficiency Directive, measurement, monitoring, and evaluation Web site: http://www.evaluate-energy-savings.eu/emeees/en/home/index.php

International Energy Program Evaluation Conference: http://www.iepec.org/

Maine State Energy Program: http://www.state.me.us/msep/

Northeast Energy Efficiency Council: http://www.neec.org

Northeast Energy Efficiency Partnerships: http://www.neep.org

Northwest Energy Efficiency Alliance: http://www.nwalliance.org/

New York State Energy Research and Development Authority: http://www.nyserda.org

Texas Energy Efficiency Programs: http://www.texasefficiency.com/

Western Renewable Energy Generation Information System: http://www.wregis.org/

United Nations Framework Convention for Climate Change, Clean Development Mechanism: http://cdm.unfccc.int/index.html

U.S. Department of Energy:

- Efficiency and renewable energy: http://www.eere.energy.gov
- 1605b Program: http://www.eia.doe.gov/environment.html

U.S. Environmental Protection Agency:

- Clean Energy Programs: http://www.epa.gov/solar/epaclean.htm
- ENERGY STAR: http://www.energystar.gov/

World Business Council for Sustainable Development: http://www.wbcsd.org

World Resources Institute: http://www.wri.org

E.4 Notes

1. The Efficiency Valuation Organization (EVO). The IPMVP and related M&V resources can be found at http://www.evo-world.org.
2. Along with the FEMP M&V Guidelines, a number of other M&V resource documents, including some on the use of stipulations for determining savings, M&V checklists, and M&V resource lists, can be found at the Lawrence Berkeley National Laboratory Web site: http://ateam.lbl.gov/mv/.
3. The Guideline can be purchased at http://www.ashrae.org. As of the publication of this document, a new version of Guideline 14 is under development.

Appendix F: Renewables and Combined Heat and Power Project Measurement and Verification

This Guide addresses energy efficiency programs. However, other clean energy program types are related to efficiency. This appendix provides a brief overview of some of the approaches to the M&V of savings from renewable electrical energy projects and combined heat and power (CHP) projects.

F.1 Renewables Project Electricity Savings

This section introduces methods for determining savings from on-grid electric renewable energy projects and discusses some related issues. There are a variety of diverse technologies that convert renewable energy into electricity. Despite individual differences, these renewable energy technologies supply electricity and reduce the use of other grid-connected sources. In contrast, energy efficiency projects reduce electricity consumption. The implication is that renewable energy project M&V for electricity savings is simpler than energy efficiency M&V. This is because, in most instances, M&V simply involves measuring the electrical output of the subject system to determine the quantity of other grid-based electricity "saved." For renewable generation that produces emissions, however, a net emissions rate for each pollutant will be needed, adding a complication to the emissions estimation step. Life cycle emissions may also be important to compare in cases where major differences between renewables and baseline systems occur upstream.

The renewable energy projects covered in this chapter are the installation of devices or systems that displace grid electricity production through the use of renewable energy resources. Examples of renewable technologies include solar photovoltaics, biomass conversion systems (e.g., landfill gas methane recovery projects), and wind generators.

F.1.1 M&V Approaches and Options

There are two general approaches for calculating electricity savings:

1. **Direct measurement.** This approach assumes that the electricity produced by the renewable system displaces energy that would have been provided by an electric generating unit (EGU). With this one-for-one replacement approach, one only needs to directly measure the net amount of energy produced by the renewable system. This approach is most common with photovoltaic, wind, and biomass electricity production projects (assuming there is no supplementary firing with fossil fuels at the biomass facility).

2. **Net-energy use calculation.** With this approach, purchased electrical energy used at the project site during the reporting period is compared with a baseline to determine the savings in electricity purchases. When a baseline is adopted, there are four methods for calculating savings as defined in the 2003 IPMVP renewables protocol (IPMVP, 2003).

   - **Comparison with a control group.** Electricity consumption of the renewable energy system is compared with the electricity consumption of a control group, with similar characteristics under similar conditions. The control group is used as the baseline.

   - **Before and after comparison.** Electricity consumption of the renewable energy system is compared with the electricity consumption measured before the renewable system was installed for the same loads. The pre-installation situation is the baseline.

   - **On and off comparison.** Electricity consumption with the renewable energy system "on" is compared

to consumption with the system "off." The baseline equals the situation with the system "off."

- **Calculated reference method.** The baseline is determined with engineering calculations, and estimated electricity consumption is compared to metered energy use when the renewable energy system is in place. This approach has the weakness of using two different analyses methods (engineering estimates and metered data) to determine a difference, i.e. the savings.

These four methods usually require measurement of electricity consumption or supply over an extended period in order to capture the variation due to changing climatic conditions.

The four IPMVP Options (A, B, C and D) can also be used for renewable energy projects. Options A and B involve measurements of system performance and are the most common. Option A involves stipulation of some parameters, while Option B requires maximum use of measurements in the energy savings analyses. Option C measures the change in whole-facility electricity use, usually with utility metering data, associated with the installation of the renewable system. Option D involves the use of computer simulations, calibrated with actual data, to determine savings from a renewable system installation.

F.1.2 Net Metering of Electrical Output and Fuel Use

In some situations, the electrical output of the renewable system is not directly indicative of electricity savings (and the avoided savings). These are when:

The system consumes electricity in order to produce electricity. The consumption is associated with what is known as *parasitic loads*. For example, a solar thermal electric system consumes electricity to power pumps that circulate fluid through the system. In these situations, either the parasitic loads have to be directly measured and subtracted from the measured output of the system, or a "net output" meter that accounts for parasitic loads is used.

The system consumes a fuel. An example is a landfill gas generation system that uses natural gas as a supplemental fuel. In these situations, incremental fuel usage must be accounted for when calculating energy savings.

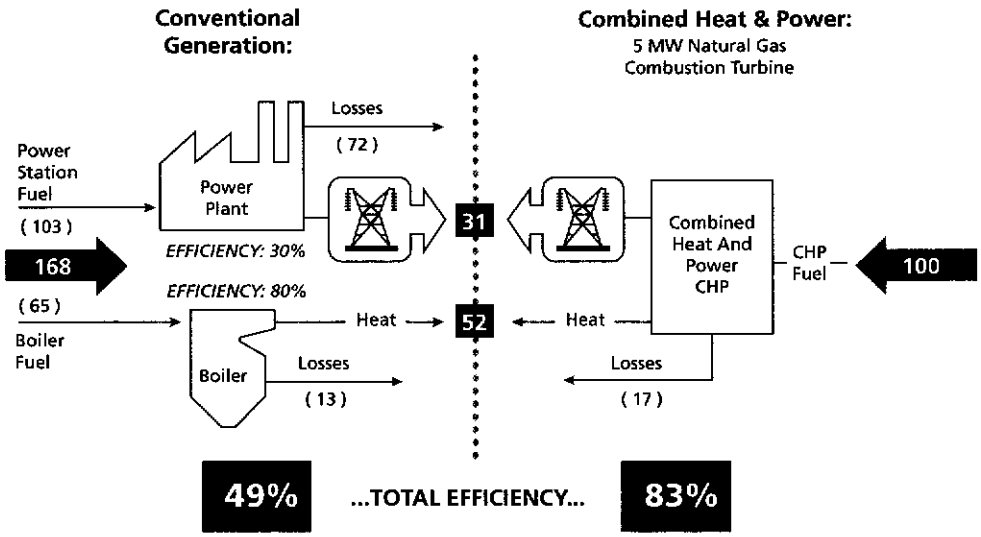
F.2 Efficiency Metrics for CHP Systems: Total System and Effective Electric Efficiencies[1]

CHP is an efficient and clean approach to generating power and useful thermal energy from a single fuel source. CHP is used either to replace or supplement conventional separate heat and power (SHP) (e.g., central station electricity available via the grid and an onsite boiler or heater). Every CHP application involves the recovery of otherwise wasted thermal energy to produce additional power or useful thermal energy; as such, CHP offers energy efficiency and environmental advantages over SHP. CHP can be applied to a broad range of applications and the higher efficiencies result in lower emissions than SHP. The advantages of CHP broadly include the following:

- The simultaneous production of useful thermal energy and power in CHP systems leads to increased fuel efficiency.
- CHP units can be strategically located at the point of energy use. Such onsite generation prevents the transmission and distribution losses associated with electricity purchased via the grid from central station plants.
- CHP is versatile and can be designed for many different applications in the industrial, commercial and institutional sectors.

Figure F.1 shows how CHP can save energy compared to SHP.2 CHP typically requires only two thirds to three quarters of the primary energy to produce the same thermal and electric service compared to separate heat and power. This reduced primary fuel consumption is key to the environmental benefits of CHP since burning the same fuel but using more of its energy means fewer emissions for the same level of output.

Figure F-1. CHP and SHP Energy Savings



Efficiency is a prominent metric used to evaluate CHP performance and compare it to SHP. Two methodologies are most commonly used to determine the efficiency of a CHP system: total system efficiency and effective electric efficiency.

F.2.1 Key Terms Used in Calculating CHP Efficiency

Calculating a CHP system's efficiency requires an understanding of several key terms, described below.

- **CHP system.** The CHP system includes the unit in which fuel is consumed (e.g. turbine, boiler, engine), the electric generator, and the heat recovery unit that transforms otherwise wasted heat to useable thermal energy.

- **Total fuel energy input (QFUEL).** The energy associated with the total fuel input. Total fuel input is the sum of all the fuel used by the CHP system. The total fuel energy input is often determined by multiplying the quantity of fuel consumed by the heating value of the fuel.[3]

  Commonly accepted heating values for natural gas, coal, and diesel fuel are:

  - 1020 Btu per cubic foot of natural gas
  - 10,157 Btu per pound of coal
  - 138,000 Btu per gallon of diesel fuel

- **Net useful power output (W_E).** Net useful power output is the gross power produced by the electric generator minus any parasitic electric losses. An example of a parasitic electric loss is the electricity that may be used to compress the natural gas before the gas can be fired in a turbine.

- **Net useful thermal output (SQ_{TH}).** Net useful thermal output is equal to the gross useful thermal output of the CHP system minus the thermal input. An example of thermal input is the energy of the condensate return and makeup water fed to a heat recovery steam generator. Net useful thermal output represents the otherwise wasted thermal energy that was recovered by the CHP system and used by the facility.

Gross useful thermal output is the thermal output of a CHP system utilized by the host facility. The term *utilized* is important here. Any thermal output that is not used should not be considered. Consider, for example, a CHP system that produces 10,000 pounds of steam per hour, with 90 percent of the steam used for space heating and the remaining 10 percent exhausted in a cooling tower. The energy content of 9,000 pounds of steam per hour is the gross useful thermal output.

F.2.2 Which CHP Efficiency Metric Should You Select?

The selection of an efficiency metric depends on the purpose of calculating CHP efficiency.

- If the objective is to compare CHP system energy efficiency to the efficiency of a site's SHP options, then the *total system efficiency metric* may be the right choice. Calculation of SHP efficiency is a weighted average (based on a CHP system's net useful power output and net useful thermal output) of the efficiencies of the SHP production components. The separate power production component is typically 33 percent efficient grid power. The separate heat production component is typically a 75- to 85-percent-efficient boiler.
- If CHP electrical efficiency is needed for a comparison of CHP to conventional electricity production (i.e., the grid), then the *effective electric efficiency metric* may be the right choice. Effective electric efficiency accounts for the multiple outputs of CHP and allows for a direct comparison of CHP and conventional electricity production by crediting that portion of the CHP system's fuel input allocated to thermal output.

Both the total system and effective electric efficiencies are valid metrics for evaluating CHP system efficiency. They both consider all the outputs of CHP systems and, when used properly, reflect the inherent advantages of CHP. However, since each metric measures a different performance characteristic, use of the two different metrics for a given CHP system produces different values.

For example, consider a gas turbine CHP system that produces steam for space heating with the following characteristics:

Fuel input (MMBtu/hr)	57
Electric output (MW)	5.0
Thermal output (MMBtu/hr)	25.6

According to the total system efficiency metric, the CHP system efficiency is 75 percent: (5.0 × 3.413 + 25.6) ÷ 57).

Using the effective electric efficiency metric, the CHP system efficiency is 68 percent: (5.0 × 3.413) ÷ (57 – (25.6/0.8)).

Calculating Total System Efficiency

The most common way to determine a CHP system's efficiency is to calculate *total system efficiency*. Also known as *thermal efficiency*, the total system efficiency (η_o) of a CHP system is the sum of the net useful power output (W_E) and net useful thermal outputs (SQ_{TH}) divided by the total fuel input (Q_{FUEL}):

$$\eta_o = \frac{W_E + \Sigma Q_{TH}}{Q_{FUEL}}$$

The calculation of total system efficiency is a simple and useful method that compares what is produced (i.e., power and thermal output) to what is consumed (i.e., fuel). CHP systems with a relatively high net useful thermal output typically correspond to total system efficiencies in the range of 60 to 85 percent.

Note that this metric does not differentiate between the value of the power output and the thermal output; instead, it treats power output and thermal output as additive properties with the same relative value. In reality and in practice, thermal output and power output are not interchangeable because they cannot be converted easily from one to another. However, typical CHP applications usually have coincident power and thermal demands that must be met. It is reasonable, therefore, to consider the values of power and thermal output from a CHP system to be equal in many situations.

Calculating Effective Electric Efficiency

Effective electric efficiency calculations allow for a direct comparison of CHP to conventional power generation system performance (e.g., electricity produced from central stations, which is how the majority of electricity is produced in the United States). Effective electric efficiency accounts for the multiple outputs of CHP and allows for a direct comparison of CHP and conventional electricity production by crediting that portion of the CHP system's fuel input allocated to thermal output. The calculation of effective electric efficiency is analogous to the method many states use to apply a CHP thermal credit to output-based emissions estimates.

Effective electric efficiency (e_{EE}) can be calculated using the equation below, where (W_E) is the net useful power output, (SQ_{TH}) is the sum of the net useful thermal outputs, (Q_{FUEL}) is the total fuel input, and α equals the efficiency of the conventional technology that otherwise would be used to produce the useful thermal energy output if the CHP system did not exist:

$$\varepsilon_{EE} = \frac{W_E}{Q_{FUEL} - \Sigma\,(Q_{TH} / \alpha)}$$

For example, if a CHP system is natural gas–fired and produces steam, then α represents the efficiency of a conventional natural gas–fired boiler. Typical α values for boilers are 0.8 for a natural gas–fired boiler, 0.75 for a biomass-fired boiler, and 0.83 for a coal-fired boiler.

The effective electric efficiency is essentially the CHP net electric output divided by the fuel the CHP system consumes over and above what would have been used by conventional systems to produce the thermal output for the site. In other words, this metric measures how effectively the CHP system generates power once the thermal demand of a site has been met.

Typical effective electrical efficiencies for combustion turbine–based CHP systems are in the range of 50 to 75 percent. Typical effective electrical efficiencies for reciprocating engine–based CHP systems are in the range of 65 to 80 percent.

Obtaining the Required Data to Calculate CHP System Performance

Typically, CHP systems are sized so that their full electric and thermal output can be used during most of the year. Thermal output is always available from the CHP system when it is running; however, it is only useful when it can be applied to meet specific thermal loads at the site. The useful thermal output from the CHP system displaces load from a boiler, furnace, chiller, or other system. Many thermal loads, such as space heating, only occur for part of the year. As such, the utilization of the thermal output of a CHP system can vary with time of day, month, or season. The annual impact of these variations must be considered to accurately account for the efficiency benefits of CHP systems.

A reasonable M&V program for CHP systems must be able to credibly estimate the net power output and useful thermal output on an annual basis, yet impose only minimal additional burden on the end-user. An effective M&V plan must define the CHP system boundaries, identify applicable thermal loads and how they are served by the CHP system, include simple measurement and calculations approaches, and specify reporting requirements. The plan can be based on key performance assumptions and design estimates contained in initial permit applications. These assumptions can be verified with steady-state measurements at commissioning. However, the primary approach to verifying net power and useful thermal output of a system is long-term cumulative measurement or readings of power and thermal output from the system. These readings can be obtained through the installation of specific metering equipment (as an example, power metering is likely to be installed on most CHP systems; often, electric meters are required by an area's local utility as part of the interconnection requirements), or in many cases through the CHP system's automated control system, programmed to accumulate and log power and thermal data. Cumulative readings of system output can be collected either monthly or annually. The M&V plan should contain procedures to confirm the completeness of the information and the validity of any calculations that estimate thermal energy actually used based on measured system output.

The plan should also recognize that the CHP system may not operate for brief periods during the year due to planned maintenance or unscheduled outages. The availability[4] of CHP systems is an important component of overall system performance, and affects the reliability of power and thermal supply to the user. In general, the availability of CHP systems is high and the use of CHP systems operating in parallel to the grid often improves the reliability of energy supply to the site. The most recent comprehensive review of DG/CHP availability was conducted for Oak Ridge National Laboratory in 2003 (Energy and Environmental Analysis, 2004). Of the systems studied, the availability factor for reciprocating

engines averaged 96 to 98 percent. Gas turbines had availability factors ranging from 93 to 97 percent.

F.3 Notes

1. This section was provided by the U.S. EPA.
2. Conventional power plant efficiency based on average U.S. fossil heat rate of 12,215 Btu/kWh (2004 eGRID) and average T&D losses of 7 percent; comparison assumes that thermal energy produced by the CHP system is used on site.
3. Fuel heating values are denoted as either lower heating value (LHV) or higher heating value (HHV). HHV includes the heat of condensation of the water vapor in the products of combustion. Unless otherwise noted, all heating value and efficiency measures in this section are reported on an HHV basis.
4. The availability factor is the proportion of hours per year that a unit "could run" (based on planned and unplanned maintenance) divided by the total hours in the year.

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Ameren Ex 7.2

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