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Environmental Technology Verification (ETV) Program Case Studies

DEMONSTRATING PROGRAM OUTCOMES

volume 3.

Office of Research and Development
National Risk Management Research Laboratory

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Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments, and groundwater; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment, advancing scientific and engineering information to support regulatory and policy decisions, and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

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Decentralized Wastewater Treatment Technologies: Joyce Hudson, EPA Office of Water; Barry Tonning, Tetra Tech; Thomas Stevens, NSF International; Raymond Frederick, EPA Office of Research and Development, National Risk Management Research Laboratory; and Claude Smith, International Wastewater Systems, Inc.

Waste-to-Energy Technologies: Rachel Goldstein, EPA Landfill Methane Outreach Program; Neeharika Naik-Dhungel, EPA Combined Heat and Power Partnership; Christopher Voell and Kurt Roos, EPA AgSTAR Program; P. Ferman Milster, University of Iowa; Doug Tolrud, Minnesota Power; James Foster, New York State Energy Research and Development Authority; Timothy Hansen, Southern Research Institute; Lee Beck and Julius Enriquez, EPA Office of Research and Development, National Risk Management Research Laboratory; Joseph Staniunas, UTC Power; and Jim Mennell, renewaFUEL, LLC.

All Case Studies: J. E. Smith; Patrick Topper, The Pennsylvania State University; and Teresa Harten, Evelyn Hartzell, and Abby Waits, EPA Office of Research and Development, National Risk Management Research Laboratory.

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Exhibits

Acronyms and Abbreviations

AQMD	Air Quality Management District
ARRA	American Recovery and Reinvestment Act of 2009
ASERTTI	Association of State Energy Research and Technology Transfer Institutions
ASTM	American Society for Testing and Materials
BAT	best available technology
BOD	biochemical oxygen demand
BOD_5	5-day biochemical oxygen demand
Btu	British thermal unit
CH_4	methane
CHP	combined heat and power
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
COD	chemical oxygen demand
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
ESTCP	Environmental Security Technology Certification Program
ESTE	Environmental and Sustainable Technology Evaluation
EVRU	Eductor Vapor Recovery Unit
g/h	grams per hour
GHG	greenhouse gas
GPRA	Government Performance and Results Act
H_2S	hydrogen sulfide
IPCC	Intergovernmental Panel on Climate Change
IWS	International Wastewater Systems
kW	kilowatt
kWh	kilowatt-hour
lbs	pounds
lbs/h	pounds per hour
lbs/kWh	pounds per kilowatt-hour
LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
MACT	maximum achievable control technology
MassDEP	Massachusetts Department of Environmental Protection
mg/L	milligrams per liter
MGD	millions of gallons per day
MMBtu/h	British thermal unit per hour
MOU	Memorandum of Understanding
MW	megawatt
MWh	megawatt-hour
N_2O	nitrous oxide
NaOH	sodium hydroxide
NPDES	National Pollutant Discharge Elimination System
NO_x	nitrogen oxides
NYPA	New York Power Authority
NYSERDA	New York State Energy Research and Development Authority
OAQPS	Office of Air Quality Planning and Standards
OAR	Office of Air and Radiation
ODW	Office of Drinking Water

OPP	Office of Pesticide Programs
OWHH	outdoor wood-fired hydronic heaters
PM	particulate matter
PON	Program Opportunity Notice
ppb	parts per billion
ppm	parts per million
ppmv	parts per million by volume
RCCH	RCC Holdings Corporation
REC	Rapids Energy Center
SBR	sequencing batch reactor
SO_2	sulfur dioxide
SWTS	subsurface wastewater treatment system
Tg	teragram
THCs	total hydrocarbons
TSS	total suspended solids
TxLED	Texas Low Emission Diesel
UI	University of Iowa
USDA	U.S. Department of Agriculture
UV	ultraviolet
VIWMA	Virgin Islands Waste Management Authority
VOC	volatile organic compound

1. Introduction and Summary

1.1 Purpose

This document contains two case studies that highlight some of the actual and potential outcomes and benefits of the United States Environmental Protection Agency's (EPA's) Environmental Technology Verification (ETV) Program. The ETV Program was initiated in 1995 to verify the performance of innovative technologies that have the potential to improve human health and the environment. The program operates, in large part, as a public-private partnership through competitive cooperative agreements between EPA and the nonprofit testing and evaluation organizations—called ETV verification organizations—listed in Exhibit 1.1-1. ETV also verifies technologies to address EPA high-priority environmental problems through Environmental and Sustainable Technology Evaluation (ESTE) projects; these verifications are performed under contracts.

The ETV Program develops testing protocols and publishes detailed performance results in the form of verification reports and statements, which can be found on ETV's Web Site (http://www.epa.gov/etv/verifiedtechnologies.html). EPA technical and quality assurance staff review the protocols, test plans, verification reports, and verification statements to ensure that the verification data have been collected, analyzed, and presented in a manner that is consistent with EPA's quality assurance requirements. ETV also relies on the active participation of environmental technology information customers in technology-specific stakeholder groups. ETV stakeholders represent the end-users of verification information and assist in developing protocols, prioritizing technology areas to be verified, reviewing documents, and conducting outreach to the customer groups

Exhibit 1.1-1

ETV Centers and Verification Organizations

ETV Center	Verification Organization	Technology Areas and Environmental Media Addressed
ETV Advanced Monitoring Systems Center	Battelle	Air, water, and soil/surface monitoring Site characterization
ETV Air Pollution Control Technology Center	RTI International	Air pollution control
ETV Drinking Water Systems Center	NSF International	Drinking water treatment
ETV Greenhouse Gas Technology Center	Southern Research Institute	Greenhouse gas reduction, mitigation, and sequestration Advanced and renewable energy generation
ETV Materials Management and Remediation Center	Battelle	Materials management, recycling, and reuse Contaminated land and groundwater remediation
ETV Water Quality Protection Center	NSF International	Storm and wastewater control and treatment

they represent. Through rigorous and quality-assured testing, ETV provides credible performance information for commercial-ready environmental technologies. This information can help vendors market and sell their technologies and help users make purchasing decisions. Ultimately, the environment and public health benefit.

The Government Performance and Results Act (GPRA) of 1993 holds federal agencies accountable for using resources wisely and achieving program results. Among other things, GPRA requires agencies to measure their performance and communicate this information to Congress and the public. In measuring performance, GPRA distinguishes between "output" measures, which assess a government program's activities in their simplest form, and "outcome" measures, which assess the results of these activities compared to their intended purpose.

Initially, the ETV Program measured its performance with respect to outputs; for example, the number of technologies verified and testing protocols developed. ETV expanded its approach to include measurement and estimation of outcomes, such as potential pollution reductions attributable to the use of ETV technologies and subsequent health or environmental impacts. In 2006, ETV published two case study booklets, *Environmental Technology Verification (ETV) Program Case Studies: Demonstrating Program Outcomes, Volume I* (EPA/600/R-06/001, January 2006) and *Volume II* (EPA/600/R-06/082, September 2006). These booklets contain 15 case studies and one update. This new booklet builds on the original case studies and features newer technology areas. The case studies presented here highlight how the program's outputs (verified technologies and protocols) translate into actual and potential outcomes. The program also uses the case studies to communicate information about verified technology performance, applicability, and ETV testing requirements to the public and decision-makers.

In reviewing these case studies, the reader should keep in mind the following:

- Given the current state of science, there can be considerable uncertainty in assessing environmental outcomes and human health benefits. Therefore, many of the outcomes quantified in these case studies are described as "potential" outcomes and should be treated as estimates only.
- Vendors of ETV-verified technologies are not required to track their sales or report the impacts of ETV verification to EPA. Therefore, the ETV Program does not have access to a comprehensive set of sales data for the verified technologies. Faced with this limitation, ETV has estimated outcomes using market penetration scenarios. That is, ETV has estimated the total potential market for a given technology or technology group and applied scenarios (e.g., 10% and 25% of the market) to project the potential number of installations for the technology category. Of course, in cases in which sales information is available, ETV incorporates this information into the outcomes estimates (see, for example, the case study in Chapter 2).
- The ETV Program calculated the outcomes in these case studies by combining the verified performance results (which can be found in the verification reports and statements at http://www.epa.gov/etv/verifiedtechnologies.html) with data from publicly available sources (e.g., regulatory impact analyses), reasonable assumptions, and logical extrapolations.
- These case studies are not intended as a basis for making regulatory decisions, developing or commenting on policy, or choosing to purchase or sell a technology. They merely are intended to show potential benefits or other outcomes that could be attributed to verification and verified technology use.
- The ETV Program does not rate or compare technologies. Where possible, when a case study discusses a group of similar verified technologies, it summarizes performance as a range of results. When results are listed in a tabular format, vendor and product names are arranged by technology category or are listed in alphabetical order by company or technology name. Technologies or technology areas were selected for inclusion in these case studies because information on program outcomes was available.
- Verified technology performance data and other information found in the verification reports were used, in part, to develop the case studies. The cooperative agreement recipients, or ETV verification organizations, make the final decisions on the content of the verification reports. These reports are the products of the ETV cooperative agreement recipients. EPA technical and quality assurance staff review the protocols, test plans, verification reports, and verification statements to ensure that the data have been collected, analyzed, and presented in a manner that is consistent with EPA's quality assurance requirements.

- ETV verification organization representatives, EPA project officers, and appropriate program office and other EPA personnel have reviewed the case studies throughout the development process (see Acknowledgements). These reviews, as well as external peer review, were performed to ensure that the information presented in the case studies is technically accurate, consistent with the Agency's current understanding of the underlying issues, summarized fairly, and, in the case of potential outcomes, estimated in a reasonable manner. Vendors also were provided with an opportunity to review the case studies.
- EPA does not endorse the purchase or sale of any of the products and services from companies mentioned in this document. Also, the use of company- and/or product-specific sales information, images, quotations, or other outcomes-related information does not constitute the endorsement of any verified company or product over another, nor do the comments made by these organizations necessarily reflect the views of EPA.

1.2 Organization and Scope

This document includes two case studies featuring the following technology areas: decentralized wastewater treatment technologies (Chapter 2) and waste-to-energy technologies for power generation and heat recovery (Chapter 3). Each chapter also includes a complete list of references. A set of appendices provide a detailed discussion of the methods used to estimate outcomes in the case studies. In addition to outcomes information presented for the technology categories above, Appendix C lists recent examples of ETV outcomes—how ETV data, reports, and protocols have been used in regulation, permitting, purchasing, and other decision-making and similar activities—for other technologies or technology areas.

Exhibit 1.2-1 identifies the case studies, the ETV center that verified each technology or technology area, and the priority environmental topics and significant pollutants addressed by each.

Exhibit 1.2-1

Case Studies, ETV Centers, and Priority Environmental Topics and Significant Pollutants

Case Study	ETV Center	Priority Environmental Topics	Significant Pollutants
Decentralized Wastewater Treatment Technologies (Chapter 2)	Water Quality Protection	Decentralized wastewater systems, drinking and groundwater protection, watershed protection, community development	Nitrogen, phosphorus, total suspended solids, biochemical oxygen demand, chemical oxygen demand, total coliform bacteria
Waste-to-Energy Technologies: Biomass Co-Fired Boilers (Chapter 3)	Greenhouse Gas Technology	Greenhouse gases, waste-to-energy, industrial emissions	Carbon dioxide, nitrogen oxides, sulfur dioxide, carbon monoxide, particulate matter
Waste-to-Energy Technologies: Distributed Generation Energy Systems (Chapter 3)	Greenhouse Gas Technology	Greenhouse gases, waste-to-energy, animal feeding operations, landfills, wastewater treatment	Carbon dioxide, nitrogen oxides, sulfur dioxide, methane, carbon monoxide, particulate matter, ammonia, total hydrocarbons
Waste-to-Energy Technologies: Gas Processing Systems (Chapter 3)	Greenhouse Gas Technology	Greenhouse gases, waste-to-energy, animal feeding operations, landfills, wastewater treatment	Carbon dioxide, nitrogen oxides, hydrogen sulfide and other sulfur compounds, hydrocarbons, methane, halides, volatile organic compounds

Each case study begins with an introduction, followed by three sections. The first section, "Environmental, Health, and Regulatory Background," describes the pollutant or environmental issue(s) that the technology is designed to address, human health and environmental impacts associated with the pollutant or issue, and regulatory programs or voluntary initiatives that apply. The second section, "Technology Description," describes the technology(ies), identifies what makes the technology(ies) innovative, and summarizes the performance results as verified by ETV. The third section, "Outcomes," presents the ETV Program's estimates of actual and potential outcomes from verification and from applying the technology. These outcomes may include:

- Pollutant reduction outcomes, such as tons of pollutant emissions reduced by potential applications of the technology.
- Resource conservation outcomes, such as the types of natural resources that the technology can conserve.
- Economic and financial outcomes, such as the economic value of cost savings to users of the technology.
- Regulatory compliance outcomes, such as how the technology can assist users in complying with federal and state regulations.
- Technology acceptance and use outcomes, such as evidence that ETV verification has led to increased use of the technology.
- Scientific advancement outcomes, such as improvements in technology performance and standardization of technology evaluation or development of a protocol that has advanced efforts to standardize protocols across programs.

Within outcome categories, the ETV Program has made every effort to quantify (i.e., place a numerical value on) the outcome. For instances in which insufficient data were available to quantify an outcome, the case studies present information about that outcome and describe its potential significance qualitatively.

Each case study is written to stand on its own, so that readers interested in one or more technology categories can comprehend the section(s) of interest without needing to review the full document. For this reason, each case study spells out all acronyms (other than EPA and ETV) on first use (even if they have been used in previous case studies) and includes its own acronyms list at the end of the section. For readers who wish to review both case studies together, a complete list of acronyms is included at the beginning of this document. Additionally, Appendix C also contains its own list of acronyms and abbreviations.

1.3 Summary of Outcomes

The case studies presented here address a variety of pollutants and environmental issues (see Exhibit 1.2-1). As discussed previously, the ETV Program examined different types of outcomes and attempted, within the limits of the available data, to quantify each outcome. This section identifies the types of outcomes associated with each case study or subtopics within the case studies and provides examples of the most significant, quantifiable actual and potential outcomes. Exhibit 1.3-1 lists the case studies with the types of outcomes identified in each. It also indicates which of the outcomes the ETV Program was able to quantify.

Examples of significant potential outcomes from those identified in Exhibit 1.3-1, which are described in further detail within the case studies, include the following:

- Based on current installations, the ETV-verified decentralized wastewater treatment technology, when compared to traditional technologies, reduced total nitrogen discharges during the 3-year period since installation by 0.14 tons (0.25 pounds [lbs]/day on average) at one site and by 0.21 tons (0.38 lbs/day on average) at a second site; total suspended solids (TSS) discharge was reduced by 1.6 tons (3.0 lbs/day on average) and 2.4 tons (4.5 lbs/day on average) at each site, respectively. During the same time period, 5-day biochemical oxygen demand (BOD_5) was reduced by 4.2 tons (7.7 lbs/day on average) and 6.3 tons (11 lbs/day on average) at each site, respectively.
- Based on near-term pending installations (to occur during 2010), the ETV-verified decentralized wastewater treatment technology could produce additional annual pollutant reductions of 110 to 220 lbs (an average of 0.30 to 0.61 lbs/day) of nitrogen, 0.65 to 1.3 tons (3.6 to 7.1 lbs/day on average) of TSS, and 1.7 to 3.4 tons (9.2 to 18 lbs/day on average) of BOD_5 when compared to traditional technologies.
- A decentralized wastewater treatment technology vendor reports that demonstrated technology perfor-

Exhibit 1.3-1

Types of Outcomes Identified for Each Case Study

Case Study	Pollutant or Emissions Reduction	Resource Conservation	Economic and Financial	Regulatory Compliance	Technology Acceptance and Use	Scientific Advancement
Decentralized Wastewater Treatment Technologies (Chapter 2)	Q		Q	X	Q	
Waste-to-Energy Technologies: Biomass Co-Fired Boilers (Chapter 3)	Q	X	X	X	X	X
Waste-to-Energy Technologies: Distributed Generation Energy Systems (Chapter 3)	Q	X	Q		X	X
Waste-to-Energy Technologies: Gas Processing Systems (Chapter 3)		X	X		X	

Q = ETV identified this type of outcome and was able to quantify its potential impact.
X = ETV identified this type of outcome but was not able to quantify its potential impact.
Blank = ETV did not identify this type of outcome.

mance through verification resulted in five projects totaling $1.4 million in revenue and that ETV verification testing has had indirect benefits in the form of added company value and partnerships; the vendor estimates that the total value added to the company as a result of participation in ETV could be as much as $5 million.

- Using 10% and 25% market penetration scenarios, the ETV-verified decentralized wastewater treatment technology could potentially be applied at approximately 140 to 350 residential clusters of homes with annual pollutant reductions of 0.58 to 1.4 tons of nitrogen (3.2 to 7.9 lbs/day on average), 6.8 to 17 tons of TSS (37 to 93 lbs/day on average), and 18 to 44 tons of BOD_5 (96 to 240 lbs/day on average) when compared to traditional septic systems; associated environmental and human health benefits also could be realized.

- At least nine states currently use ETV protocols in the evaluation of alternative technologies for wastewater treatment, and three identify the protocol used for the verification described in the decentralized wastewater treatment technologies case study.

- Based on current installations, eight ETV-verified fuel cell distributed generation systems in operation at wastewater treatment plants in or near New York City reduce carbon dioxide (CO_2) emissions by more than 11,000 tons per year. The vendor reports that, cumulatively, these fuel cell installations have generated more than 56,000 megawatt-hours of electricity with an associated economic value of $5.6 million.

- The ETV-verified distributed power generation systems highlighted in the waste-to-energy technologies case study could potentially be applied, using 10% and 25% market penetration scenarios, at:

  - Approximately 820 to 2,100 animal feeding operations with annual CO_2 equivalent emissions reductions of up to 5.9 million to 15 million tons and associated climate change, environmental, and human health benefits.

  - Approximately 44 to 110 wastewater treatment facilities with annual CO_2 equivalent emissions reductions of 63,000 to 160,000 tons and annual nitrogen oxides emissions reductions of 80 to 200 tons; associated climate change, environmental, and human health benefits also could be realized.

- The estimated potential energy generation and cost benefits of using the ETV-verified distributed generation technologies described in the waste-to-energy technologies case study at 10% and 25% market penetration are as follows:

    - If candidate animal feeding operations used these technologies, up to 1.4 million to 3.5 million megawatts (MW) of electricity could be generated annually with associated cost benefits of up to $140 million to $350 million.

    - If candidate landfills used these technologies, up to 75,000 to 190,000 MW of electricity could be generated annually with associated cost benefits of up to $7.5 million to $19 million.

    - If candidate wastewater treatment facilities used these technologies, 74,000 to 190,000 MW of electricity could be generated annually with associated cost benefits of $7.4 million to $19 million.

- ETV verification results from the biomass co-fired boilers described in the waste-to-energy technologies case study were used to assist in permit analysis and permitting of test burns at universities, public utilities, and large industrial operations in five states.

2. Decentralized Wastewater Treatment Technologies

The ETV Program's Water Quality Protection Center, operated by NSF International under a cooperative agreement with EPA, has verified the performance of a decentralized wastewater treatment technology designed for use in areas that are not served by centralized wastewater treatment facilities (sewers and municipal sewage treatment plants) and expects to verify another technology in 2010. Decentralized wastewater systems treat wastewater close to the source, and most discharge directly to the soil. Decentralized systems include septic systems that provide treatment to individual homes and larger capacity systems that treat discharges from clusters of homes, businesses, subdivisions, or small towns (U.S. EPA, 2005a; NSF International, 2006). This case study focuses on larger capacity systems, like the International Wastewater Systems, Inc. Model 6000 sequencing batch reactor (SBR) verified by ETV[1], that are used to treat discharges of approximately 5,000 gallons per day or more.

High-volume decentralized wastewater treatment systems can have economic and ecological advantages compared to centralized systems when used in appropriate locations. They can be more protective of groundwater and surface water quality, allowing for new development in areas with nondegradation limits, and can lead to decreased threats to public health if used to replace failing or improperly maintained septic systems. The technology verified by ETV uses a combination of biological treatment, sand filtration, and ultraviolet (UV) treatment to treat wastewater generated by a small cluster of homes, thereby greatly decreasing levels of bacterial contaminants and pollutants such as nitrogen and phosphorus in the water.

Section 2.3 of this case study presents the ETV Program's estimates of verification outcomes from actual and potential applications of the technology. Appendix A provides a detailed description of the methodology and assumptions used to estimate these outcomes. Using the analyses in this case study, ETV reports the following outcomes:

The 50-home Trellis Subdivision in Eagle, Idaho, that uses the International Wastewater Systems, Inc. Model 6000 SBR.

- Based on current installations, the ETV-verified decentralized wastewater treatment technology, when compared to traditional technologies, reduced total nitrogen discharges during the 3-year period since installation by 0.14 tons (0.25 pounds [lbs]/day on average) at one site and by 0.21 tons (0.38 lbs/day on average) at a second site; total suspended solids (TSS) discharge was reduced by 1.6 tons (3.0 lbs/day on average) and 2.4 tons (4.5 lbs/day on average) at each site, respectively. During the same time period, 5-day biochemical oxygen demand (BOD_5) was reduced by 4.2 tons (7.7 lbs/day on average) and 6.3 tons (11 lbs/day on average) at each site, respectively.
- Based on near-term pending installations (to occur during 2010), the technology could produce additional annual pollutant reductions of 110 to 220 lbs (an average of 0.30 to 0.61 lbs/day) of nitrogen, 0.65 to 1.3 tons (3.6 to 7.1 lbs/day on average) of TSS, and 1.7 to 3.4 tons (9.2 to 18 lbs/day on average) of BOD_5, when compared to traditional technologies.
- The vendor reports that verification of technology performance resulted in five projects totaling $1.4 million in revenue and that ETV verification testing has had indirect benefits in the form of added company value and partnerships; the vendor estimates that the total value added to the company as a result of participation in ETV could be as much as $5 million.
- Using 10% and 25% market penetration scenarios, the ETV-verified decentralized wastewater treatment technology could potentially be applied at approximately 140 to 350 residential clusters of homes

1. At the time of verification (2006), the technology was manufactured by International Wastewater Systems, Inc. In 2007, RCC Holdings Corporation purchased International Wastewater Systems, Inc., renaming the company International Wastewater Systems. In 2009, the company filed paperwork to modify its corporate name to IWS Water Solutions, Inc., but will maintain use of the name International Wastewater Systems.

with annual pollutant reductions of 0.58 to 1.4 tons of nitrogen (3.2 to 7.9 lbs/day on average), 6.8 to 17 tons of TSS (37 to 93 lbs/day on average), and 18 to 44 tons of BOD_5 (96 to 240 lbs/day on average), when compared to traditional septic systems; associated environmental and human health benefits also could be realized.

Additionally, technologies such as the one verified by ETV provide an opportunity to re-use the reclaimed water to benefit the local community. The treated effluent from such systems is of high enough quality that it can be used for landscape irrigation. For example, reclaimed water from treatment systems similar to those verified by ETV has been used to water golf courses and school athletic fields in the immediate vicinity (International Wastewater Systems, 2010). Other benefits of ETV verification include the establishment of a well-accepted protocol that has advanced efforts to standardize protocols across programs. At least nine states currently use ETV protocols in the evaluation of alternative technologies for wastewater treatment, and three specifically identify the protocol used for the verification described in this case study.

2.1 Environmental, Human Health, and Regulatory Background

Well-designed and well-managed decentralized wastewater treatment systems, including onsite and septic systems and larger capacity cluster systems, can help protect human health and water quality. These systems can have economic and ecological advantages compared to centralized systems when used in appropriate locations. Decentralized wastewater systems treat and disperse wastewater as close as possible to its source and maximize re-use opportunities. They use relatively low-cost equipment and release small volumes of treated wastewater to the environment at multiple locations (EPA, 2010a). When used in existing developments, decentralized systems can serve dense areas with small lots, considerably improve treatment levels, and increase groundwater recharge to a great extent, which in turn conserves water within the watershed. In new developments, these systems can provide advanced treatment for sites with poor soils, steep slopes, or high groundwater. They are useful to promote smart growth and low-impact development and foster the preservation of woodlands and open space by promoting the clustering of homes and businesses. Other advantages include enhanced assimilation via multiple smaller discharges, avoidance of large mass loadings at outfalls, and malfunction risks that are small and easier to manage compared to centralized systems (EPA, 2008d).

In the past, decentralized wastewater treatment systems commonly were viewed as temporary approaches to waste management and were intended for use only until centralized treatment systems could be installed. There are many situations (e.g., low-density communities, hilly terrain, ecologically sensitive areas) in the United States, however, in which centralized systems are neither the most cost effective nor the most sustainable treatment option for a variety of reasons. Under these circumstances, decentralized systems should be considered long-term solutions (Rocky Mountain Institute, 2004; Siegrist, 2001; U.S. EPA, 1997a).

Decentralized wastewater treatment systems can be major sources of groundwater and surface water contamination if they are improperly sited, operated, or maintained (U.S. EPA, 2005c). Typical pollutants from these systems can include suspended solids, bacteria and other pathogens, biodegradable organics, nitrogen, phosphorus, and other inorganic and organic chemicals (U.S. EPA, 2005b). Conventional onsite wastewater treatment systems remove solids, biodegradable organic compounds, and fecal coliform. These systems, however, may not be adequate for minimizing nitrate contamination of groundwater, removing phosphorus, and treating pathogenic organisms (U.S. EPA, 2002). States have identified improperly maintained septic systems as the second most frequently reported groundwater contaminant source (U.S. EPA, 2010b). When used to replace failing or malfunctioning systems or as an alternative to conventional septic systems, modern decentralized wastewater treatment systems can decrease nitrogen, phosphorus, and bacterial discharges to groundwater and surface water, thereby protecting environmental quality and reducing public health threats.

Approximately one-half of the U.S. population relies on groundwater for its drinking water supply, with groundwater being the sole source of drinking water in many rural areas and some large cities. Groundwater used for drinking water can have substantial problems with nitrate contamination, a significant source of which is improperly installed or maintained decentralized wastewater treatment systems. In areas that rely on groundwater for drinking water, high levels of nitrate and nitrite in the water can pose a health hazard. Excessive nitrate or nitrite in drinking water can increase the risk of methemoglobinemia in infants who drink formula made with the water (Greer, et al., 2005). Methemoglobinemia is a disorder in which excessive levels of methemoglobin, a form of hemoglobin that cannot carry oxygen, accumulate in the body, causing illness. To protect against this hazard, under the Safe Drinking Water Act, EPA requires that nitrate concentrations in drinking water not exceed 10 milligrams per liter (mg/L) as nitrogen (56 FR 3526). Although many sources, including inorganic fertilizer, animal manure, and particles from industry or automobiles, may contribute to nitrogen contamination of groundwater, improperly maintained decentralized wastewater systems are a significant source of nitrogen contamination in some areas. For example, in one area of Nevada, these systems were found to be responsible for almost all of the nitrogen pollution of the local groundwater—an important problem because the community relies on groundwater for its drinking water supply, and nitrogen contamination has increased to near the EPA maximum contaminant level (U.S. Geological Survey, 2006).

Decentralized wastewater treatment systems also may contribute to bacterial contamination of drinking water sources. EPA estimates that 185,000 viral illnesses occur each year as a result of consumption of drinking water from systems that rely on groundwater contaminated by improperly treated wastewater (71 FR 65573). The contaminants of primary concern are waterborne pathogens from fecal contamination. Wastewater treatment systems are a potential source of this fecal contamination and also may contribute to the increased levels of fecal bacteria that prompt beach and shellfish harvesting area closures.

Additionally, these systems may pollute lakes and other surface waters with the nutrients nitrogen and phosphorus, which promote excessive growth of algae and impair water quality (U.S. EPA, 2003a, 2008a). Excessive growth of algae can lead to harmful algal blooms and make shallow waters green and cloudy, with accumulations of "pond scum." The decomposition of algae consumes oxygen in water, creating oxygen-starved "dead zones" in which fish and other aquatic organisms cannot survive and sometimes leading to extensive kills of fish and shellfish (Camargo and Alonso, 2006; U.S. EPA, 2008c). The decline in oxygen levels also can promote formation of toxic substances, such as hydrogen sulfide, that have harmful effects on aquatic life. Some of the algae and other organisms whose growth is promoted by nutrient pollution, such as cyanobacteria, are themselves toxic and pose hazards to both aquatic animals that live in the water and land animals that drink it (Camargo and Alonso, 2006). As a result of these impacts, excess nutrients may present significant losses to ecological, commercial, recreational, and aesthetic uses of surfaces waters.

One specific area of risk is the Chesapeake Bay watershed. EPA estimates that there were 2.3 million decentralized systems in the Chesapeake Bay watershed as of 2008, and this number is expected to increase to 3.1 million by 2030 (U.S. EPA, 2009b). These systems contributed about 4% of nitrogen loading—approximately 6,000 tons of nitrogen—to the Chesapeake Bay in 2008, particularly because typical systems are not designed to reduce nitrogen (U.S. EPA, 2009b). On May 12, 2009, Executive Order 13508 was issued, requiring EPA to protect and restore the health, heritage, natural resources, and social and economic value of the Chesapeake Bay, which is the Nation's largest estuary system. EPA recommends using nitrogen-reduction technologies to protect Chesapeake Bay watershed surface waters from nitrogen discharged by decentralized wastewater treatment systems (U.S. EPA, 2010c).

BOD is a measure of the amount of oxygen consumed by microorganisms in decomposing organic matter in water, including wastewater from decentralized wastewater treatment systems. BOD_5 is a measure of the amount of oxygen consumed by these organisms during a 5-day period at 20°C. The greater the BOD, the more rapidly oxygen is depleted. This results in stress and death of aquatic organisms because less oxygen is available to higher forms of aquatic life (U.S. EPA, 1997b). The Clean Water Act recognizes BOD as a conventional pollutant, and EPA uses BOD to establish effluent guidelines under this Act. TSS is a measure of the suspended solids in wastewater, effluent, or water bodies. High concentrations of TSS also can have a variety of negative impacts on aquatic life, including decreased photosynthesis, death of aquatic plants, and increased surface water temperature, all of which result in decreased dissolved oxygen, which in turn results in fish kills. TSS also can clog fish gills, affect the ability of fish to feed, reduce fish growth rates and resistance to disease, smother insect and fish eggs, and have a variety of detrimental effects on aquatic invertebrates, including death (U.S. EPA, 2003b). TSS limits are set via the National Pollutant Discharge Elimination System (NPDES).

To mitigate risks of water quality degradation from traditional decentralized wastewater treatment systems, which typically discharge directly to soil or a substrate for secondary treatment, regulatory oversight often is provided at the local, state, or tribal level rather than at the federal level. The verified technology includes secondary (biological) treatment, which allows it to meet EPA-established standards for BOD_5 and TSS removal; therefore, it is able to discharge directly to surface water. Larger capacity systems that discharge directly to surface waters, such as the verified technology, generally are regulated at the state level through NPDES permits and managed by wastewater districts, homeowners' associations, water users' associations, and others. In contrast, soil-discharging wastewater systems that serve more than one residence are classified by EPA as large capacity septic systems and are regulated via the Underground Injection Control Program of the federal Safe Drinking Water Act (U.S. EPA, 2007).

EPA works with organizations, local governments, and states in information exchange and technical assistance for decentralized wastewater treatment technologies. In 2008, EPA renewed a Memorandum of Understanding (MOU), originally signed in 2005, with 14 other organizations involved in various aspects of decentralized wastewater treatment system regulation, operation, and environmental impacts. These organizations include the Consortium of Institutes for Decentralized Wastewater Treatment, National Environmental Health Association, National Onsite Wastewater Recycling Association, Inc., Association of State Drinking Water Administrators, and others. The MOU is intended to upgrade professionalism within the industry and facilitate collaboration among EPA and its regions, state and local governments, and national organizations representing practitioners in this area, leading to improved decentralized wastewater treatment system performance (U.S. EPA, 2008e). EPA also has developed voluntary guidelines and a handbook for the management of decentralized wastewater treatment technologies (U.S. EPA, 2003a, 2005b). As of September 2008, 13 states (Alabama, Arizona, Delaware, Florida, Georgia, Iowa, Maryland, New Jersey, North Carolina, Oklahoma, Rhode Island, Virginia, and Wisconsin) had adopted these management guidelines (U.S. EPA, 2008b).

Beginning in 2008, EPA recommended that states adopt numeric nutrient standards (U.S. EPA, 2008c), which provide quantitative measures for nitrogen, phosphorus, and other water quality parameters. States and tribes retain the authority to adopt these water quality standards; as of 2008, seven states had adopted numeric nutrient standards for at least one water quality parameter for at least one waterbody type, 18 states had adopted numeric nutrient standards for at least one water quality parameter for selected individual waters in a waterbody type, and 46 states had EPA-reviewed nutrient criteria plans that were being used to guide numeric nutrient criteria development (U.S. EPA, 2008c).

EPA's *2006–2011 Strategic Plan* states that the Agency will continue to encourage state, tribal, and local governments to adopt voluntary guidelines for managing decentralized wastewater treatment systems and will use Clean Water State Revolving Funds to finance systems where appropriate (U.S. EPA, 2006). The American Recovery and Reinvestment Act of 2009 (ARRA) provides an additional $4 billion for the Clean Water State Revolving Funds. Twenty percent of each state's capitalization grant can support "Green Reserve" projects, which are defined as green infrastructure, energy efficiency projects, water efficiency projects, or innovative environmental projects. Decentralized wastewater treatment systems qualify for Green Reserve funding in the category of "innovative environmental projects." States may use ARRA funding for solutions to existing deficient or failing onsite systems (U.S. EPA, 2009a).

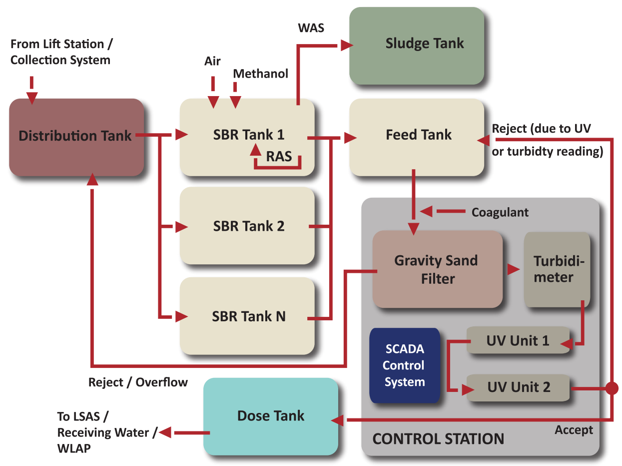
2.2 Technology Description

In 2006, ETV verified the International Wastewater Systems, Inc. Model 6000 SBR, which includes a 6,000 gallon equalization tank, a 6,000 gallon modified SBR, a 3,000 gallon holding tank, a coagulation injection system, a gravity sand filtration system, and a UV disinfection system. The Model 6000 SBR is designed to meet secondary wastewater treatment standards of 30 mg/L TSS and 30 mg/L BOD, and the entire Model 6000 system is designed to meet direct discharge standards and water reclamation and reuse standards, depending on local requirements. The Model 6000 SBR verified by ETV is a full-scale, commercially available unit that treated a maximum volume of 6,000 gallons per day during verification testing. The technology was verified at Moon Lake Ranch, a housing development of 18 homes in Eagle, Idaho, which is served by a centralized wastewater collection system. The vendor operates and maintains the wastewater treatment system under contract to the

Moon Lake Ranch Homeowners Association. Treated water is discharged to a lake within the housing development. Waste sludge from the SBR is transferred to the sludge holding tank and allowed to settle. Sludge is pumped from the holding tank and disposed of at the local wastewater treatment plant approximately every 6 to 12 months. Specific details of the Model 6000 SBR technology can be found in the verification report (NSF International, 2006), available at *http://www.epa.gov/nrmrl/std/etv/pubs/600r06130.pdf*.

The ETV verification test determined the performance of the Model 6000 SBR for treating TSS, BOD_5, nutrients (phosphorus and nitrogen), and total coliform bacteria in domestic wastewater. The SBR was evaluated separately and in combination with the subsequent treatment steps of filtration and UV disinfection. The verification protocol is described in the *Protocol for the Verification of Wastewater Treatment Technologies* (NSF International, 2001), available at *http://www.epa.gov/etv/pubs/04_vp_wastewater.pdf*.

The treatment system was monitored throughout a 1-year test period. Samples were collected from the untreated wastewater, treated effluent from the SBR, and final effluent from the system after filtration and UV disinfection. The samples were analyzed for BOD_5, chemical oxygen demand (COD), TSS, nitrogen compounds, phosphorus compounds, and total coliform. Other operating parameters such as flow, pH, alkalinity, turbidity, temperature, and operation and maintenance characteristics (e.g., reliability of the equipment and the level of required operator maintenance) also were monitored. The verification results for BOD_5, TSS, and COD are summarized in Exhibit 2.2-1. The mean value was very close to the detection limit for the COD test (20 mg/L), as most of the test results were below the detection limit.



SBR Model 6000 Process Flow Diagram

The results of the nutrient and total coliform sample analyses are summarized in Exhibit 2.2-2. The UV system reduced total coliform levels to below the detection limit on most sample days. More detailed performance data are available in the verification report (NSF International, 2006), which can be found at the above link.

2.3 Outcomes

2.3.1 Pollutant Reduction Outcomes

The Model 6000 SBR currently is installed at two commercial sites in Montana—a commercial center at East Gallatin Airport outside Bozeman and a casino project on an Indian reservation north of Great Falls (Smith, 2010a). Two additional systems are completing installation in Montana. One of the systems is being installed in a 50-home subdivision, and the other will be shared by a fitness center and a children's rehabilitation center (Smith, 2010d). An additional system also was scheduled be installed in a 30-home subdivision during 2010,

Exhibit 2.2-1

Performance of ETV-Verified Decentralized Wastewater Treatment Technology: BOD, TSS, and COD

	BOD_5 (mg/L)			TSS (mg/L)			COD (mg/L)		
	Influent	SBR Effluent	Final Effluent[B]	Influent	SBR Effluent	Final Effluent[B]	Influent	SBR Effluent	Final Effluent[B]
Mean Concentration[A]	230	12	4	170	26	6	480	49	22
% Reduction	n/a	95	98	n/a	85	96	n/a	90	95

[A] Based on 64 samples.
[B] Final effluent refers to effluent following gravity sand filtration and UV disinfection.

Exhibit 2.2-2

Performance of ETV-Verified Decentralized Wastewater Treatment Technology: Nutrients and Total Coliform

	Nitrogen[A] (mg/L as N)									Total Phosphorus[A] (mg/L as P)			Total Coliform[B] (MPN[C]/100 mL)		
	Total Kjeldahl Nitrogen			Nitrite Plus Nitrate ($NO_2 + NO_3$ - N)			Total Nitrogen								
	Influent	SBR Effluent	Final Effluent[D]	Influent	SBR Effluent	Final Effluent[D]	Influent	SBR Effluent	Final Effluent[D]	Influent	SBR Effluent	Final Effluent[D]	Influent	SBR Effluent	Final Effluent[D]
Mean Concentration	38	3.2	1.2	0.08	3.1	3.1	38	6.3	4.4	5.4	2.4	1.3	7.1×10^6	1.2×10^5	4
% Reduction	n/a	92	97	n/a	n/a	n/a	n/a	83	88	n/a	56	76	n/a	98	99.999

[A] Based on 16 samples.

[B] Based on 63 influent and SBR effluent samples and 53 final effluent samples. Total coliform values are geometric means.

[C] MPN = Most probable number.

[D] Final effluent refers to effluent following gravity sand filtration and UV disinfection.

but the subdivision project currently is pending funding (Smith, 2010e). The average daily flows of these five sites range from 10,000 to 24,000 gallons per day, as shown in Exhibits 2.3-1 and 2.3-2. Four of the five sites have severe nitrogen problems, as improperly managed and maintained septic tanks have contaminated the soil and/or the soil is saturated with nitrogen from historical mining use (Smith, 2010a, 2010f). All of the sites discharge to drainfields designed by state-licensed engineers whose calculations determined the drainfield dimensions. A backup drainfield is adjacent to each site in the event the initial drainfield becomes unusable (Smith, 2010g).

The two currently operating sites were installed in early 2007. The Bozeman site has an average wastewater volume of 10,000 gallons per day; the Great Falls site has an average wastewater volume of 15,000 gallons per day (Smith, 2010a). Using these average volumes and system performance observed during verification, ETV determined the reductions in nitrogen, TSS, and BOD_5 achieved to date as compared to what would have been achieved with traditional onsite wastewater treatment, as shown in Exhibit 2.3-1. The methodology and assumptions used to calculate these reductions are described in Appendix A. The calculations for the Bozeman site may be conservative, as they compare reductions achieved by the verified system to those achieved by traditional onsite wastewater treatment systems. According to the vendor, because the nitrogen impairment in the area is substantial, traditional technology would have been unsatisfactory. Without the use of the ETV-verified technology or an alternative treatment technology of equivalent performance, the Bozeman airport commercial center most likely would not have been built (Smith, 2010a).

Again, using system performance observed during ETV testing, the potential annual reductions in nitrogen, TSS, and BOD_5 compared to what would be achieved with traditional onsite wastewater treatment can be calculated for the three systems scheduled to be installed in 2010. The first installation is in a 30-home rural subdivision in Kalispell with an average daily wastewater volume of 12,000 gallons; the second is a 50-home upscale subdivision in Butte with an average daily wastewater volume of 15,000 gallons; and the third is a commercial installation in Missoula with an average daily wastewater volume of 24,000 gallons (Smith, 2010a). ETV calculated the expected annual reductions in nitrogen, TSS, and BOD_5 at the three sites, as shown in Exhibit 2.3-2. Appendix A describes the methodology and assumptions used to calculate these estimated reductions. Once again, these estimates may be conservative as the nitrogen impairment in each area is significant enough that traditional technology would be unsatisfactory. According to the vendor, without the availability of the ETV-verified technology or an alternative treatment technology of equivalent performance, the two subdivisions and the commercial installation most likely could not be built (Smith, 2010a).

The verified technology primarily is installed in new subdivisions and developments in rural or rural/suburban areas. Estimates indicate that an average of 1,400 new cluster systems currently are being installed each year in the United States (Tonning, 2010a). The ETV Program used this approximation of the total potential market to estimate the number of clusters of homes that could utilize the Model 6000 SBR based on two market penetration scenarios, 10% and 25% of the total potential market, as shown in Exhibit 2.3-3. The ETV Program also used these scenarios to estimate the pollutant reduction outcomes shown below. Homeowners and builders in areas where residential discharges might present a threat to groundwater or surface water quality from nitrogen, phosphorus, and other contaminants are those most likely to benefit from the technology, as are the communities in which these homes are located. It should be noted, however, that because of the current U.S. economy, new home construction has decreased by 50%; the potential market could be as high as 2,500 to 3,000 clusters of homes annually as the economy improves (Tonning, 2010b). Additionally, the verified technology also can be installed in smaller commercial facilities and businesses. Because these types of installations are not included in the ETV estimate, the potential pollutant reductions are even greater.

Using assumptions regarding total potential market, daily water use, and nitrogen concentration, combined with system performance observed during ETV testing, the ETV Program estimated annual pollutant reductions from potential application of the ETV-verified decentralized wastewater treatment technology for residential clusters of homes, compared to reductions

Exhibit 2.3-1

Calculated Pollutant Reductions Achieved During 3-Years of Operation at Installed Sites

Location	Flow (gallons per day)	Nitrogen		TSS		BOD_5	
		3-Year Total (tons)	Average Daily (lbs/day)	3-Year Total (tons)	Average Daily (lbs/day)	3-Year Total (tons)	Average Daily (lbs/day)
Bozeman	10,000	0.14	0.25	1.6	3.0	4.2	7.7
Great Falls	15,000	0.21	0.38	2.4	4.5	6.3	11

Values rounded to two significant figures.

Exhibit 2.3-2

Expected Annual Pollutant Reductions for Scheduled Installation Sites

Location	Flow (gallons per day)	Nitrogen		TSS		BOD_5	
		Annual Total (lbs)	Average Daily (lbs/day)	Annual Total (tons)	Average Daily (lbs/day)	Annual Total (tons)	Average Daily (lbs/day)
Kalispell	12,000	110	0.30	0.65	3.6	1.7	9.2
Butte	15,000	140	0.38	0.81	4.5	2.1	11
Missoula	24,000	220	0.61	1.3	7.1	3.4	18

Values rounded to two significant figures.

Exhibit 2.3-3

Estimated Potential Pollutant Reductions for the ETV-Verified Decentralized Wastewater Treatment Technology

Market Penetration	Number of Clusters of Homes	Nitrogen		TSS		BOD_5	
		Annual Total (tons)	Average Daily (lbs/day)	Annual Total (tons)	Average Daily (lbs/day)	Annual Total (tons)	Average Daily (lbs/day)
10%	140	0.58	3.2	6.8	37	18	96
25%	350	1.4	7.9	17	93	44	240

Values rounded to two significant figures.

A view of the Model 6000 SBR following installation at the Trellis Subdivision in Eagle, Idaho.

seen with traditional septic systems (see Exhibit 2.3-3). Appendix A describes the methodology and assumptions used to develop these estimates.

Quantitative data are not available to estimate the environmental and health outcomes associated with these pollutant reductions. As discussed in Section 2.1, however, nutrient loadings are a significant environmental concern, and nitrates and nitrites have human health impacts. Therefore, the benefits of reducing nitrogen loading also could be significant.

2.3.2 Technology Acceptance, Use, and Financial and Economic Outcomes

The manufacturer of the ETV-verified system has indicated that participation in the ETV Program and the availability of credible information on demonstrated technology performance and capabilities has helped the company to market and sell its Model 6000 SBR system. According to the vendor, the State of Montana gave the company a preferred position within the state in areas where rural wastewater systems are required, based on the ETV verification test results. This recognition resulted in five projects totaling $1.4 million in revenue for the vendor. These project sites are located in nitrogen-sensitive ecosystems. Because the ETV results demonstrated that the system was able to meet nitrogen standards, the vendor was given a recommendation for the Bozeman project. The vendor was awarded the Kalispell project because the ETV verification resulted in a state nitrogen approval rating of 7.5 mg/L for the technology, which met the total nitrogen discharge limit of 12.5 mg/L for the project. New construction at the Butte and Missoula sites was considered impossible because of severe nitrogen problems from nearby improperly constructed and maintained septic tanks and historical use, resulting in discharge limits for nitrogen in these areas of 7.5 mg/L. According to the vendor, these projects were approved solely on the basis of the Model 6000 SBR's ability to meet the nondegradation requirements of the State of Montana, as demonstrated through ETV testing. Although the Great Falls project did not have major environmental requirements associated with it, the Indian reservation wanted the best environmental treatment system possible. The vendor's system had documented performance through ETV verification and was awarded the project. The vendor also has $9 million worth of new bids in progress (Smith, 2010a). Additionally, Minnesota and New Jersey have nondegradation limits similar to those of Montana, so the verified technology could be used to meet the requirements in these states as well (State of Minnesota, 2008; State of New Jersey, 1993).

The vendor reports that the payback period for the cost of the ETV verification was 11 months (Smith, 2010g) and that demonstrated technology performance as verified by the ETV Program has had indirect benefits in the form of valuation and partnerships. Based on an audit of company assets by an outside valuation firm, the vendor reports that the value added to the company as a result of ETV verification could range from $2 million or $3 million up to as much as $5 million. The audit determined that the company's primary asset was participation in ETV verification because of the competitive advantage it provides in states that recognize the ETV Program (Smith, 2010c). According to the vendor, another important benefit of ETV verification testing has been the reputation that it provides with new customers and partners, allowing the company to compete in a much broader range of activities than it could have without ETV verification. The value of these partnerships is worth much more than the $5 million valuation of the ETV asset and would not have been available to the company without the ETV results (Smith, 2010a). The vendor states that because of the ETV name recogni-

"It can't be emphasized enough that ETV ignited our company and its growth and continues to be used by us every day in the expansion of our company. So, in a very unique way, you can never put a fixed value on ETV, because it has become a cornerstone of our company's existence, and it allows us to increase in value every day."

—Claude Smith, President, International Wastewater Systems (Smith, 2010a).

tion, various partners and relationships have been created that have allowed the company to compete in the new construction market and the already-existing installed building market. These relationships also have aided the vendor in gaining access to the commercial building and Federal Government building markets. Without the ETV Program and the name recognition from EPA, it is unlikely that these relationships could have been developed. Independent of the technical aspects of ETV testing, the marketing recognition that has been attained as a result of the ETV verification is quite valuable to the vendor (Smith, 2010b).

As stated in Section 2.1, decentralized wastewater treatment systems can have economic advantages compared to centralized systems when used in appropriate areas. Decentralized systems allow capacity to more closely match actual growth because decentralized capacity can be built on an as-needed basis, providing a number of important benefits. Capacity capital costs are moved to the future, typically reducing the net present value, resulting in a more affordable approach compared to building centralized treatment capacity or extending sewers. Communities are able to incur less debt because it is not necessary to borrow large up-front capital, which also can reduce financing costs. Because decentralized systems can be expanded depending on growth, if less growth occurs than predicted initially, the community does not have overbuilt capacity and a large debt load that must be spread across fewer-than-expected residents. Also, making decentralized investments over time allows the community to adjust its technology choices as improved or less expensive technologies become available. Finally, more expensive nutrient removal technologies can be targeted only to locations that are nutrient sensitive, as opposed to upgrading treatment of all of the community's wastewater at a centralized plant (Rocky Mountain Institute, 2004). The verified system detailed in this case study is an example system that can potentially provide these economic advantages.

2.3.3 Regulatory Compliance Outcomes

In addition to adopting regulations or guidelines for decentralized wastewater discharge, states also establish water quality standards to protect water bodies for drinking, recreation, and ecological activities. Total maximum daily loads and maximum contaminant levels are used to ensure that drinking water meets safety criteria for pollutants and contaminants (e.g., total nitrogen). The ETV-verified technology described in this case study can be used to help states and other governing bodies to meet drinking water regulations, standards, and guidelines.

A view of the Model 6000 SBR following installation at the Trellis Subdivision in Eagle, Idaho.

The Chesapeake Bay Program has outlined how EPA can protect the Bay watershed, including requiring all newly developed communities and densely populated areas to use cluster systems employing advanced nitrogen removal technology (U.S. EPA, 2009b). The new discharge standards specify total nitrogen levels of not more than 20 mg/L throughout the Bay watershed and in some areas no more than 5 mg/L. The Chesapeake Bay Program specifically cites ETV and several verified products when discussing available technologies to meet these new standards (U.S. EPA, 2010c). The verified technology discussed in this case study meets the nitrogen recommendations for use in the Chesapeake Bay watershed.

As mentioned in Section 2.1 and above, a number of states have adopted regulations or guidelines for management of decentralized wastewater and nutrient discharge. Such regulations and guidelines rely in part on the use of alternative technologies, some of which are approved by the states. In the residential wastewater treatment sector, regulators rely on third-party testing and standards. Additionally, some states have processes that allow for innovative approvals of systems that perform outside the scope of the existing certification protocols. At least nine states currently use ETV protocols in the evaluation of alternative technologies for wastewater treatment and three identify the protocol used for the verification described in this case study:

- North Carolina has stated that vendors requesting innovative approval for wastewater treatment systems can use ETV verification protocols, including the protocol used for the verification described in this case study to support their requests. The state also suggests

A finished view of the Model 6000 SBR installation at the Trellis Subdivision in Eagle, Idaho.

that data gathered outside these protocols might not be considered equally valid (Jeter, 2001).

- Florida indicates that applications for innovative system permits for onsite sewage treatment and disposal systems shall include "compelling evidence that the system will function properly and reliably to meet the requirements [e.g., permitting, inspection] of this chapter...Such compelling evidence shall include one or more of the following from a third-party testing organization approved through the NSF [*sic*] Environmental Technology Verification Program: (1) testing of innovative systems in other states with similar soils and climate; (2) side stream testing where effluent is discharged into a treatment system regulated pursuant to Chapter 403, FS; and (3) laboratory testing" (State of Florida, 2006).
- The State of Idaho *Technical Guidance Manual for Individual and Subsurface Sewage Disposal Systems* states that extended (wastewater) treatment package systems and nitrogen reduction systems may be approved if they have successfully completed an EPA-sanctioned ETV verification test (State of Idaho, 2007).
- Pennsylvania's Experimental Onlot Wastewater Technology Verification Program requires that onlot sewage system technologies accepted for performance verification complete appropriate testing that follows a protocol developed by or in cooperation with the American National Standards Institute and/or the U.S. EPA (Pennsylvania Department of Environmental Protection, 2004).
- Washington testing requirements for proprietary treatment products require that certain categories of residential and high-strength wastewater treatment systems complete testing following an ETV verification protocol, including the protocol used for the verification described in this case study (State of Washington, 2007).
- Minnesota testing requirements for proprietary treatment products require that technologies designed for treating high-strength sewage typical of commercial sources (restaurants, grocery stores, group homes, medical clinics, etc.) and reducing total nitrogen and phosphorous complete testing following an ETV verification protocol, including the protocol used for the verification described in this case study, or the equivalent (Minnesota Administrative Rules, 2008).
- The Oregon State *Administrative Rules for Approval of New or Innovative Technologies, Materials, or Designs for Onsite Systems* specify that the Department of Environmental Health and Quality may approve new or innovative technologies, materials, or designs for onsite systems pursuant to the rule if it determines that they will protect public health, safety, and waters of the state as effectively as systems authorized by the division. One of the factors on which the department may base approval is meeting the criteria established by EPA's ETV Program, including several NSF International and ETV protocols for wastewater treatment (State of Oregon, 2009).
- The Administrative Rules of Montana *17.30.718: Criteria for Nutrient Reduction from Subsurface Wastewater Treatment System* (SWTS) state that results from an SWTS that has been tested by ETV may be used to demonstrate compliance with requirements (e.g., collection and analysis of raw sewage for total Kjeldahl nitrogen, BOD, and TSS; sampling frequency) for nutrient reduction as outlined in the regulation (State of Montana, 2004).
- The Virginia Department of Environmental Quality encourages innovative wastewater treatment technology developers and vendors to use technology templates, such as the EPA ETV Program, to serve as means for potential customers and regulators to see consistent descriptions, application information, and performance data on new wastewater treatment technologies (Virginia Department of Environmental Quality, 2009).

Acronyms and Abbreviations Used in This Case Study:

ARRA	American Recovery and Reinvestment Act of 2009
BOD	biochemical oxygen demand
BOD_5	5-day biochemical oxygen demand
COD	chemical oxygen demand
lbs	pounds
mg/L	milligrams per liter
MOU	Memorandum of Understanding
NPDES	National Pollutant Discharge Elimination System
SBR	sequencing batch reactor
SWTS	subsurface wastewater treatment system
TSS	total suspended solids
UV	ultraviolet

2.4 References

56 FR 3526. *National Primary Drinking Water Regulations; Final Rule*. *Federal Register* 56, no. 20 (30 January 1991).

71 FR 65573. *National Primary Drinking Water Regulations: Groundwater Rule; Final Rule*. *Federal Register* 71, no. 216 (8 November 2006).

Camargo JA and Alonso A. 2006. Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: a global assessment. *Environment International* 32:831–849.

Greer FR, Shannon M, the Committee on Nutrition, and the Committee on Environmental Health. 2005. *Infant Methemoglobinemia: The Role of Dietary Nitrate in Food and Water*. *Pediatrics* 116(3):784–786.

International Wastewater Systems. 2010. *International Wastewater Systems Projects*. Last accessed 22 June. *http://www.rcciws.com/index-5.html*

Jeter WC. 2001. *Memorandum from William C. Jeter (North Carolina Department of Environment and Natural Resources) Concerning Innovative Wastewater Treatment System Verification*. 30 April.

Minnesota Administrative Rules. 2008. *7083.4010: Testing Requirements for Proprietary Treatment Products*. 18 February.

NSF International. 2001. *Protocol for the Verification of Wastewater Treatment Technologies.* April.

NSF International. 2006. *Environmental Technology Verification Report: Evaluation of a Decentralized Wastewater Treatment Technology—International Wastewater Systems, Inc. Model 6000 Sequencing Batch Reactor System (With Coagulation, Sand Filtration, and Ultraviolet Disinfection)*. Prepared by NSF International under a cooperative agreement with the U.S. Environmental Protection Agency. 06/28/WQPC-SWP EPA/600/R-06/130. August.

Pennsylvania Department of Environmental Protection. 2004. *Experimental Onlot Wastewater Technology Verification Program*. Bureau of Water Supply and Wastewater Management. 3 July.

Rocky Mountain Institute. 2004. *Valuing Decentralized Wastewater Technologies: A Catalog of Benefits, Costs, and Economic Analysis Techniques*. November.

Siegrist RL. 2001. *Advancing the Science and Engineering of Onsite Wastewater Systems*. In: *Proceedings of Ninth National Symposium on Individual and Small Community Sewage Systems*, ASAE, March 11-14, 2001, Fort Worth, TX.

Smith C. 2010a. E-mail communication. International Wastewater Systems, Inc. 6 January.

Smith C. 2010b. E-mail communication. International Wastewater Systems, Inc. 3 March.

Smith C. 2010c. E-mail communication. International Wastewater Systems, Inc. 27 April.

Smith C. 2010d. E-mail communication. International Wastewater Systems, Inc. 18 August.

Smith C. 2010e. E-mail communication. International Wastewater Systems, Inc. 19 August.

Smith C. 2010f. E-mail communication. International Wastewater Systems, Inc. 7 September.

Smith C. 2010g. E-mail communication. International Wastewater Systems, Inc. 17 September.

State of Florida. 2006. *Chapter 64E-6, Florida Administrative Code: Standards for Onsite Sewage Treatment and Disposal Systems*. Department of Health. 26 November.

State of Idaho. 2007. *Technical Guidance Manual for Individual and Subsurface Sewage Disposal Systems*. Department of Environmental Quality. 4 October.

State of Minnesota. 2008. *Minnesota Rules*. Chapters 7050 and 7053. April 1.

State of Montana. 2004. *Administrative Rules of Montana 17.30.718: Criteria for Nutrient Reduction from Subsurface Wastewater Treatment System*. 18 June.

State of New Jersey. 1993. *New Jersey Administrative Code 7:9-6—Groundwater Quality Standards*. January 7.

State of Oregon. 2009. *Approval of New or Innovative Technologies, Materials, or Designs for Onsite Systems*. 340-071-0135. Department of Environmental Quality. Last accessed 21 October. *http://arcweb.sos.state.or.us/rules/OARs_300/OAR_340/340_071.html*

State of Washington. 2007. *Rules and Regulations of the State Board of Health: On-site Sewage Systems Chapter 246-272A WAC*. Department of Health. 1 July. (Formatting revised September 2009).

Tonning B. 2010a. E-mail communication. Tetra Tech. 17 March.

Tonning B. 2010b. Personal communication. Tetra Tech. March.

U.S. EPA. 1997a. *Response to Congress on Use of Decentralized Wastewater Treatment Systems*. EPA-832-R-97-001b. April.

U.S. EPA. 1997b. *Volunteer Stream Monitoring: A Methods Manual*. Office of Water. EPA-841-B-97-003. November.

U.S. EPA. 2002. *Onsite Wastewater Treatment Systems Manual*. Office of Water. EPA-625-R-00-008. February.

U.S. EPA. 2003a. *Voluntary National Guidelines for Management of Onsite and Clustered (Decentralized) Wastewater Treatment Systems*. Office of Water. EPA-832-B-03-001. March.

U.S. EPA. 2003b. *Developing Water Quality Criteria for Suspended and Bedded Sediments (SABS): Potential Approaches (Draft)*. Office of Water. August.

U.S. EPA. 2005a. *Decentralized Wastewater Treatment Systems: A Program Strategy*. Office of Water. EPA-832-R-05-002. January.

U.S. EPA. 2005b. *Handbook for Managing Onsite and Clustered (Decentralized) Wastewater Treatment Systems: An Introduction to Management Tools and Information for Implementing EPA's Management Guidelines*. Office of Water. EPA-832-B-05-001. December.

U.S. EPA. 2005c. *Decentralized Wastewater Treatment Systems: A Program Strategy*. Office of Water. EPA-832-R-05-002. January.

U.S. EPA. 2006. *EPA's 2006–2011 Strategic Plan*. EPA-190-R-06-001. 29 September.

U.S. EPA. 2007. *Large Capacity Systems*. Last updated 12 December. *http://www.epa.gov/ogwdw000/uic/class5/types_lg_capacity_septic.html*

U.S. EPA. 2008a. *U.S. EPA's 2008 Report on the Environment (Final Report)*. EPA-600-R-07-045F. May.

U.S. EPA. 2008b. *What is EPA Doing To Address Septic Systems?* Office of Wastewater Management. Presented at the Groundwater Protection Council's 2008 Annual Forum. 23 September.

U.S. EPA. 2008c. *State Adoption of Numeric Nutrient Standards (1998–2008)*. Office of Water. EPA-821-F-08-007. December.

U.S. EPA. 2008d. *EPA's MOU Partnership: Improving Communication, Cooperation, and Coordination in Decentralized Wastewater Management*. Webinar. 3 November.

U.S. EPA. 2008e. *Memorandum of Understanding: EPA Partners for Decentralized Wastewater Management*. 19 November.

U.S. EPA. 2009a. *Activity Update: Funding Decentralized Wastewater Treatment Systems Using the Clean Water State Revolving Fund*. Office of Water. EPA 832-F-09-005. Summer.

U.S. EPA. 2009b. *The Next Generation of Tools and Actions to Restore Water Quality in the Chesapeake Bay: A Revised Report Fulfilling Section 202a of Executive Order 13508*. 9 September.

U.S. EPA. 2010a. Septic (Onsite) Systems—*Education and Outreach*. Last updated 22 June. *http://cfpub.epa.gov/owm/septic/septic.cfm?page_id=277*

U.S. EPA. 2010b. *National Water Quality Inventory Report to Congress Electronic Integrated Reporting*. Last updated 15 June. *http://www.epa.gov/waters/ir*

U.S. EPA. 2010c. *Guidance for Federal Land Management in the Chesapeake Bay Watershed. Chapter 6: Decentralized Wastewater Treatment Systems*. Office of Wetlands, Oceans, and Watersheds. EPA841-R-10-002. 12 May.

U.S. Geological Survey. 2006. *Quantification of the Contribution of Nitrogen from Septic Tanks to Groundwater in Spanish Springs Valley, Nevada*. Scientific Investigations Report 2006-5206. September.

Virginia Department of Environmental Quality. 2009. *Innovative Technology: Technology Verifications and Inventories*. Last updated 8 January. *http://www.deq.state.va.us/innovtech/dem2.html*

3. Waste-to-Energy Technologies: Power Generation and Heat Recovery

The ETV Program has verified the performance of eight technologies that produce or use fuels generated from biomass or other wastes (opportunity fuels). Six of the technologies, including four distributed generation energy systems and two biogas processing systems, were verified by ETV's Greenhouse Gas Technology Center, which is operated by Southern Research Institute under a cooperative agreement with EPA. These technologies have applications at municipal solid waste landfills, animal feeding operations, wastewater treatment facilities, or other sources of methane (CH_4) or high-energy-content gaseous waste streams. Two biomass co-fired boilers also were verified under an ETV Environmental and Sustainable Technology Evaluation (ESTE) project; these are applicable for co-firing in industrial, commercial, or institutional boilers in the 100 million to 1,000 million British thermal unit per hour (MMBtu/h) range. Collaborators during these verifications included the Colorado Governor's Office of Energy Management and Conservation, New York State Energy Research and Development Authority (NYSERDA), University of Iowa (UI), Minnesota Power, and EPA's Office of Solid Waste, Office of Air Quality Planning and Standards (OAQPS), and Office of Air and Radiation. The Greenhouse Gas Technology Center also is conducting a joint demonstration and verification of a microturbine using landfill gas with the Department of Defense's (DoD) Environmental Security Technology Certification Program (ESTCP); the verification is expected to be completed in 2011. Completed and ongoing verifications are summarized in Exhibit 3-1. Additionally, the Greenhouse Gas Technology Center is performing a preverification technology assessment of the environmental and economic impacts from gasification of aqueous sludge from paper mills and wastewater treatment. The project may include verification of these technologies for use in onsite energy or fuel production for the pulp and paper and municipal wastewater treatment industries.

Waste-to-energy technologies use opportunity fuels that usually are byproducts or waste streams from other processes, thus reducing the need to use fossil fuels and the quantity of wastes treated, disposed of, or emitted. Although these fuels may not have the same heating value as conventional fossil fuels, they are beneficial as a potential source of alternative energy, especially when used with distributed generation energy systems that generate electricity at the point of use. These technologies also can employ heat recovery systems that capture excess thermal energy and use it to provide domestic water and space heating, process heat, or steam. Distributed generation systems that include heat recovery are referred to as combined heat and power (CHP) systems.

The University of Iowa main power plant.

Common opportunity fuels include landfill gas, anaerobic digester gas, wood, and grass. These fuels are derived mostly from biomass waste such as crop residues, farm waste from animal feeding operations, food waste, municipal solid waste, sludge waste, and waste from forestry and agricultural operations. Benefits and outcomes of the use of selected opportunity fuels include decreased dependence on fossil fuels; decreased waste volume requiring disposal; and reduced CH_4, carbon dioxide (CO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and total hydrocarbons (THCs) emissions. CO_2 and CH_4 are greenhouse gases (GHGs) linked to global climate change. CO, THCs, compounds in the NO_x family, and derivatives formed when NO_x reacts in the environment cause a wide variety of health and environmental impacts.

Waste-to-energy technologies can significantly reduce the environmental impacts of municipal solid waste by redirecting and reducing the volume of waste disposed of in landfills and decreasing the amount of GHGs that otherwise would be released. For example, according to EPA's Landfill Methane Outreach Program, waste-to-

Exhibit 3-1

Completed and Ongoing ETV Verifications for Waste-to-Energy Technologies[A,B]

Company/Technology Name	Technology Description/ Application	Opportunity Fuel Source
Biogas Processing Systems		
NATCO Group, Inc., Paques THIOPAQ®	A sour gas processing system for biogas purification that removes hydrogen sulfide (H_2S).	Anaerobic digester gas from a water pollution control facility (verified in 2004).
US Filter/Westates Carbon, Gas Processing Unit (verified with the UTC Fuel Cells, LLC, PC25C Fuel Cell Power Plant—Model C)	A carbon-based filter that removes H_2S, other sulfur species and hydrocarbons from biogas.	Anaerobic digester gas from a water pollution control facility (verified in 2004).
Fuel Cells		
UTC Fuel Cells, LLC, PC25C Fuel Cell Power Plant—Model C (formerly the combined PC25™ 200 kW Fuel Cell and gas processing unit by International Fuel Cells Corporation and currently the PureCell™ Model 200 by UTC Power) (*technology was tested using two different opportunity fuel sources*)	A 200 kilowatt (kW) phosphoric acid fuel cell with an included gas processing unit for commercial or institutional use with the potential for heat recovery in a CHP application.	Biogas from two municipal solid waste landfills; included a landfill gas processing unit (verified in 1998). Anaerobic digester gas from a wastewater treatment facility; included a gas processing unit verified separately (verified in 2004).
Internal Combustion Engines		
Martin Machinery, Caterpillar Model 379 (200 kW) Engine/Generator Set with Integrated CHP System	A distributed generation/CHP system consisting of a Caterpillar Model 379, 200 kW engine-generator with integrated heat recovery capability.	Anaerobic digester gas from a dairy farm with 1,725 cows and heifers (verified in 2007).
Martin Machinery, Caterpillar Model 3306 ST (100 kW) Engine, Generator, and Heat Exchanger	A distributed generation/CHP system consisting of a Caterpillar Model 3306 ST, 100 kW engine-generator with integrated heat recovery capability.	Anaerobic digester gas from a swine facility with up to 5,000 sows (verified in 2004).
Microturbines		
Capstone Turbine Corporation, Capstone Model 330 30 kW (currently the Capstone Model C30) microturbine system	A 30 kW biogas-fired microturbine combined with heat recovery system for distributed electrical power and heat generation.	Anaerobic digester gas from a swine facility with up to 5,000 sows (verified in 2004).
Flex Energy, Flex-Powerstation® (planned verification 2011)	A microturbine using a thermal oxidizer system to oxidize and destroy hydrocarbons in the waste fuel stream before entering the turbine.	Landfill and other waste gases.
Biomass Co-Fired Boilers		
Pelletized wood fuel, developed by renewaFUEL, LLC, co-fired with coal at the University of Iowa Main Power Plant Boiler 10	A Riley Stoker Corporation boiler unit rated at 170,000 pounds/hour (lbs/h) steam co-firing pelletized wood fuel with coal.	Wood pellets from a renewaFUEL, LLC facility in Michigan co-fired with coal (verified in 2008).
Wood waste co-fired with coal at the Minnesota Power, Rapids Energy Center Boiler 5	A Foster Wheeler spreader stoker boiler with a steaming capacity of 175,000 lbs/h co-firing western subbituminous coal with wood waste, railroad ties, onsite generated waste oils and solvents, and paper wastes.	Waste wood and bark from a paper mill and waste wood from other facilities co-fired with coal (verified in 2008).

[A] Complete verification reports and statements for the verified technologies may be found at *http://www.epa.gov/etv/vt-ggt.html#advanceenergy*.

[B] Adapted from ETV, 2009.

energy technologies that utilize landfill gas from municipal solid waste landfills have the potential to reduce CH_4 emissions from these sources by up to 90%; this would have resulted in a reduction of 2.7 million metric tons of CO_2 equivalent (CO_2e) in 2008 (U.S. EPA, 2010e). Certain waste-to-energy technologies also can serve as an integral element in the waste and energy management chains at different facilities, helping to limit releases to land and water bodies, as well as assisting with facility-specific waste processing or treatment needs.

The utilization or conversion of waste streams for alternative energy involves many different types of technologies and sources of waste (e.g., municipal solid waste combustion). This case study, and in particular the "Technology Description" and "Outcomes" sections of this study, focus on the types of waste-to-energy technologies verified by the ETV Program, namely those that utilize CH_4 or other gaseous waste streams for power generation and biomass co-fired boilers.

Section 3.3 of this case study presents the ETV Program's estimates of verification outcomes from actual and potential applications of the technologies. Appendix B provides a detailed description of the methodology and assumptions used to estimate these outcomes. Using the analyses in this case study, ETV reports the following outcomes:

- Based on current installations, eight ETV-verified fuel cell distributed generation systems in operation at wastewater treatment plants in or near New York City reduce CO_2e emissions by more than 11,000 tons per year. The vendor reports that cumulatively, these fuel cell installations have generated more than 56,000 megawatt-hours (MWh) of electricity with an associated economic value of $5.6 million.
- The ETV-verified distributed power generation systems could potentially be applied, using 10% and 25% market penetration scenarios, at:
  - Approximately 820 to 2,100 animal feeding operations with annual CO_2e emissions reductions of up to 5.9 million to 15 million tons and associated climate change, environmental, and human health benefits.
  - Approximately 44 to 110 wastewater treatment facilities with annual CO_2e emissions reductions of 63,000 to 160,000 tons and annual NO_x emissions reductions of 80 to 200 tons; associated climate change, environmental, and human health benefits also could be realized.
- The estimated potential energy generation and cost benefits of using ETV-verified distributed generation technologies at 10% and 25% market penetration are as follows:
  - If candidate animal feeding operations used these technologies, up to 1.4 million to 3.5 million megawatts (MW) of electricity could be generated annually with associated cost benefits of up to $140 million to $350 million.
  - If candidate landfills used these technologies, up to 75,000 to 190,000 MW of electricity could be generated annually with associated cost benefits of up to $7.5 million to $19 million.
  - If candidate wastewater treatment facilities used these technologies, 74,000 to 190,000 MW of electricity could be generated annually with associated cost benefits of $7.4 million to $19 million.
- ETV verification results from the biomass co-fired boilers described in this case study were used to assist in permit analysis and permitting of test burns at universities, public utilities, and large industrial operations in five states.

3.1 Environmental, Human Health, and Regulatory Background

Opportunity fuels often originate from sources or sectors that are regulated independently under various environmental laws. As a result, the environmental, human health, and regulatory issues associated with waste-to-energy technologies are broader and more complex than just those found in the energy and climate change sector. To effectively address the range of environmental, human health, and regulatory issues associated with different waste-to-energy applications, this section has been divided into five subsections: (1) energy, GHGs, and climate change; (2) animal feeding operations; (3) landfills; (4) wastewater treatment; and (5) boilers.

3.1.1 Energy, GHGs, and Climate Change

EPA estimates that, in 2007, the United States emitted CO_2 in the amount of 6,100 teragrams of CO_2e (Tg CO_2e) and nitrous oxide (N_2O) in the amount of 312 Tg CO_2e. Electricity generation is the largest single source of CO_2 emissions, accounting for approximately 42% of the U.S. total in 2007 (U.S. EPA, 2009a). N_2O emissions from electricity generation represent 25% of emissions from fossil fuels in 2008 (U.S. EPA, 2009a). A variety of other pollutants also are emitted during electricity generation, including sulfur dioxide (SO_2), particulate matter (PM), ammonia, and THCs. Each of these emissions can have significant environmental and health effects. Conventional electricity generation also consumes finite natural resources, with environmental and economic repercussions.

According to the Intergovernmental Panel on Climate Change (IPCC), CO_2 concentration in the atmosphere has increased 35% (from 280 parts per million [ppm] to 379 ppm) since preindustrial times (AD 1000 to 2005) (IPCC, 2007a). The IPCC has concluded that global average surface temperature rose 0.6°C in the 20th century, with the 1990s being the warmest decade on record. Sea level rose 0.12 to 0.22 meters during the same time. Snow cover has decreased by about 10%, and the extent and thickness of Northern Hemisphere sea ice have decreased significantly (IPCC, 2007b). Resultant flooding can cause health impacts, including direct injuries and increased incidence of waterborne diseases from pathogens such as *Cryptosporidium* and *Giardia*, altered marine ecology, displacement of coastal populations, and saltwater intrusion into coastal freshwater supplies. Higher average surface temperatures caused by GHG impacts on climate are expected to result in severe heat waves that are intensified in magnitude and duration. This will in turn result in increased heat-related morbidity and mortality. The range of some zoonotic disease carriers (e.g., ticks carrying the agent of Lyme disease) may expand with rise in temperature (74 FR 66496; U.S. EPA, 2009b). GHG-related climate change is expected to elevate regional ozone levels, accompanied by increased risk for respiratory illness and premature death. Additionally, evidence indicates that elevated CO_2 concentrations can lead to changes in aeroallergens that could increase the potential for allergenic illnesses. Many of these impacts depend on whether rainfall increases or decreases, which cannot be reliably projected for specific areas. Scientists currently are unable to determine which parts of the United States will become wetter or drier, but there is likely to be an overall trend toward more precipitation and evaporation, more intense rainstorms, and drier soils (74 FR 66496; U.S. EPA, 2009b).


The Martin Machinery Caterpillar Model 3306 internal combustion engine combined heat and power system installed at Colorado Pork in Lamar, Colorado.

The various compounds in the NO_x family (including N_2O, nitrogen dioxide, nitric acid, nitrates, and nitric oxide) and derivatives formed when NO_x reacts in the environment cause a wide variety of health and environmental impacts, including formation of ground-level ozone (or smog) and acid rain, water quality deterioration, respiratory problems, and global warming, as well as reacting to form nitrate particles and toxic chemicals (U.S. EPA, 1998; U.S. EPA, 2003). Ozone is capable of reducing or damaging vegetation growth and causing respiratory problems in humans (U.S. EPA, 2008c).

Other pollutants emitted during electricity generation also can have significant environmental and health effects. For example, SO_2 contributes to the formation of acid rain (U.S. EPA, 2009c). THCs and CO can contribute to ground-level ozone formation, and CO can be fatal at high concentrations (U.S. EPA, 2000; U.S. EPA, 2010g). PM can cause premature mortality and respiratory effects, including aggravated asthma, difficult or painful breathing, decreased lung function, and chronic bronchitis (70 FR 65984). Finally, ammonia can contribute to PM levels and result in adverse environmental effects after deposition to surface water, such as eutrophication and fish kills. Ammonia also can be fatal at high concentrations (U.S. EPA, 2004a).

CH_4 is another important GHG of concern. CH_4 can remain in the atmosphere for approximately 9 to 15 years. As one of several non-CO_2 gases that contribute to climate change, CH_4 is 20 times more effective in trapping atmospheric heat than CO_2 during a 100-year period. It is emitted from a variety of sources, including landfills, natural gas and petroleum systems, agricultural activities, coal mining, wastewater treatment, and others. CH_4 is a primary constituent of natural gas and an important energy source. Use of CH_4 emissions for waste-to-energy technologies can provide significant energy, economic, and environmental benefits (U.S. EPA, 2010a).

There are several regulatory drivers for using waste-to-energy technologies to reduce GHGs and improve energy independence. In April 2007, the U.S. Supreme Court ruled that GHGs are air pollutants that fall under the Clean Air Act and that EPA has the responsibility and jurisdiction to regulate them (549 U.S. 497). The Energy Independence and Security Act of 2007 includes provisions to increase energy efficiency and the availability of renewable energy (Public Law no. 110-140). In December 2009, the EPA Administrator signed an endangerment finding that states that current and projected concentrations of CO_2 and five other GHGs—CH_4, N_2O, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride—in the atmosphere threaten the public health and welfare of current and future generations (74 FR 66496).

EPA has established a number of partnerships and programs to mitigate GHGs and promote clean and efficient energy technologies, including for waste-to-energy. EPA established the voluntary CHP Partnership to reduce the environmental impact of power generation by promoting the use of CHP. The partnership works closely with energy users, the CHP industry, state and local governments, and other clean energy stakeholders to facilitate the development of new projects and promote their environmental and economic benefits. As of January 2010, the CHP Partnership had more than 350 partners dedicated to promoting and installing CHP and had assisted more than 460 CHP projects, representing 4,900 MW of new CHP capacity. Of these projects, 321 are waste-to-energy CHP applications, with a capacity of 1,700 MW (Energy and Environmental Analysis, Inc., 2010).

EPA also initiated Climate Choice, a new partnership program that recognizes innovative emerging technologies that can substantially reduce GHG emissions when widely adopted. The program offers innovative technologies and practices that dramatically reduce energy use and carbon emissions. EPA is partnering with progressive organizations to bring these technologies to market (U.S. EPA, 2009d). An international initiative, the Methane to Markets Partnership, engages 32 countries and the European Commission in advancing cost-effective, near-term CH_4 recovery and use as clean fuel from four major CH_4 sources: landfills, underground coal mines, natural gas and oil systems, and animal waste management. The partnership's goal is to reduce global CH_4 emissions while enhancing economic growth, strengthening energy security, improving air quality, and reducing GHG emissions (Methane to Markets Partnership, 2010).

3.1.2 Animal Feeding Operations

EPA defines animal feeding operations as agricultural operations in which animals are kept and raised in confinement. Feed is brought to the animals rather than the animals grazing for or seeking food (e.g., in pastures, fields, or rangelands). The U.S. Department of Agriculture (USDA) estimates that there are approximately 450,000 animal feeding operations in the United States (USDA, 2009). If not properly managed, animal feeding operations may have environmental and human health impacts, as pollutants from these operations may degrade groundwater, surface water, air, and soil. Animal waste and wastewater from these operations may enter groundwater or surface water from production areas and areas in which manure is applied to land and cause nutrient contamination. Animal feeding operations also can be a significant source of odorous and potentially harmful air emissions, such as ammonia, hydrogen sulfide (H_2S), CH_4, volatile organic compounds (VOCs), and PM. Clusters of animal feeding operations in certain areas of the country can contribute to air quality problems. For example, the California Air Resources Board estimates that dairy operations, mainly concentrated in the San Joaquin Valley, are the third-largest source of air pollution in the state, after vehicle exhaust and composting (U.S. EPA, 2008).

Biogas, which is composed of approximately 60% CH_4, approximately 40% CO_2, and trace amounts of H_2S and water vapor, is produced and emitted during the anaerobic decomposition of organic material in livestock manure at animal feeding operations. The quantity of CH_4 emitted is a function of the manure composition, type of treatment or storage facility, and climate (U.S. EPA, 2006a). In the United States, manure management is the fifth-largest source of human-related CH_4 emissions, accounting for approximately 7.5% of these emissions in 2007 (U.S. EPA, 2010e). Globally, CH_4 emissions from these types of operations are projected to increase by 21% between 1990 and 2020 (U.S. EPA, 2006b).

Operations that meet the regulatory definition of a concentrated animal feeding operation are regulated as point sources of pollution to U.S. waters under the Clean Water Act and are required to obtain discharge permits under the National Pollutant Discharge Elimination System (NPDES) (68 FR 7175; 73 FR 70417). Animal feeding operations also may be subject to permitting requirements under the Clean Air Act and reporting requirements under the Comprehensive Environmental Response, Compensation, and Liability Act and the Emergency Planning and Community Right-to-Know Act if they emit large quantities of air pollutants. In January 2005, EPA announced the Air Quality Compliance Agreement to monitor, evaluate, and reduce emissions from certain animal feeding operations and ensure compliance with regulatory requirements (U.S. EPA, 2010i).

Voluntary programs, such as the AgSTAR Program and Methane to Markets Partnership, help animal feeding operations reduce CH_4 emissions while promoting other environmental benefits. The AgSTAR Program, jointly sponsored by EPA, USDA, and the U.S. Department of Energy (DOE), is a voluntary program that encourages the use of CH_4 recovery (biogas) technologies at animal feeding operations that manage manure as liquids or slurries. This program has successfully encouraged the development and adoption of anaerobic digestion technology. Annually, these systems reduce CH_4 emissions by about 800,000 metric tons of CO_2e and produce more than 370,000 MWh of energy (U.S. EPA, 2010b).

The implementation of biogas recovery for livestock manure treatment and energy production has increased quickly over the past few years as a result of a number of factors: increased technical reliability of anaerobic digesters through deployment of successful systems, growing concerns about environmental quality, increasing number of state and federal programs designed to help provide funding for development of these systems, increasing energy costs, emphasis on energy security, and emergence of state energy policies and incentive programs to promote renewable energy and green power markets. Financial incentives have been instrumental in increasing the development of anaerobic digester systems. For example, the USDA Rural Development Business and Cooperative Programs provide loans and grants to farm owners to partially fund installation of commercially proven livestock waste digestion technologies (U.S. EPA, 2010p; USDA, 2010b).

3.1.3 Wastewater Treatment

Wastewater from municipal sewage is treated to remove soluble organic matter, suspended solids, pathogenic organisms, and chemical contaminants. Anaerobic treatment of wastewater produces CH_4, which can be released to the atmosphere if controls to capture these emissions are not in place. Wastewater treatment facilities are the eighth-largest source of human-related CH_4 emissions in the United States, emitting 24.4 Tg CO_2e and accounting for approximately 4.2% of total emissions in 2007 (U.S. EPA, 2010e).

More than 75% of the U.S. population is served by centralized wastewater collection and treatment systems (U.S. EPA, 2004b). Based on the results of EPA's 2004 Clean Watersheds Needs Survey, more than 16,000 municipal wastewater treatment facilities operate in the United States, ranging in capacity from several hundred millions of gallons per day (MGD) to less than 1 MGD (U.S. EPA, 2008b). According to EPA, 1,066 of these facilities operate with a total influent flow rate greater than 5 MGD (U.S. EPA, 2004c, as cited in U.S. EPA, 2007), making them potential candidates for performing anaerobic digestion and off-gas utilization for CHP applications (U.S. EPA, 2007). Only 544 of these treatment facilities, however, employ anaerobic digestion to process wastewater, and only 106 of the facilities utilize the biogas produced by their anaerobic digesters to generate electricity and/or thermal energy (U.S. EPA, 2004c, as cited in U.S. EPA, 2007).

Wastewater treatment facilities are critical for maintaining public sanitation and a healthy environment and must be continually operated during power outages or in the event of a natural or man-made disaster. Because of its ability to produce electricity and heat onsite, independent of the power grid, CHP is a valuable addition for wastewater treatment facilities. A well-designed CHP system that is powered by digester gas offers many benefits for wastewater treatment facilities because it produces power at a cost below retail electricity, displaces fuels normally purchased for the facility's thermal needs, qualifies as a renewable fuel for green power programs, offers an opportunity to reduce GHG and other air pollution emissions, and enhances power reliability for the treatment plant (U.S. EPA, 2010f).

Wastewater treatment facilities use several methods to manage and dispose of sludges produced during sewage treatment, including aerobic or anaerobic digestion. Under aerobic digestion, microorganisms convert organic material to CO_2 and water, resulting in a 35% to 50% reduction in volatile solids content (USDA, 2010a). The disadvantage compared to anaerobic digestion is that its byproducts cannot be used to make energy, whereas anaerobic digestion produces CH_4 that can be harnessed. Additionally, anaerobic digestion has a higher rate of pathogen destruction as compared to aerobic digestion, eliminating more than 99% of pathogens (U.S. EPA, 2010h).

Several regulations cover various aspects of wastewater treatment. The Clean Water Act sets limits, via permitting under the NPDES, on the amount of pollutants that may be discharged and states that pollution discharge must be controlled by best available technology. Section 503 of the Clean Water Act covers biosolids, which are defined as treated residuals from wastewater treatment that can be used beneficially, and governs land application of wastewater treatment residuals (40 CFR Part 503). Part 133 of the Clean Water Act requires municipal waste treatment facilities to meet secondary treatment standards, ensuring that the discharged effluents meet minimal removal standards for biochemical oxygen demand, total suspended solids, and pH (40 CFR Part 133). Several states, including Minnesota and Montana, require wastewater treatment facilities to obtain air emission permits if there is the potential to emit certain pollutants (e.g., NO_x) above federal and state thresholds (Minnesota Pollution Control Agency, 1998; Montana Department of Environmental Quality, 2009).

3.1.4 Landfills

Municipal solid waste landfills are the second-largest source of human-related CH_4 emissions in the United States, accounting for approximately 22% of these emissions in 2008 (U.S. EPA, 2010e). Possibly the biggest health and environmental concerns are related to the uncontrolled surface emissions of landfill gas into the air. Landfill gas is created when organic waste in a municipal solid waste landfill decomposes. On average, this gas is made up of approximately 50% CH_4, approximately 50% CO_2, and a small amount of non-CH_4 organic compounds, including VOCs that contribute to ozone formation and hazardous air pollutants that can affect human health (U.S. EPA, 2010k).

Landfill gas can be captured, converted, and used as an energy source. Using it helps to reduce odors and other hazards associated with emissions and helps to prevent CH_4 from migrating into the atmosphere and contributing to global climate change. Landfills are regulated to control air emissions under the authority of Section 111 of the Clean Air Act (71 FR 53271). Current regulatory standards correspond to emissions of non-CH_4 organic compounds, which generally make up less than 1% of landfill gas. Landfill gas possesses a heat content equal to roughly one-half that of natural gas (Southern Research Institute, 1998). Landfills emitting greater than 50 metric tons per year of non-CH_4 organic compounds are required to install a gas collection system and a treatment system capable of destroying 98% of the non-CH_4 organic compounds in the gas or reducing their concentration to less than 20 parts per million by volume (ppmv) (71 FR 53271). In this process, CH_4 also is converted to CO_2 while being utilized to produce electricity or heat (Southern Research Institute, 1998). Under the *Final Mandatory Reporting of Greenhouse Gases Rule*, effective December 29, 2009, certain municipal solid waste landfills that generate CH_4 in amounts equivalent to 25,000 metric tons of CO_2e must report these emissions (74 FR 56260). Finally, in many cases, landfill gas is collected and flared, which often requires additional fossil fuels to sustain the flare and assure complete combustion. In such cases, valuable fossil fuels are consumed and potential renewable energy is not utilized.

The anaerobic digester at Colorado Pork in Lamar, Colorado.

The EPA Landfill Methane Outreach Program is a voluntary assistance program that helps reduce CH_4 emissions from landfills by encouraging the recovery and use of landfill gas for energy production. The program forms partnerships with companies, state agencies, organizations, landfills, and communities and provides industry networking and technical and marketing resources to aid project development (U.S. EPA, 2010e). Additional voluntary programs, such as the international Methane to Markets Partnership, also help landfills reduce CH_4 emissions while promoting other environmental benefits.

3.1.5 Boilers

With increasing concern about climate change and fossil fuel energy supplies, there continues to be interest in biomass as a renewable and sustainable energy source. Biomass is organic material typically derived from plant matter such as trees, grasses, and agricultural crops. Co-firing involves substituting biomass, commonly wood or waste wood from paper mill operations, for a portion of the fossil fuel used in a boiler. Use of biomass can generate CO_2 credits for power producers while enhancing their renewable energy portfolios. Many studies have shown the efficacy and environmental impacts of biomass co-firing at large, coal-fired utility boilers, but data have been limited for biomass co-firing in industrial-size boilers. Areas with limited renewable energy resources, such as solar and wind, may need to rely on biomass as an alternative renewable energy option. To decrease the investment needed to establish a biomass combustion facility and utilize existing resources, current coal-fired generation units can explore opportunities to co-fire biomass with coal.

The co-firing of wood waste with coal in boilers can reduce emissions of GHGs and criteria pollutants. Using wood waste reduces the need to burn fossil fuels and conserves finite natural resources. Co-firing also significantly reduces SO_2 emissions because biomass contains significantly less sulfur than coal (U.S. DOE, 2000). In recognition of these benefits, an increasing number of organizations are promoting the co-firing of wood or waste wood from paper mill operations in coal boilers. Co-firing does not require significant changes to the boiler beyond burner modifications, nor any additions necessary to burn the new type of fuel. In the United States, the Northeast Regional Biomass Program and NYSERDA are working to increase co-firing in industrial, institutional, and other nonutility coal-fired boilers. The Northeast is ideally suited for the use of wood waste as there is a large supply available (Northeast Regional Biomass Program, NYSERDA, 1999).

On April 29, 2010, EPA's OAQPS proposed a new maximum achievable control technology (MACT) standard for boilers—the Boiler Area Source Rule—that regulates emissions from biomass co-fired boilers at industrial, commercial, and institutional facilities (U.S. EPA, 2010l). The court-ordered date for promulgating the rule is December 16, 2010 (Eddinger, 2010).

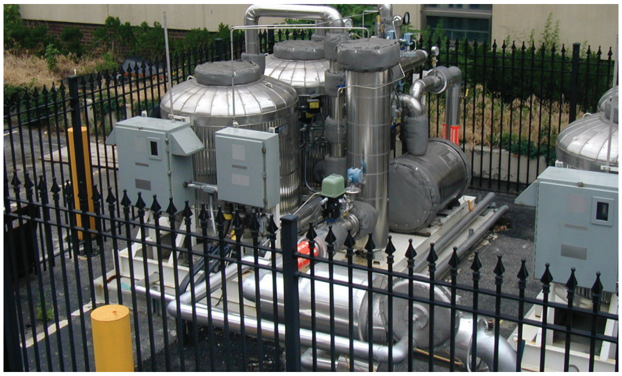
3.2 Technology Description

ETV's Greenhouse Gas Technology Center, managed by Southern Research Institute, has verified the performance of two biogas processing systems and four distributed generation energy systems that utilize CH_4 or other gaseous waste streams as fuel, including one fuel cell, two internal combustion engines, and one microturbine. ETV also verified the performance of two biomass co-fired boilers under an ESTE project (see Exhibit 3-1). All eight systems were operated onsite using either landfill gas, anaerobic digester gas generated from animal waste, municipal wastewater sludge, or solid biomass. Although the regulations and drivers that govern these sectors are different, with the possible exception of the co-fired boilers, the technologies used to process and generate power from these sources are generally applicable to more than one sector. As a result, the following information has been divided into subsections based on technology categories, rather than environmental sectors, with the understanding that these technologies may be applicable across sectors.

3.2.1 Biogas Processing Systems

Biogases from wastewater treatment plants, livestock manure management facilities, and landfills are promising alternatives to natural gas for fueling distributed generation technology. The gases are produced onsite, either through natural decomposition of organic wastes in a landfill or controlled decomposition of manure and human waste in anaerobic digesters, and require treatment to remove contaminants before they can be used as fuel. Biogas can be made more usable and environmentally benign if contaminants, primarily H_2S, are removed prior to use as an energy source. Biogas processing systems remove the H_2S and other sulfur species from the biogas before it is introduced to a distributed generation system as fuel, where these contaminants can cause corrosion in engines, increase maintenance requirements, and poison catalyst materials. A variety of technologies and techniques are available for removing H_2S from biogas, including air injection, reaction with iron oxide or hydroxide (iron sponge), water scrubbing, and biological treatment (Krich, et al., 2005). Certain H_2S removal technologies, such as caustic scrubbers, may be costly to operate and produce hazardous effluents. Redox processes also are available, but these require use of chelating agents and generate potentially hazardous effluents (Southern Research Institute, 2004e).

The ETV Program verified two biogas processing systems. The first technology, the Paques THIOPAQ® gas purification system manufactured by NATCO Group, Inc., is designed to remove H_2S from biogas and other sour gases. The system minimizes the generation of harmful emissions or effluents by aerobically digesting the waste into a more benign sulfurous product and regenerating and reusing the caustic sodium hydroxide (NaOH) used in the scrubber. This caustic scrubber-based system was verified at a 40-MGD Midwestern water pollution control facility designed to process industrial wastewater streams from local industries, including grain and food processing plants and a paper mill. The second technology, an anaerobic digester gas processing unit manufactured by USFilter/Westates Carbon[2], was verified with the PC25C Fuel Cell Power Plant–Model C manufactured by UTC Fuel Cells, LLC at the Red Hook Water Pollution Control Plant, a 60-MGD secondary wastewater treatment facility in Brooklyn, New York (see Section 3.2.2 for additional information on the fuel cell verification). This technology is a carbon-based filter that removes H_2S, other sulfur species, and heavy hydrocarbons from biogas. It differs from the first technology in that it was integrated with a waste heat recovery system and was designed specifically to remove impurities, such as H_2S, that are potentially damaging to the fuel cell. Specific details of the gas processing units can be found in the verification reports (Southern Research Institute, 2004c, 2004e), available at *http://www.epa.gov/nrmrl/std/etv/pubs/sriusepaghgvr32.pdf* and *http://www.epa.gov/nrmrl/std/etv/pubs/sriusepaghgvr26b.pdf*. ETV-verified performance for these systems is described in the text following and in Exhibit 3.2-1.



The USFilter/Westates Carbon gas processing unit installed at Red Hook Water Pollution Control Plant.

Additionally, a combined fuel cell and gas processing unit produced by International Fuel Cells Corporation (now UTC Power) was verified at two municipal solid waste landfills, one in California and one in Connecticut. The gas processing unit, described in the text following and in Exhibit 3.2-1, is designed to remove

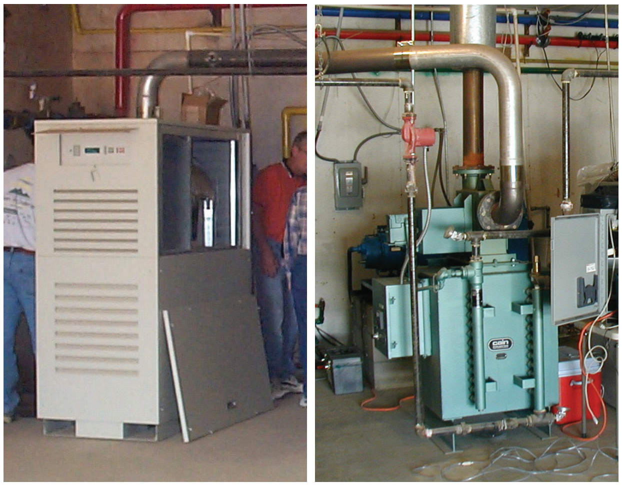
2. Westates Carbon was acquired by the former USFilter Corporation in December 1996. USFilter was acquired by Siemens in July 2004 and now operates as Siemens Water Technologies.

Exhibit 3.2-1

Performance of ETV-Verified Biogas Processing Units

Technology[A]	Testing Location	Processed Gas Composition (%)			Heat Content Lower Heating Value (Btu per standard cubic foot)	H_2S Removal Efficiency (%)/ Average Final Concentration
		CH_4	CO_2	N_2		
International Fuel Cells Gas Processing Unit	Penrose Landfill Facility (Los Angeles, CA)	44.11	37.88	17.31	401.3	99/0.04 ppmv
	Groton Landfill Facility (Groton, CT)	57.30	41.21	1.16	522.8	99/0.02 ppmv
NATCO Group, Inc. Paques THIOPAQ®	Water Pollution Control Facility (Midwest)	68.89	28.71	2.03	617.2	99.8/27.5 ppm
USFilter/Westates Carbon Gas Processing Unit	Red Hook Water Pollution Control Plant (Brooklyn, NY)	61.37	37.10	1.23	551.2	>99.996/<4 ppb

[A] The ETV Program does not compare technologies. In this exhibit, technologies are listed alphabetically by vendor company name. Order of appearance of technologies in this table does not necessarily reflect technology performance results.



The Capstone Model 330 microturbine combined with heat recovery system installed at Colorado Pork.

impurities from biogas, making it amenable for use by the company's PureCell™ Model 200 fuel cell. Additional details of the technology can be found in the verification report (Southern Research Institute, 1998), available at *http://www.epa.gov/nrmrl/std/etv/pubs/epavsghg01.pdf*. Information and results for the fuel cell verification are discussed in Section 3.2.2.

During testing of the three biogas processing units, the ETV Program verified the composition and properties of raw and processed biogas. Sulfur compound removal efficiency was verified for all three biogas processing units.

Halide removal efficiency was verified for the USFilter/Westates Carbon unit and the International Fuel Cells unit. Moisture and VOC removal also were verified for the USFilter/Westates Carbon unit. System effects on biogas composition and heating value were verified for the NATCO and USFilter/Westates Carbon technologies tested at wastewater treatment facilities. NaOH consumption rates were monitored and reported for the NATCO system.

The International Fuel Cells gas processing unit installed at the two landfills consistently reduced contaminants in the landfill gas to levels significantly below the initial goals of less than 3 ppmv total sulfur and less than 3 ppmv total halides. Additionally, VOC removal efficiencies for the USFilter/Westates Carbon gas processing unit ranged from 17.5% to 99.9% for the 12 VOCs detected in the raw biogas samples at concentrations of 50 parts per billion (ppb) or greater. Total halide removal efficiency averaged 65%. For the NATCO gas processing unit, the average 50% NaOH consumption rate normalized to biogas feed rate was 0.12 gallons per thousand cubic feet of biogas processed, or 0.44 pounds (lbs) of NaOH per lb of sulfur. Further verification results are described in Exhibit 3.2-1.

3.2.2 Distributed Generation Energy Systems

Fuel cells, internal combustion engines, and microturbines are well suited to provide electricity at the point of use because of their small size, flexibility in connection methods, ability to be arrayed in parallel to serve larger loads, ability to provide reliable energy, and low emissions profile (National Renewable Energy Laboratory, 2003). These technologies may be used to convert opportunity fuels (e.g., gas from municipal solid waste landfills) to energy. When used in stationary applications to generate electricity at the point of use, distributed generation systems reduce the need to generate electricity from sources such as large electric utility plants, which emit significant quantities of CO_2, NO_x, and CO. When well-matched to building or facility needs in a properly designed CHP application, distributed generation systems can utilize waste heat to increase operational efficiency and avoid power transmission losses, thereby reducing overall emissions and net fuel consumption compared to traditional power and heat generation systems.

Below are descriptions of the verified waste-to-energy distributed generation systems, as well as their applications. ETV-verified unit performance is described in the text following and in Exhibit 3.2-2.

- **Fuel cells:** Fuel cells use hydrogen to generate electricity. They consist of two electrodes separated by an electrolyte (U.S. DOE, 2008; U.S. EPA, 2008a). During operation, hydrogen-rich fuel reacts with the anode to produce positive ions and electrons. The positive ions pass through the electrolyte to the cathode, where they react to produce water and heat. The electrons must travel around the electrolyte in a circuit, generating an electric current (U.S. DOE, 2008). Fuel cells typically are categorized by the type of electrolyte used (U.S. EPA, 2008a). As mentioned in Section 3.2.1, the ETV Program verified the performance of the PC25C Fuel Cell Power Plant—Model C (now called PureCell™ Model 200) manufactured by UTC Fuel Cells, LLC (now UTC Power). The PureCell™ Model 200 fuel cell uses liquid phosphoric acid as the electrolyte (Southern Research Institute, 2004b). Per the manufacturer, this fuel cell is capable of producing 200 kilowatts (kW) of electrical power with the potential to produce an additional 205 kW of heat. The PureCell™ Model 200 fuel cell was tested in 2004 at the Red Hook Water Pollution Control Plant in Brooklyn, New York. The fuel cell also was tested in 1998 (then as the combined PC25™ 200 kW fuel cell and gas processing unit manufactured by International Fuel Cells Corporation) at the Penrose Landfill in Los Angeles, California, and the Groton Landfill in Groton, Connecticut. The PureCell™ Model 200 system consists of three major components: (1) a gas processing unit (developed by USFilter/Westates Carbon), (2) a power module, and (3) a cooling module. Two PureCell™ Model 200 systems were installed at the Red Hook plant, and both were configured to use anaerobic digester gas produced at the site as the primary fuel and natural gas for fuel cell startup or as a backup fuel. The landfill gas from the Penrose site was waste gas recovered from four nearby landfills, containing mostly industrial waste material. The Groton test site is a relatively small landfill but with greater-heat-content gas. Specific details of the technologies can be found in the verification reports (Southern Research Institute, 1998, 2004b), available at *http://www.epa.gov/nrmrl/std/etv/pubs/sriusepaghgvr26.pdf* and *http://www.epa.gov/nrmrl/std/etv/pubs/epavsghg01.pdf*.

- **Microturbines:** Large- and medium-scale combustion turbines have been used by electric utilities since the 1950s. Recent advances have allowed the development and limited application of microturbines (U.S. EPA, 2002). The Capstone Model 330 (now the Model C30) 30 kW microturbine system, manufactured by Capstone Turbine Corporation, is a microturbine combined with a heat recovery system for distributed electrical power

Exhibit 3.2-2

Performance of ETV-Verified Distributed Generation Technologies

Technology[A]	Testing Location	Test Condition (Power Command) (kW)	Efficiencies (site-specific maximums)			Maximum Electrical Power Output (kW)	Emissions Rates (lbs/kWh)	
			Electrical	Thermal	Total System		CO_2	NO_x
Capstone Model C30 Microturbine	Colorado Pork, LLC Swine Farm (Lamar, CO)	30	20.4%	33.3%	53.7%	19.9[B]	3.45	8.2×10^{-5}
Martin Machinery Caterpillar Model 379 Engine/Generator with Integrated Heat Recovery	Patterson Farms Dairy Farm (Auburn, NY)	200	26.7%	8.14%[C]	34.8%[C]	191	1.44	0.021
Martin Machinery Caterpillar Model 3306 ST Engine/Generator and Heat Exchanger	Colorado Pork, LLC Swine Farm (Lamar, CO)	45[D]	19.7%	32.4%	52.1%	44.7	1.97	0.012
UTC Power PureCell™ Model 200 Fuel Cell	Red Hook Water Pollution Control Plant (Brooklyn, NY)	200	36.8%	56.9%	93.8%[E]	193	1.44	1.3×10^{-5}

[A] The ETV Program does not compare technologies. In this exhibit, technologies are listed alphabetically by vendor or technology name. Order of appearance of technologies in this table does not necessarily reflect technology performance results.

[B] The relatively high altitude of the facility and the parasitic load introduced by the gas compressor limited the microturbine's power output.

[C] The site was not designed to maximize heat use. Higher total system efficiency could be realized at other sites. Also, if low-quality hot water (approximately 140°F) could be utilized, higher thermal efficiency could be realized.

[D] The configuration of the engine's fuel input jets and the low heating value of the biogas restricted the engine's power command output to 45 kW during verification, which is lower than the equipment manufacturer's recommended minimum rating for this engine.

[E] This value represents the maximum potential heat usage based on heat exchanger inlet and outlet temperatures; however, the site did not actually utilize this heat because of the availability of steam onsite at no cost.

and heat generation. The heat recovery system in the verified application was manufactured by Cain Industries and recovered waste heat from the microturbine. The Capstone Model C30 microturbine was verified at the Colorado Pork facility in Lamar, Colorado—a sow farrow-to-wean farm that houses up to 5,000 sows. The facility employs a complete mix anaerobic digester that promotes bacterial decomposition of volatile solids in animal wastes. The resulting effluent stream is allowed to evaporate from a secondary lagoon. Solids accumulate in the digester and are manually removed. Recovered heat from the microturbine CHP is circulated through the waste in the digester to maintain the digester temperature.[3] Details of the Capstone Model C30 microturbine and a heat recovery system can be found in the verification report (Southern Research Institute, 2004a), available at *http://www.epa.gov/etv/pubs/sriusepaghgvr22.pdf*.

- **Reciprocating internal combustion engines:** Reciprocating internal combustion engines are widespread and well-understood technology suited for a variety of distributed generation and CHP applications. Internal combustion engines depend on the process of combustion (i.e., the reaction of a fuel with an oxidizer, usually air) to generate useful mechanical energy. Although commonly fueled with fossil fuels, recent technological advances have allowed introduction of biogases and other renewable fuel sources (Southern Research Institute, 1998, 2004a, 2004b, 2004c, 2004d, 2004e, 2007) capable of providing significant environmental and economic benefits (Southern Research Institute, 2007). The ETV Program verified the performance of two internal combustion engines with CHP. The verified distributed generation/CHP systems, designed and installed by Martin Machinery, Inc., are: (1) Caterpillar Model 379, 200 kW engine and generator set with integrated heat recovery; and (2) Caterpillar Model 3306 ST, 100 kW engine, generator (manufactured by Marathon Electric), and heat exchanger. The first test was conducted using biogas from the Colorado Pork facility described above. The second test was conducted using anaerobic digester gas from Patterson Farms, a dairy farm with 1,725 cows and heifers near Auburn, New York. Details of the internal combustion engines can be found in the verification reports (Southern Research Institute, 2004d, 2007), available at *http://www.epa.gov/nrmrl/std/etv/pubs/03_vr_martin.pdf* and *http://www.epa.gov/nrmrl/std/etv/pubs/vr600etv07049.pdf*.

3. The information provided was applicable at the time of verification; the digester at this facility no longer is in operation.

ETV verification of the distributed generation technologies outlined above included tests to verify heat and power production, emissions, and power quality. The four technologies reported in Exhibit 3.2-2 included heat recovery for CHP. Power production tests measured electrical power output and electrical efficiency at selected loads. In the tests in which potential heat production was verified, ETV measured heat recovery, potential thermal efficiency, and potential total system efficiency at selected loads. For the Capstone Model C30 microturbine, when tested at less than full load, electrical efficiencies were lower, but thermal efficiencies were higher. It should be noted that the test site was not designed to maximize heat use, and higher total system efficiency could be realized at other sites.

The verification tests measured emissions concentrations and rates at selected loads. Verified emissions rates for CO_2 and NO_x are reported in Exhibit 3.2-2. Additionally, three of the verification reports estimated total annual CO_2 reductions by comparing measured emissions rates during testing with corresponding emission rates for baseline power-production systems (e.g., average regional grid emission factors or baseline scenarios for the testing sites). Annual changes in NO_x emissions were estimated in a similar manner. Annual emissions reductions as compared to the grid were not evaluated for the Capstone Model C30 microturbine verified at the animal feeding operation. Additional information on the annual emissions reductions estimates is available in Appendix B. The ETV Program also verified concentrations and emissions rates for other pollutants and GHGs, including CO, THCs, and CH_4 (in two of the cases), as well as flare destruction efficiency at the two landfill applications. More detailed performance data are available in the verification reports for each technology (Southern Research Institute, 2004b), which can be found at the links above.

For the PureCell™ Model 200 fuel cell verified at the two landfills in California and Connecticut, the maximum electrical power outputs were 140 kW and 165 kW at the Penrose and Groton sites, respectively. Energy conversion efficiency was determined to be 37.1% at Penrose and 38% at Groton. Average emissions rates were 0.12 ppmv or 0.29 grams per hour (g/h) for NO_x; 0.77 ppmv or 1.15 g/h for CO; SO_2 emissions were below the detection limit. Annual emissions reductions as compared to the grid were not evaluated for the fuel cells verified at the landfills.

3.2.3 Biomass Co-Fired Boilers

Coal-fired boilers use thermal energy to produce electri-city and steam. Because of increasing concerns about fossil fuel use, alternatives to burning coal have been sought, and many coal-fired boilers now are co-fired using a mixture of biomass and coal. Since approximately 1990, an increasing number of electric utilities across the United States have implemented biomass co-firing (U.S. DOE, 2000). This transition is occurring because renewable wood waste is an energy source that can be used to: reduce the amount of coal used in coal-fired boilers; reduce emissions of CO_2, SO_2, NO_x, and acid gases; and decrease waste sent to landfills (U.S. DOE, 2000, 2004). Depending on the price of coal and the availability of wood waste in the area, co-firing also has the potential to lower fuel costs (U.S. DOE, 2004). Many studies have been conducted on the efficacy and environmental impacts of biomass co-firing on large, coal-fired utility boilers, but data regarding biomass co-firing in industrial-size boilers have been limited (Southern Research Institute, 2008a).

The ETV Program verified the performance, including emissions reductions, of two biomass co-fired industrial boilers. The pelletized wood fuel developed by renewaFUEL, LLC was used for one verification. The renewaFUEL pellets, which have a moisture content of 6.6% by weight, were tested at the University of Iowa (UI) Main Power Plant Boiler 10 (a Riley Stoker Corporation unit) in Iowa City, Iowa. The Main Power Plant is a CHP facility that serves the main campus and university hospitals and clinics. The plant continuously supplies steam service and cogenerated electric power. This boiler co-fired the pellets with coal in an 85:15 ratio of coal to biomass. In the second verification, wood waste was co-fired with coal at the Minnesota Power Rapids Energy Center (REC) Boiler 5 (a Foster Wheeler spreader stoker boiler) in Grand Rapids, Minnesota. REC provides power and heat for the neighboring Blandin Paper Mill. This boiler co-fired wood waste and bark from the paper mill, railroad ties, and onsite generated waste oils and solvents with coal in an 08:92 ratio of coal to biomass and moisture content of 46.5% by weight.

ETV evaluated changes in boiler performance resulting from co-firing woody biomass with coal. Boiler operational performance with regard to efficiency, emissions, and fly ash characteristics was evaluated while combusting 100% coal and then reevaluated while co-firing biomass with coal. The UI Boiler 10 verification indicated that SO_2 emissions were 12.4% lower while combusting the blended fuel, which correlates well with the approximately 15% biomass-to-coal ratio. The reduction in SO_2 indicates that co-firing woody biomass may be an option for reducing SO_2 emissions without adding emission-control technologies. NO_x emissions rose by 10.2% at the UI Boiler 10 site, which may be attributable to the higher temperatures within the boiler that occurred while firing the dryer, lighter blended fuel. The two verifications serve as a useful comparison between relatively dry and very moist woody fuels and how these factors can impact emissions. The characteristics and verification results are highlighted in Exhibit 3.2-3.


renewaFUEL pelletized wood fuel

Metals emissions were extremely low during testing at both sites, ranging from $4.80 \times 10^{-7} \pm 8.42 \times 10^{-9}$ for arsenic to $4.34 \times 10^{-5} \pm 6.8 \times 10^{-6}$ for selenium. The REC Boiler 5 site showed significant reductions in mercury and selenium emissions, and the UI Boiler 10 site showed a significant reduction in selenium emissions. Fly ash composition changes also were verified. The two sites differed in changes in fly ash content. In general, changes were small—with the exception of carbon content, which was significantly lower—following co-firing in UI Boiler 10. Changes were significant at the REC Boiler 5 site, with the exception of carbon content, which was not significantly changed. Loss on ignition was significantly impacted at both sites. More detailed performance data, including impacts on ash quality can be found in the verification reports for each technology (Southern Research Institute, 2008a, 2008b), available at *http://epa.gov/etv/pubs/600etv08018.pdf* and *http://www.epa.gov/etv/pubs/600etv08017.pdf*.

Exhibit 3.2-3

Characteristics and Performance of ETV-Verified Biomass Co-Fired Boilers

	Ratio of Coal to Biomass	Moisture Content (by weight)	Boiler Operational Efficiency[A]	Emissions Reductions[A]				
				SO_2	CO_2	NO_x	CO	PM
UI Boiler 10, renewaFUEL pelletized wood fuel co-fired with coal	85:15	6.60%	−0.90%	12.4%*	−0.82%	−10.2%*	5.02%	28.1%
REC Boiler 5, wood waste co-fired with coal	08:92	46.5%	−17.7%*	99.7%*	18.3%*	63.2%*	−142%*	81.2%*

[A] Compared to operation while combusting 100% coal

* Statistically significant (*t*-test with 90% confidence interval)

3.3 Outcomes

Waste-to-energy technologies harness the energy potential of waste streams, including organic wastes. Gas from digesters and landfills can be used in distributed generation applications to generate reliable electricity and power for facilities, thus replacing fossil fuels and decreasing the amount of waste sent to landfills or otherwise emitted. Benefits for the facility and the environment include producing onsite power, displacing purchased fuels for thermal needs, qualifying as a renewable fuel for green power programs and incentives, enhancing power reliability for the facility, and reducing GHGs and other air emissions. Waste-to-energy technologies also offer an important security and safety benefit for many facilities, particularly wastewater treatment facilities. To help maintain public health, these facilities must operate continuously or come back online quickly in the event of a grid power loss, such as from a catastrophic event or natural disaster. Waste-to-energy technologies can continue to provide onsite power generation to these and other critical facilities in the event of utility failures and are a valuable infrastructure addition (U.S. EPA, 2010f). There are, however, some barriers to implementing such systems for waste-to-energy applications. Considering current market conditions, many facilities do not view installation as economically viable based on installation and operating and maintenance costs that may not allow payback of the investment, especially as some public utilities are not willing to accept excess power from these facilities. Regulatory and statutory frameworks are needed to promote waste-to-energy conversion technologies, and public and elected officials need to be educated regarding the benefits of waste-to-energy (California Integrated Waste Management Board, 2001).

The ETV-verified technologies for processing and generating power from CH_4 or other gaseous waste streams are generally applicable to more than one sector. As such, the ETV Program estimated the following market scenarios and potential outcomes—including emissions reductions, energy generation, and cost benefits—associated with use of verified technologies by sector or application.

3.3.1 Emissions Reduction Outcomes

The emissions reductions discussed here were estimated for distributed generation systems and biomass co-fired boilers. Biogas processing units were not evaluated directly for their applicability to reduce emissions and so are not discussed in this section, although they allow distributed generation systems to use biogas as an alternative fuel source. Biogas production is considered to be CO_2 neutral, and utilization of landfill gas and manure digester biogas directly prevents atmospheric pollution by preventing CH_4 from being emitted into the atmosphere (U.S. EPA, 2010e). ETV estimates that the potential markets for the biogas processing units would be similar to those identified for the distributed generation systems.

Distributed Generation Systems

Emissions reductions from using distributed generation systems depend on a number of factors, including the electricity and heating demand of the specific application, the technology's emissions rates, and the emissions rates of the conventional source that the technology replaces. These factors vary by geographic location. Characterizing these factors for all potential applications of ETV-verified distributed generation systems is not reasonably feasible. ETV used geographic-specific estimates developed by Southern Research Institute for the verified technologies, as well as estimates generated by the CHP Partnership, USDA, and DOE to estimate potential markets and project CO_2, NO_x, CH_4, and other emissions reductions from these sectors, as indicated below. Additionally, the ETV-verified technologies have the potential to reduce emissions of other pollutants such as CO and THCs. As environmental and human health effects of GHGs and other pollutants are significant, the benefits of reducing these emissions also should be significant. Appendix B describes ETV's methods for using these estimates to project nationwide emissions reductions for the applications below. Based on these analyses and verified technology performance, potential emissions reductions from use of waste-to-energy distributed generation systems include the following:

- **Animal feeding operations:** Dairy operations with more than 500 cows and heifers and swine operations with more than 2,000 sows are good candidates for anaerobic digestion and biogas use. The potential for manure-produced biogas is highest for manure that is collected and stored as a liquid, slurry, or semisolid. Given these parameters, EPA AgSTAR estimates that 2,600 dairy operations and 5,600 swine operations are potential candidates for significant manure biogas production and anaerobic digestion in the United States, greatly exceeding the estimates for systems that currently are in use (see text box; U.S.EPA, 2010c). Based on AgSTAR estimates and ETV verification results, Exhibit 3.3-1 presents annual CO_2 or CO_2e emissions reductions that could be realized through use of ETV-verified technologies at 10% and 25% of these operations. Appendix B describes the methodology and assumptions used to develop these estimates. Based on verified technology performance, average annual NO_x emissions could potentially increase by approximately 0.37 to 14.7 tons per installation when compared to baseline regional grid emissions rates. Because ammonia generated by anaero-

Exhibit 3.3-1

Estimated Potential Emissions Reductions for ETV-Verified Technologies Used at Animal Feeding Operations

Market Penetration	Number of Animal Feeding Operations	Annual CO_2 Emissions Reductions (tons per year)[A,B]	
		Lower Bound	Upper Bound
10%	820	2,500	5.9 million
25%	2,100	6,300	15 million

Values rounded to two significant figures.

[A] The verification results used to calculate the upper bound for annual emissions reductions outcomes include estimated reductions in CO_2 equivalent emissions associated with the use of waste generated CH_4 as fuel; the verification results used to calculate the lower bound did not include these additional reductions.

[B] Emissions reductions outcomes do not include additional reductions associated with the recovery and use of waste heat; the annual CO_2 emissions reductions above are for electricity generation only.

As of April 2010, AgSTAR estimated that 151 anaerobic digester systems are operating at commercial livestock farms in the United States, and 125 of these generate electrical or thermal energy from the captured biogas, producing about 360,000 MWh annually. The combustion of biogas at these digesters prevents the emission of about 36,000 metric tons of CH_4 annually (760,000 metric tons of CO_2e). In addition, the combustion of biogas displaces the use of fossil fuels, thus achieving additional emissions reductions of GHGs and air pollutants (U.S. EPA, 2010h). If biogas recovery systems are installed at all feasible dairy and swine operations, total CH_4 emissions can be reduced by an estimated 66%—or 1.6 million tons—compared to 2002 CH_4 emissions (U.S. EPA, 2010c). The ETV-verified technologies discussed in this case study are potential candidates for these types of projects.

bic digester systems is burned in an energy recovery system, ammonia output is ultimately reduced compared to a standard lagoon or pit. Although not quantified, additional significant environmental benefits also can be realized from the recovery and use of waste heat and odor reduction.

- **Wastewater treatment facilities:** Wastewater treatment facilities with influent flow rates greater than 5 MGD are good candidates for distributed generation anaerobic digestion and biogas utilization.[4] The EPA 2004 Clean Watersheds Needs Survey estimates that 544 wastewater treatment facilities in the United States currently produce biogas using anaerobic digesters. Of these, only 106 facilities utilize the biogas produced by their anaerobic digesters to generate electricity and/or thermal energy (U.S. EPA, 2004c, as cited in U.S. EPA, 2007), for an additional potential market of 438 facilities that could install distributed generation waste-to-energy technologies. Based on this additional market potential and ETV verification results, Exhibit 3.3-2 presents annual CO_2 and NO_x emissions reductions that could be realized through use of ETV-verified technologies at 10% and 25% of these facilities. Appendix B describes the methodology and assumptions used to develop these estimates. The 2004 EPA Clean Watersheds Needs Survey identified a total of 1,066 wastewater treatment facilities in the United States with flow rates greater than 5 MGD (U.S. EPA, 2004c, as cited in U.S. EPA, 2007)—more of these facilities could perform anaerobic digestion, but treatment process modifications most likely would be required. Emissions reductions for the ETV-verified technologies could be even greater if market scenarios are based on the total number of treatment facilities with flow rates suitable for performing anaerobic digestion.

CO_2 and NO_x emission reductions also have been estimated for commercial applications of a verified fuel cell at wastewater treatment facilities in New York. Under a partnership between NYSERDA, the New York Power Authority (NYPA), and others, eight UTC PureCell™ Model 200 fuel cells are operating at four wastewater treatment plants managed by the New York City Department of Environmental Protection and located in or near New York City (NYPA, 2010; Staniunas, 2010a). A ninth PureCell™ Model 200 system operating at a fifth site near Yonkers, New York, has been decommissioned (Staniunas, 2010a). Each system is fueled by biogas from anaerobic digestion of sewage sludge. As described in Section 3.2.2, in 2004, ETV verified one of the PureCell™ Model 200 fuel cell installations at the Red Hook Water Pollution Control Plant in Brooklyn; ETV collaborated with NYSERDA and NYPA on this verification. These fuel cell projects are part of a program to offset emissions from NYPA's PowerNow!—six small natural gas-powered plants designed to increase electrical generating capacity for New York City. NYPA initiated a zero net emissions program to offset the small amount of emissions from the generators by reducing pollutants from other sources, including the installation of the UTC fuel cells to harness waste gas from sewage treat-

4. Analyses conducted by the EPA CHP Partnership indicate that treatment facilities with influent flow rates less than 5 MGD typically do not produce enough biogas from anaerobic digestion to make CHP technically and economically feasible (U.S. EPA, 2007).

Exhibit 3.3-2

Estimated Potential Emissions Reductions for ETV-Verified Technologies Used at Wastewater Treatment Facilities

Market Penetration	Number of Wastewater Treatment Facilities	Annual Emissions Reductions (tons per year)[A]	
		CO_2	NO_x
10%	44	63,000	80
25%	110	160,000	200

Values rounded to two significant figures.

[A] Estimates for annual emissions reductions include emissions reductions for flare offset.

ment facilities and produce clean electricity (NYPA, 2010). According to the vendor, collectively, the nine fuel cells reduced NO_x emissions by 50,000 lbs annually (UTC Power, 2007). Based on verified technology performance, the ETV Program estimates that the eight UTC fuel cells currently operating at wastewater treatment plants in or near New York City collectively reduce CO_2 emissions by approximately 11,000 tons annually.

- **Landfills:** The EPA Landfill Methane Outreach Program estimates that there are approximately 518 landfills already collecting landfill gas for energy recovery in the United States. These landfills generate approximately 13 billion kilowatt-hours (kWh) of electricity per year and deliver 100 billion cubic feet of landfill gas to direct-use applications annually. This represents the equivalent of the carbon sequestered annually by approximately 20 million acres of pine or fir forests, CO_2 emissions from approximately 216 million barrels of oil consumed, or annual GHG emissions from approximately 18 million passenger vehicles (U.S. EPA, 2010k). EPA estimates that an additional 520 landfills are good candidates for landfill gas energy projects based on gas generation and recovery estimates; feasibility assessments on biogas generation and recovery potential, potential end uses, and approximate costs of using gas for energy; and other analyses (U.S. EPA, 2010e). Based on this additional market potential and ETV verification results, Exhibit 3.3-3 presents the number of landfills that could apply ETV-verified technologies at 10% and 25% of the market. The ETV Program did not calculate annual emissions reductions during the waste-to-energy verifications performed at landfill sites; therefore, quantitative data are not available to estimate emissions reductions associated with the market scenarios outlined in Exhibit 3.3-3. It also should be noted that according to EPA, internal combustion engines are the most commonly used waste-to-energy technology for landfill gas applications (used in more than 70% of current landfill gas energy recovery projects in the United States) because of their relatively low cost, high efficiency, and good size match with the gas output of most landfills (U.S. EPA, 2010o). Several of the ETV-verified distributed generation technologies described in Section 3.2.2 could be applied for landfill gas recovery and achieve associated emissions reductions.

Exhibit 3.3-3

Number of Landfills That Could Apply ETV-Verified Technologies

Market Penetration	Number of Landfills
10%	52
25%	130

Values rounded to two significant figures.

EPA's estimates for the number of landfills that are candidates for waste-to-energy applications do not necessarily include older landfills that produce low-British thermal unit (Btu) landfill gas. The microturbine scheduled to be verified in 2011 jointly by ETV and DoD's ESTCP claims the ability to operate on low-Btu landfill gas, which may extend the usefulness and decrease CO_2 emissions further in the long term. The ETV Greenhouse Gas Technology Center estimates that the technology could have applicability at approximately 100 DoD landfill sites with potential to generate 90 MW of electricity annually. This translates to an estimated offset of 710,000 tons of CO_2e annually assuming that all sites are operating at maximum capacity and flare is offset (Hansen, 2010a).[5]

Co-Fired Boilers

According to the vendor, use of renewaFUEL's pelletized wood fuel in place of coal at the permitted capacity of 210,000 tons per year will result in direct reduction of

5. The estimate for potential applicability at DoD landfill sites is based solely on landfill size, closure date, and other similar information; actual application at these sites would require further analysis, including site logistics, economical feasibility, etc.

If a 3-MW landfill gas electricity project starts up at a landfill with previously uncontrolled landfill gas, the project would reduce CH_4 by approximately 6,000 tons per year and 110,000 tons of CO_2e per year. The combined emissions reduction of 130,000 tons of CO_2e per year would be equivalent to any one of the following annual environmental benefits for 2010: annual GHG emissions from 24,000 passenger vehicles, carbon sequestered annually by 27,000 acres of pine or fir forests, or CO_2 emissions from 14.3 million gallons of gasoline consumed. Additionally, annual energy savings for a 3-MW project equate to powering 1,800 homes (U.S. EPA, 2010e). The ETV-verified technologies discussed in this case study are candidates for these types of projects.

Minnesota Power's Rapids Energy Center woody biomass feed.

creditable GHG emissions of approximately 550,000 tons per year, which is equivalent to the emissions from the annual use of more than 56,000 vehicles. There is an even greater reduction in total lifecycle GHG emissions (direct and indirect) compared to coal given the reduced transportation emissions from renewaFUEL's local sources and the absence of CH_4 releases from coal mining. Based on a 90% reduction in the sulfur content of renewaFUEL pellets compared to the coal they displace, SO_2 emissions also are reduced. Per the vendor, there has been a demonstrated reduction in CO emissions by greater than 25% as a result of the combustion qualities of renewaFUEL pellets. Solid waste and ash disposal are reduced because the ash content of renewaFUEL's product, which is less than 1% by weight, contains approximately 80% less ash postcombustion than the coal it displaces (Mennell, 2010a, 2010c).

Minnesota Power—one of the host sites for the biomass co-fired boilers verification testing—co-fires woody biomass in Boilers 5 and 6. This facility has been co-firing since it was built in 1980 (Tolrud, 2010). Based on verification testing results, ETV estimates the following emissions reductions for biomass co-firing at Minnesota Power's Boiler 5: 107,000 tons of CO_2 per year, based on a typical heat generating rate of 200 MMBtu/h, an availability and utilization rate of 75%, and an estimated CO_2 emission reduction of 90% as compared to the grid or 148 lbs/MMBtu output during co-firing. Appendix B describes the methodology and assumptions used to develop these estimates.

3.3.2 Resource Conservation, Economic, and Financial Outcomes

Use of biogas and landfill gas as alternative energy sources results in the conservation of finite natural resources, such as natural gas, oil, and coal used as conventional fuels. Waste-to-energy technologies can produce cost benefits by allowing the use of an on-hand fuel source instead of relying on more costly purchased fuels. The NATCO Paques THIOPAQ® system produces elemental sulfur that can be recycled for sale or use, increasing the cost efficiency of the biogas processing unit. Because distributed generation systems generate and use electricity onsite, these systems avoid economic losses associated with the transmission of electricity, which can be in the range of 4.7% to 7.8% (Southern Research Institute, 2004b). Waste heat recovery also provides an opportunity to significantly reduce fossil fuel consumption in boilers, furnaces, and other generation devices. Although cost savings vary depending on the configuration of the individual installation and the cost of electricity and fuels, these savings can be significant, as noted below:

- The EPA AgSTAR Program estimates that 2,600 dairy operations and 5,600 swine operations are potential candidates for anaerobic digestion and biogas use in the United States. It is estimated that these operations could generate 13 million MWh of electricity per year (U.S. EPA, 2010c). Based on an average electricity price of \$0.10/kWh[6] (U.S. DOE, 2010), this equates to \$1.3 billion worth of electricity annually.
- The EPA 2004 Clean Watersheds Needs Survey estimates that there are 544 municipal wastewater treatment facilities in the United States with influent flow rates greater than 5 MGD that operate anaerobic digesters. If all of these facilities used their biogas to fuel CHP systems, approximately 340 MW of electricity could be generated annually (U.S. EPA, 2004c, as cited in U.S. EPA, 2007) worth \$300 million based on an average electricity price of \$0.10/kWh. Of the 544 wastewater treatment facilities that operate anaerobic digesters,

6. Average electricity price is based on the average retail price to ultimate consumers in all end-use sectors in the 50 states and the District of Columbia from January 2008 to June 2010 as reported by DOE.

In general, a wastewater treatment facility with a total influent flow rate of 4.5 MGD can produce approximately 100 kW of electricity to offset purchased electricity or sell to the grid, and 12.5 million Btu per day of thermal energy that can be used to heat an anaerobic digester and/or for space heating (U.S. EPA, 2010f).

438 facilities could install ETV-verified technologies to utilize the biogas produced by the digesters and generate electricity or thermal energy, with associated cost benefits.

- The EPA Landfill Methane Outreach Program estimates that 518 landfills currently collect landfill gas for energy recovery in the United States. As many as 520 additional landfills could cost-effectively install waste-to-energy systems to convert CH_4 emissions into an energy resource, producing enough electricity to power 688,000 homes across the United States (U.S. EPA, 2010e). Based on an average annual usage of 12,000 kWh per household (Padgett, et al., 2008) and an average electricity price of $0.10/kWh, this would provide an estimated annual economic value of $830 million.

Based on the above market potential, energy generation, and cost benefits associated with waste heat recovery for various applications, the ETV Program estimated annual energy generation and cost benefits from application of the ETV-verified distributed generation technologies at 10% and 25% market penetration, as shown in Exhibit 3.3-4. Estimates for potential energy generation and cost benefits that could be realized through application of ETV-verified distributed generation systems at wastewater treatment facilities are conservative. As previously noted, additional benefits could be realized if market scenarios are based on the total number of treatment facilities with flow rates suitable for performing anaerobic digestion. Appendix B describes the assumptions and methodologies used for these calculations.

NATCO THIOPAQ® system with aerobic bioreactor and scrubber installed at a water pollution control facility.

Outcomes also have been estimated for actual applications of verified technologies, as discussed below:

- The Martin Machinery Caterpillar Model 379 (200 kW) Engine/Generator Set with Integrated CHP System has been installed at Patterson Farms in Auburn, New York—the ETV-verification site—since 2005. Because Patterson Farms is located near Cayuga Lake, a popular recreation area, the farm constructed an anaerobic digester to help control odor and other emissions and improve manure management. The CHP system provides heat to maintain the digester and electricity for the facility. Food waste from a nearby Kraft Foods factory is combined with dairy manure

Exhibit 3.3-4

Estimated Potential Energy Generation and Cost Benefits of Using ETV-Verified Distributed Generation Technologies

Application	Market Penetration	Number of Facilities	Annual Energy Generation (MW)		Annual Cost Benefits[A]	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Animal Feeding Operations	10%	820	320,000	1.4 million	$32 million	$140 million
	25%	2,100	820,000	3.5 million	$82 million	$350 million
Landfills	10%	52	64,000	75,000	$6.4 million	$7.5 million
	25%	130	160,000	190,000	$16 million	$19 million
			Annual Energy Generation (MW)		Annual Cost Benefits[A]	
Wastewater Treatment Facilities	10%	44	74,000		$7.4 million	
	25%	110	190,000		$19 million	

Values rounded to two significant figures.

[A] Estimated cost benefits are not net benefits and do not take into account capital costs, operation and maintenance, or depreciation; estimates include cost benefits associated with electrical and gas offsets only.

Patterson Farms in Auburn, New York—host site for verification testing of the Martin Machinery Caterpillar Model 379 internal combustion engine with CHP.

for use in the digester. Kraft Foods pays a tipping fee to Patterson Farms, which improves the economics of the system. The digester project includes the following benefits: odor and pathogen reduction; reduced risk of nutrient run-off and leaching; conversion of nutrients for use as plant fertilizer; and potential revenue from sale of excess electricity, tipping fees, and carbon credit sales (U.S. EPA, 2010m). According to a case study by Cornell University, during a 10-month period, the engine/generator set produced on average 4,451 kWh per day of electricity (Gooch and Inglis, 2008). Based on verified performance, the ETV Program estimates that, during the 5-year period of its operation at Patterson Farms, the Martin Machinery system has generated nearly 8.4 million kWh of electricity with an estimated economic value of $840,000, assuming an average electricity price of $0.10/kWh. The farm sells excess electricity back to the grid at a rate of $0.06/kWh. The farm also receives revenue from the sale of carbon credits to the Chicago Credit Exchange; for a 1-year period (2006–2007), these credits were valued at about $8,000 (Gooch and Inglis, 2008). In 2009, Patterson Farms received an EPA ENERGY STAR® CHP Award in recognition of the pollution reduction and energy efficiency associated with its CHP installation (U.S. EPA, 2010n).

- As discussed in Section 3.3.1, nine UTC PureCell™ Model 200 fuel cells were in operation at five wastewater treatment plants managed by the New York City Department of Environmental Protection and located in or near New York City (eight still are in operation at four sites). The vendor reports that, through July 2010, the nine sites have cumulatively generated 56,000 MWh of electricity (Staniunas, 2010a). Based on an average electricity price of $0.10/kWh, the ETV Program calculates that this has resulted in economic benefits of $5.6 million. Per the vendor, three additional sites—one in Portland, Oregon (operated from 1999 through 2004), and two in Las Virgenes, California (operated from 1999 to 2002 and 2004, respectively)—generated 13,000 MWh of electricity while in operation (Staniunas, 2010a). The economic benefit for these three sites, based on the same average electricity price, is estimated to be $1.3 million. Nine of the 12 domestic sites at which the PureCell™ Model 200 fuel cell has been installed have exceeded the 40,000-hour design life of the fuel cell stack (Staniunas, 2010a). The vendor also reports that a wastewater treatment facility in Köln, Germany, used the PureCell™ Model 200 fuel cell to provide electricity for its facility using digester gas from the wastewater treatment process from March 14, 2000 to August 6, 2009; during that time it logged approximately 50,000 load hours and generated 6,400 MWh of electricity (Staniunas, 2010b).

For the co-fired boiler systems, because co-firing biomass with coal at a coal:biomass ratio of 85:15 has no significant effect on efficiency, cost savings are realized solely from the use of wood waste in the place of coal. Although potentially significant, the total cost savings will depend on the amount of coal typically used in the boiler, the price of coal in the given location, and the availability and cost (if any) of the wood waste (Milster, 2010).

The performance results demonstrated through ETV verification have been helpful to renewaFUEL's efforts to commercialize its products. A production-scale research and development facility in Battle Creek, Michigan, is owned and operated by renewaFUEL; since ETV verification, the company has expanded the facility to 60,000 tons-per-year capacity (Mennell, 2010a). The company is nearing completion on a new $20 million commercial biomass fuel production facility at the Teklite Technology Park at Sawyer International Airport near Marquette, Michigan. The renewaFUEL plant will produce 150,000 tons of high-energy, low-emitting biomass fuel (Mennell, 2010a; Michigan Renewable Fuels Commission, 2009). According to the Michigan Department of Agriculture, there is a lucrative market for crop farmers, woodlot owners, and the forestry industry in Michigan, whose residues and waste streams can be productively processed into renewaFUEL's biomass cubes (Michigan Renewable Fuels Commission, 2009). The company provides direct employment of approximately 35 people in Michigan, and indirect employment, through the feedstock supply chain, of approximately 168 people with an annual investment of more than $5 million into the local economy. The company's clients include major public universities and public utilities (Mennell, 2010a).

Federal and state incentive programs provide market drivers for innovative alternative energy technologies, including waste-to-energy technologies like those verified by the ETV Program (see text box). For example, the UTC Power PureCell™ Model 200 could be used to convert landfill gas to qualify for Alabama's Biomass Energy Program, which provides up to $75,000 in interest subsidy payments on loans to install approved biomass projects, including landfill gas projects (Alabama Department of Economic and Community Affairs, 2010). The NATCO Group, Inc., Paques THIOPAQ® or USFilter/Westates Carbon Gas Processing Unit could be used to enable use of livestock CH_4 to qualify for Illinois' Biogas and Biomass to Energy Grant Program, which allows incentives up to 50% of the total project cost, awards for biogas- or biomass-to-energy feasibility studies, and grants for biogas-to-energy systems up to $225,000 and for biomass-to-energy systems up to $500,000 (Illinois Department of Commerce and Economic Opportunity, 2010).

3.3.3 Regulatory Compliance Outcomes

As mentioned in Section 3.1.1, there are regulatory drivers for creating clean and renewable energy by adopting innovative technologies. The ETV-verified technologies described in this case study can be used to meet these regulations, including those set forth by the Clean Air Act, the Energy Independence and Security Act of 2007, and the American Clean Energy and Security Act of 2009.

EPA's OAQPS, which collaborated with ETV during the verification of the biomass co-fired boilers, has developed a new MACT standard for boilers—the Boiler Area Source Rule—which includes biomass co-fired boilers in the 100 to 1,000 MMBtu/h range at industrial, commercial, and institutional facilities. The court-ordered date for promulgating the rule is December 16, 2010 (Eddinger, 2010). ETV verified the performance of biomass co-fired boilers to support development of the new MACT standard. Because electricity produced by biomass meets the Energy Policy Act of 2005 definition of renewable energy, co-fired boilers using biomass to produce electricity can be used to meet the Act's renewable energy requirements (Public Law no. 109-58). This strong incentive can increase the use and acceptance of co-fired boilers. The Federal Energy Management Pro-

Under the Renewable Energy Production Incentive, established by the Energy Policy Act of 1992, public utilities may qualify for incentive payments for generation of electricity from landfill gas, livestock CH_4 (anaerobic digestion), or biomass (42 USC § 13317). The Healthy Forests Restoration Act of 2003 established a biomass commercial utilization grant program that provides grants to facilities that use biomass as a raw material to produce electric energy (Public Law no. 108-148). The Energy Improvement and Extension Act of 2008 allows businesses to claim an investment tax credit for using qualifying fuel cells, microturbines, or CHP systems; qualifying energy resources include biomass and municipal solid waste (Public Law no. 110-343). A renewable energy grant program, created by the American Recovery and Reinvestment Act of 2009, will be administered by the U.S. Department of Treasury that recognizes qualifying fuel cells, microturbines, and CHP systems, including those that use biomass (Public Law no. 111-5); this program extended investment tax credits for qualifying technologies permitted under the Energy Improvement and Extension Act of 2008.

In addition to federal incentives, most states have enacted renewable portfolio standards or goals—legislative requirements for utilities to generate or sell a certain percentage of their electricity from renewable energy sources. Maryland, Montana, and the District of Columbia allow energy derived from wastewater treatment plants to count as a renewable source for their standards (Council of the District of Columbia, 2005; State of Maryland, 2007; State of Montana, 2005), and many states accept co-firing with biomass as a renewable energy source. Currently, 36 states and the District of Columbia have renewable portfolio standards or goals that include landfill gas (U.S. EPA, 2010j). Virtually all states have implemented loans, grants, rebates, environmental regulations, or tax credits for CHP and biomass projects (2010d). The Database of State Incentives for Renewables and Efficiency (http://www.dsireusa.org) is a comprehensive source of information on state, local, utility, and federal incentives and policies that promote renewable energy and energy efficiency.

"Prior to 2001, there was little or no credible independent test results available for real-world emissions or performance data for many new distributed generation/(CHP) technologies such as fuel cells, reciprocating engines, and microturbines. Recognizing this need, a collaborative program between NYSERDA, Southern Research Institute, and EPA was developed under the ETV Program that established a protocol for field testing of these new technologies...The timely, accurate data obtained from this testing has helped guide NYSERDA's program and has been valuable in program metrics assessment. In addition, with the performance data developed under this program, technology buyers, financiers, and permitting authorities in the United States and abroad will be better equipped to make informed decisions regarding environmental technology purchase and use."

—James Foster, Project Manager for Transportation and Power Systems Research, NYSERDA (Foster, 2010).

gram is examining the feasibility of switching existing federal coal-fired boilers to co-fired boilers utilizing biomass (Federal Energy Management Program, 2004). This move would significantly increase the number of co-fired boilers currently operating in the United States. According to renewaFUEL, LLC, a third-party organization under consent decree modified its decree based on proposed use of the company's wood pellets and the resulting anticipated emission decreases (Mennell, 2010b).

3.3.4 Technology Acceptance and Use Outcomes

With growing concerns about fossil fuel depletion and GHG atmospheric increases, waste-to-energy technologies are becoming more commonplace. Access to reliable information on the performance of these technologies is an essential element of this acceptance. The ETV Program allows the capabilities of verified technologies to be demonstrated and documented. Vendors believe that ETV verification provides them with greater marketing power for their verified technologies, as shown by the mention of ETV verification in vendor press releases, marketing materials, and company Web sites (Capstone Turbine Corporation, 2003; UTC Power, 2005; Cleveland-Cliffs, Inc., 2007). Others also use ETV data to discuss the performance of waste-to-energy technologies in relevant literature. For example, the Intermountain CHP Center, formed by DOE to increase CHP use and installation in five Western states, profiled Colorado Pork, LLC, highlighting the ETV verification of the Martin Machinery Caterpillar Model 3306 CHP system and the Capstone Model C30 microturbine that the company installed to use digester gas produced at its facility (Intermountain CHP Center, 2004). The American Society of Healthcare Engineering also featured an article about the ETV Program in its *Inside ASHE* journal. The article profiled ETV verification of energy technologies, including the Capstone Model C30 microturbine and the UTC Power PureCell™ Model 200 system discussed in this case study (American Society of Healthcare Engineering, 2008).

ETV has strong partnerships with NYSERDA and DoD's ESTCP, both of which are committed to increasing innovative technology evaluation and acceptance to solve energy and environmental challenges; these joint efforts lead to wider acceptance. NYSERDA has contributed support for several distributed generation/CHP technology verifications through Program Opportunity Notices (PONs), which can be used to co-fund innovative environmental technology demonstrations and verifications. Two of these notices mentioned the ETV Program and have resulted in funding support for verifications. PON 768, released in 2003, solicited proposals for converting waste streams into energy resources (NYSERDA, 2003). Three of the technologies discussed in this case study were verified with co-funding obtained through this opportunity: the Martin Machinery Caterpillar Model 379 Internal Combustion Engine, installed at Patterson Farms (Auburn, New York), and the combined PureCell™ Model 200 fuel cell and USFilter/Westates Carbon gas processing unit, installed at the Red Hook Water Pollution Control Plant (Brooklyn, New York).

DoD's ESTCP currently is working with ETV on joint performance verification of microturbines that utilize renewable fuel. The objective is to determine the economic and environmental benefits of the technology at DoD landfills and other sources of low-value, low-Btu waste streams. Potential benefits to DoD from use of this technology include: (1) expanded use of both renewable and domestic energy resources for sustainable and secure energy production; (2) emissions reductions associated with vented or flared landfill and other waste gases and offset of utility power production; (3) cost savings associated with the reduction in electrical purchases from the grid and fuel needed to flare waste gas; (4) an estimated payback of 3 to 6 years, depending on the site; (5) applicability to many DoD landfill installations, as well as other waste streams; and (6) extended power generation life-cycles for landfills (by more than 40 years) resulting from low-energy landfill gas requirements (Hansen, 2009).

Per publicly available information, verified vendors are marketing their technologies abroad. Capstone Turbine Corporation is working with China to increase biogas use in Asia. The technology, similar to the microturbine discussed in this case study, will be installed in several Chinese provinces to harness CH_4 waste from landfills and wastewater treatment facilities (Capstone Turbine Corporation, 2009).

According to renewaFUEL, LLC, the company provided the results from the ETV verification of the biomass co-fired boilers to assist in the permit analysis and permitting of test burns in Iowa, Michigan, Minnesota, Wisconsin, and Ohio at universities, public utilities, and large industrial operations (Mennell, 2010a). Also, the Michigan Department of Agriculture is collaborating with renewaFUEL, which has resulted in commercial biomass fuel production facilities in Battle Creek and at the Teklite Technology Park near Marquette. In its 2008 annual report, the Michigan Department of Agriculture's Renewable Fuels Commission describes the collaboration and reports that renewaFUEL's products have been tested by ETV and demonstrated substantial creditable emissions reductions compared to coal (Michigan Renewable Fuels Commission, 2009). Municipal utilities, industries, and other institutions are expected to purchase the renewaFUEL product for boiler and furnace applications to generate electricity, heat, or steam (Michigan Renewable Fuels Commission, 2009).

3.3.5 Scientific Advancement Outcomes

ETV verification of waste-to-energy technologies has resulted in scientific advancement, including improvements in technology performance and standardization of technology evaluation. According to renewaFUEL, LLC, ETV verification was helpful in directing the company's research toward improved fuels and operating practices. High NO_x emissions during the ETV verification testing led to analysis and development of recommended operating practices for combustion of renewaFUEL products and development of patent-pending additives that result in greater nitrogen capture in ash, which in turn lowers NO_x emissions. The operating practices and patent-pending technologies have, through subsequent testing, demonstrated significant decreases in NO_x emissions when renewaFUEL is co-fired with coal compared to a coal-only scenario (Mennell, 2010a).

One of the testing host sites for ETV verification of biomass co-fired boilers, UI, currently is experimenting with poplar wood chips for co-firing and most likely will use a local source of wood chips on a more permanent basis in the near future. The university also co-fires oat hulls in its circulating fluidized bed boiler, sustaining an average of 50% heat input from the oat hulls, which are obtained from the Quaker Oats production plant in Cedar Rapids, about 20 miles from the university (Milster, 2010). According to the facility, the ETV verification of biomass co-fired boilers has been useful in helping UI continue to pursue biomass co-firing (Milster, 2010).

Other benefits of ETV verification include the development of a well-accepted protocol that has advanced efforts to standardize protocols across programs. The *Generic Verification Protocol for Distributed Generation and Combined Heat and Power Field Testing* originally was developed by Southern Research Institute for the Association of State Energy Research and Technology Transfer Institutions (ASERTTI) and was adopted by the Greenhouse Gas Technology Center and published as an ETV protocol (Southern Research Institute, 2005). The protocol also was adopted by ASERTTI, DOE, and state energy offices as a national standard protocol for field testing.

Acronyms and Abbreviations Used in This Case Study:

ASERTTI	Association of State Energy Research and Technology Transfer Institutions
Btu	British thermal unit
CH_4	methane
CHP	combined heat and power
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
ESTCP	Environmental Security Technology Certification Program
ESTE	Environmental and Sustainable Technology Evaluation
g/h	grams per hour
GHG	greenhouse gas
H_2S	hydrogen sulfide
IPCC	Intergovernmental Panel on Climate Change
kW	kilowatt
kWh	kilowatt-hour
lbs	pounds
lbs/h	pounds per hour
lbs/kWh	pounds per kilowatt-hour
MACT	maximum achievable control technology
MGD	millions of gallons per day
MMBtu/h	British thermal unit per hour
MW	megawatt
MWh	megawatt-hour
N_2O	nitrous oxide
NaOH	sodium hydroxide
NPDES	National Pollutant Discharge Elimination System
NO_x	nitrogen oxides
NYPA	New York Power Authority
NYSERDA	New York State Energy Research and Development Authority
OAQPS	Office of Air Quality Planning and Standards
PM	particulate matter
PON	Program Opportunity Notice
ppb	parts per billion
ppm	parts per million
ppmv	parts per million by volume
REC	Rapids Energy Center
SO_2	sulfur dioxide
Tg CO_2e	teragrams of carbon dioxide equivalent
THCs	total hydrocarbons
UI	University of Iowa
USDA	U.S. Department of Agriculture
VOC	volatile organic compound

3.4 References

40 CFR Part 133. 2007. *Code of Federal Regulations Title 40—Protection of the Environment. Chapter 1: Environmental Protection Agency. Part 133: Secondary Treatment Regulation*. 1 July.

40 CFR Part 503. 2007. *Code of Federal Regulations Title 40—Protection of the Environment. Chapter 1: Environmental Protection Agency. Part 503: Standards for the Use or Disposal of Sewage Sludge*. 1 July.

42 USC § 13317. *United States Code, Title 42. The Public Health and Welfare. Chapter 134: Energy Policy, Renewable Energy* (24 October 1992).

549 U.S. 497. 2007. *Massachusetts v. EPA*. Supreme Court ruling.

68 FR 7175. *National Pollutant Discharge Elimination System Permit Regulation and Effluent Limitation Guidelines and Standards for Concentrated Animal Feeding Operations (CAFOs); Final Rule. Federal Register* 68, no. 29 (12 February 2003).

70 FR 65984. *Proposed Rule to Implement the Fine Particle National Ambient Air Quality Standards; Proposed Rule. Federal Register* 70, no. 210 (1 November 2005).

71 FR 53271. *Standards of Performance, Emission Guidelines, and Federal Plan for Municipal Solid Waste Landfills and National Emission Standards for Hazardous Air Pollutants; Municipal Solid Waste Landfills; Proposed Rule. Federal Register* 71, no. 174 (8 September 2006).

73 FR 70417. *Revised National Pollutant Discharge Elimination System Permit Regulation and Effluent Limitations Guidelines for Concentrated Animal Feeding Operations in Response to the Waterkeeper Decision; Final Rule. Federal Register* 73, no. 225 (20 November 2008).

74 FR 56260. *Mandatory Reporting of Greenhouse Gases; Final Rule. Federal Register* 74, no. 209 (30 October 2009).

74 FR 66496. *Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act; Final Rule. Federal Register* 74, no. 239 (15 December 2009).

Alabama Department of Economic and Community Affairs. 2010. *Biomass Energy Program. http://www.adeca.state.al.us/C16/Biomass%20Energy%20Program/default.aspx* Last accessed 1 July.

American Society of Healthcare Engineering. 2008. Nothing But the Green Truth: EPA's Environmental Technologies Verification Program. *Inside ASHA* 16:(3)31–34. *http://www.energystar.gov/ia/business/healthcare/ashe_may_june_2008.pdf*

California Integrated Waste Management Board. 2001. *Conversion Technologies for Municipal Residuals Forum Background Paper and Findings on Barriers*. 22 May.

Capstone Turbine Corporation. 2003. *Capstone MicroTurbine Fleet Amasses 5 Million Operating Hours*. Press Release. 25 November. *http://www.capstoneturbine.com/news/story.asp?id=272*

Capstone Turbine Corporation. 2009. *Capstone Turbine Names Two Distributors in China for Fast-Growing Biogas Market; C65 Sold for Landfill Power Generation in Beijing*. Press release. 2 December. *http://www.capstoneturbine.com/news/story.asp?id=538*

Cleveland-Cliffs, Inc. 2007. *Cleveland-Cliffs Acquires 70% of "Green" Energy Company*. Press release. 20 December.

Council of the District of Columbia. 2005. *Bill A15-755: Renewable Energy Portfolio Standard Act of 2004*. 19 January.

Eddinger J. 2010. E-mail communication. U.S. EPA Energy Strategies Group. 11 March.

Energy and Environmental Analysis, Inc. 2010. *Combined Heat and Power Installation Database. http://www.eea-inc.com/chpdata/index.html*. Last accessed 7 July.

ETV. 2009. *Waste-to-Energy Fueled Technologies*. TechBrief. EPA/600/S-09/027. October.

Federal Energy Management Program. 2004. *Biomass Cofiring in Coal-Fired Boilers*. Federal Technology Alert. DOE/EE-0288. June.

Foster J. 2010 E-mail communication. New York State Energy Research and Development Authority. 23 July.

Gooch C and Ingliss S. 2008. *Anaerobic Digestion at Patterson Farms, Inc.: Case Study*. Case Study AD-10. Cornell University. February.

Hansen T. 2009. *Joint Demonstration and Verification of the Performance of Microturbine Power Generation Systems Utilizing Renewable Fuels with the U.S. EPA's Environmental Technology Verification Program*. DoD ESTCP Project Number SI200823 Fact Sheet.

Hansen T. 2010a. E-mail communication. Southern Research Institute. 30 June.

Illinois Department of Commerce and Economic Opportunity. 2010. *Biogas and Biomass to Energy Grant Program. http://www.commerce.state.il.us/dceo/Bureaus/Energy_Recycling/Energy/Clean+Energy/02-BiogasBioMass.htm* Last accessed 1 July.

Intergovernmental Panel on Climate Change (IPCC). 2007a. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland.

IPCC. 2007b. *Climate Change 2007—The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the IPCC*. New York: Cambridge University Press.

Intermountain CHP Center. 2004. *Project Profile: Colorado Pork 115-kW Renewable CHP Application*. December. *http://www.chpcentermw.org/rac_profiles/intermountain/Colorado_Pork_Project_Profile.pdf*

Krich K, Augenstein D, Batmale JP, Benemann J, Rutledge B, and Salour D. 2005. *Biomethane from Dairy Waste: A Sourcebook for the Production and Use of Renewable Natural Gas in California*. Western United Dairymen. July.

Mennell J. 2010a. E-mail communication. renewaFUEL, LLC. 26 July.

Mennell, J. 2010b. E-mail communication. renewaFUEL, LLC. 5 August.

Mennell, J. 2010c. E-mail communication. renewaFUEL, LLC. 10 August.

Methane to Markets Partnership. 2010. *http://www.methaneto-markets.org.* Last accessed 13 January 2010.

Milster PF. 2010. E-mail communication. University of Iowa. 10 March.

Michigan Renewable Fuels Commission. 2009. *Renewable Fuels Commission 2008 Annual Report*. February. *http://www.michigan.gov/documents/mda/RFC2008AR_270824_7.pdf*

Minnesota Pollution Control Agency. 1998. *Facts About Air Quality Permits for Municipal Wastewater Treatment Facilities*. AQ Document. #5.10. May.

Montana Department of Environmental Quality. 2009. *Clean Air Act of Montana. Title 75: Environmental Protection. Chapter 2: Air Quality*.

National Renewable Energy Laboratory (NREL). 2003. *Gas-Fired Distributed Energy Resource Technology Characterizations.* A joint project of the Gas Research Institute (GRI) and NREL. Prepared for the Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy. October.

New York Power Authority. 2010. *PowerNow! Small, Clean Plants*. *http://www.nypa.gov/facilities/powernow.htm*. Last accessed 22 July.

New York State Energy Research and Development Authority (NYSERDA). 2003. *Environmental Product & Process Technology Program Opportunity Notice 768*.

Padgett JP, Steinemann AC, Clarke JH, and Vandenbergh MP. 2008. A Comparison of Carbon Calculators. *Environmental Impact Assessment Review* 28(2-3);106–115.

Public Law no. 108-148. 2003. *Healthy Forests Restoration Act of 2003*.

Public Law no. 109-58. 2005. *Energy Policy Act of 2005*.

Public Law no. 110-140. 2007. *Energy Independence and Security Act of 2007.*

Public Law no. 110-343. 2008. *Energy Improvement and Extension Act of 2008*.

Public Law no. 111-5. 2009. *The American Recovery and Reinvestment Act of 2009*.

Southern Research Institute. 1998. *Electric Power Generation Using a Phosphoric Acid Fuel Cell on a Municipal Solid Waste Landfill Gas Stream.* Prepared by Greenhouse Gas Technology Center, Southern Research Institute, Under a Cooperative Agreement with U.S. Environmental Protection Agency. EPA-VS-GHG-01. August.

Southern Research Institute. 2004a. *Environmental Technology Verification Report: Swine Waste Electric Power and Heat Production—Capstone 30 kW Microturbine System.* Prepared by Greenhouse Gas Technology Center, Southern Research Institute, Under a Cooperative Agreement with U.S. Environmental Protection Agency. SRI/USEPA-GHG-VR-22. September.

Southern Research Institute. 2004b. *Environmental Technology Verification Report: Electric Power and Heat Generation Using UTC Fuel Cells' PC25C Power Plant and Anaerobic Digester Gas.* Prepared by Greenhouse Gas Technology Center, Southern Research Institute, under a cooperative agreement with the U.S. Environmental Protection Agency. SRI/USEPA-GHG-VR-26. September.

Southern Research Institute. 2004c. *Environmental Technology Verification Report: UTC Fuel Cells PC25C Power Plant—Gas Processing Unit Performance for Anaerobic Digester Gas.* Prepared by Greenhouse Gas Technology Center, Southern Research Institute, under a cooperative agreement with the U.S. Environmental Protection Agency and under agreement with the New York State Energy Research and Development Authority. SRI/USEPA-GHG-VR-26b. September.

Southern Research Institute. 2004d. *Environmental Technology Verification Report: Swine Waste Electric Power and Heat Production—Martin Machinery Internal Combustion Engine.* Prepared by Greenhouse Gas Technology Center, Southern Research Institute, under a cooperative agreement with the U.S. Environmental Protection Agency and under agreement with the Colorado Governor's Office of Energy Management and Conservation. SRI/USEPA-GHG-VR-22. September.

Southern Research Institute. 2004e. *Environmental Technology Verification Report: NATCO Group, Inc.—Paques THIOPAQ Gas Purification Technology.* Prepared by Greenhouse Gas Technology Center, Southern Research Institute, under a cooperative agreement with the U.S. Environmental Protection Agency. SRI/USEPA-GHG-VR-32. September.

Southern Research Institute. 2005. *Generic Verification Protocol for Distributed Generation and Combined Heat and Power Field Testing Protocol*. Prepared by Greenhouse Gas Technology Center, Southern Research Institute, under a cooperative agreement with the U.S. Environmental Protection Agency. SRI/USEPA-GHG-GVP-34. September.

Southern Research Institute. 2007. *Environmental Technology Verification Report: Electric Power and Heat Production Using Renewable Biogas at Patterson Farms.* Prepared by Greenhouse Gas Technology Center, Southern Research Institute, under a cooperative agreement with the U.S. Environmental Protection Agency and under agreement with the New York State Energy Research and Development Authority. SRI/USEPA-GHG-VR-43. September.

Southern Research Institute. 2008a. *Environmental and Sustainable Technology Evaluation—Biomass Co-Firing in Industrial Boilers—Minnesota Power's Rapids Energy Center.* Prepared by Greenhouse Gas Technology Center, Southern Research Institute, under a cooperative agreement with the U.S. Environmental Protection Agency. EPA Contract No. EP-C-04-056. Work Assignment No. 2-8-101. April.

Southern Research Institute. 2008b. *Environmental and Sustainable Technology Evaluation—Biomass Co-Firing in Industrial Boilers—University of Iowa.* Prepared by Greenhouse Gas Technology Center, Southern Research Institute, under a cooperative agreement with the U.S. Environmental Protection Agency. EPA Contract No. EP-C-04-056. Work Assignment No. 2-8-101. April.

Staniunas J. 2010a. E-mail communication. UTC Power. 21 July.

Staniunas J. 2010b. E-mail communication. UTC Power. 31 August.

State of Maryland. 2007. *Senate Bill 595: Renewable Energy Portfolio Standard*. 24 April.

State of Montana. 2005. *Senate Bill 415: Montana Renewable Power Production and Rural Economic Development Act*. 28 April.

Tolrud D. 2010. E-mail communication. Minnesota Power. 10 March.

U.S. Department of Agriculture (USDA). 2009. *Technical Resources: Animal Feeding Operations and Confined Animal Feeding Operations*. Natural Resources Conservation Service. 6 October.

USDA. 2010a. *Energy Self Assessment: Renewable Tools—Biogas*. Natural Resources Conservation Service. *http://www.ruralenergy.wisc.edu/renewable/biogas/default_biogas.aspx*. Last accessed 3 September.

USDA. 2010b. *USDA Rural Development: Business and Cooperative Programs*. Rural Development. *http://www.rurdev.usda.gov/rbs/busp/bprogs.htm*. Last accessed 23 September.

U.S. Department of Energy (DOE). 2000. *Biomass Cofiring: A Renewable Alternative for Utilities*. National Renewable Energy Laboratory. DOE/GO-102000-1055. June.

U.S. DOE. 2004. *Federal Technology Alert: Biomass Cofiring in Coal-Fired Boilers*. National Renewable Energy Laboratory. DOE/EE-0288. June.

U.S. DOE. 2008. *Fuel Cells: Basics*. Office of Energy Efficiency and Renewable Energy. Last updated 19 December. *http://www.eere.energy.gov/hydrogenandfuelcells/fuelcells/basics.html*

U.S. DOE. 2010. *Electric Power Monthly*. 19 July. *http://www.eia.doe.gov/electricity/epm/table5_3.html*

U.S. EPA. 1998. *NO_x: How Nitrogen Oxides Affect the Way We Live and Breathe*. Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. EPA-456/F-98-005. September.

U.S. EPA. 2000. *Air Quality Criteria for Carbon Monoxide*. Office of Research and Development. EPA 600/P-99/001F. June.

U.S. EPA. 2002. *Managing Manure With Biogas Recovery Systems: Improved Performance at Competitive Cost*. Office of Air and Radiation. EPA-430-F-02-004. Winter.

U.S. EPA. 2003. *Air Pollution Control Technology Fact Sheet: Fabric Filter—Pulse-Jet Cleaned Type*. EPA-452/F-03-025.

U.S. EPA. 2004a. *Risk Assessment Evaluation for Concentrated Animal Feeding Operations*. EPA/600/R-04/042. May.

U.S. EPA. 2004b. *Primer for Municipal Wastewater Treatment Systems*. Office of Water. EPA 832-R-04-001. September.

U.S. EPA. 2004c. *Clean Watersheds Needs Survey Dataset*. *http://www.epa.gov/cwns/cwns2004db.mdb*

U.S. EPA. 2006a. *Market Opportunities for Biogas Recovery Systems: A Guide to Identifying Candidates for On-Farm and Centralized Systems*. EPA-430-8-06-004. August.

U.S. EPA. 2006b. *Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990–2020*. Office of Atmospheric Programs. EPA 430-R-06-003. June.

U.S. EPA. 2007. *Opportunities for and Benefits of Combined Heat and Power at Wastewater Treatment Facilities*. Office of Air and Radiation, Combined Heat and Power Partnership. EPA-430-R-07-003. April.

U.S. EPA. 2008a. *Catalog of CHP Technologies*. December. *http://www.epa.gov/chp/documents/catalog_chptech_full.pdf*

U.S. EPA. 2008b. *2004 Clean Watersheds Needs Survey Report to Congress*. January. *http://www.epa.gov/cwns/2004rtc/cwns2004rtc.pdf*

U.S. EPA. 2008c. *Frequently Asked Questions About Landfill Gas and How It Affects Public Health, Safety, and the Environment*. Office of Air and Radiation. June.

U.S. EPA. 2009a. *Inventory of U.S. Greenhouse Gas Emissions And Sinks: 1990–2007*. EPA 430-R-04-004. 15 April.

U.S. EPA. 2009b. *Frequently Asked Questions About Global Warming and Climate Change: Back to Basics*. Office of Air and Radiation. EPA-430-R08-016. April.

U.S. EPA. 2009c. *Health Impacts of SO_2*. Last updated 17 November. *http://www.epa.gov/air/sulfurdioxide/health.html*

U.S. EPA. 2009d. *Climate Choice*. Last updated 12 November. *http://www.epa.gov/cppd/climatechoice*

U.S. EPA. 2010a. *Methane*. Last updated 5 March. *http://www.epa.gov/methane/index.html*

U.S. EPA. 2010b. *The AgSTAR Program: Guide to Anaerobic Digesters*. Last updated 28 January. http://www.epa.gov/agstar/operational.html

U.S. EPA. 2010c. *Status, Opportunities, and Barriers in the U.S. Agricultural Digester Market*. Presented at the Fifth AgSTAR National Conference, Green Bay, WI, April 27, 2010.

U.S. EPA. 2010d. *Combined Heat and Power Partnership Funding Resources*. Last updated 30 June. *http://www.epa.gov/chp/funding/financial.html*

U.S. EPA. 2010e. *Landfill Methane Outreach Program*. Last updated 14 July. *http://www.epa.gov/lmop/index.html*

U.S. EPA. 2010f. *CHP Strategic Markets—Municipal Wastewater Treatment Facilities*. Last updated 3 June. *http://www.epa.gov/CHP/markets/wastewater.html*

U.S. EPA. 2010g. *An Introduction to Indoor Air Quality: Carbon Monoxide*. Last updated 23 April. *http://www.epa.gov/iaq/co.html*

U.S. EPA. 2010h. *Anaerobic Digesters*. AgSTAR. Last updated 24 September. *http://www.epa.gov/agstar/anaerobic/index.html*

U.S. EPA. 2010i. *Animal Feeding Operations*. Last updated 2 June. *http://www.epa.gov/oecaagct/anafoidx.html*

U.S. EPA. 2010j. *State Renewable Portfolio Standards*. Last updated 29 June. *http://www.epa.gov/lmop/publications-tools/funding-guide/renewable.html*

U.S. EPA. 2010k. *An Overview of Landfill Gas Energy in the United States*. Landfill Methane Outreach Program. May.

U.S. EPA. 2010l. *Emissions Standards for Boilers and Process Heaters and Commercial/Industrial Solid Waste Incinerators*. Last updated 29 June. *http://www.epa.gov/airquality/combustion/index.html*

U.S. EPA. 2010m. *AgSTAR Projects: Patterson Farms*. Last updated 24 September. *http://www.epa.gov/agstar/projects/profiles/pattersonfarms.html*

U.S. EPA. 2010n. *Winners of the 2009 ENERGY STAR® CHP Award*. *http://epa.gov/chp/documents/past_award_winners.pdf*. Last Accessed 22 July.

U.S. EPA. 2010o. *LFG Energy Project Development Handbook. Chapter 3: Project Technology Options*. Landfill Methane Outreach Program. January. *http://www.epa.gov/lmop/documents/pdfs/pdh_chapter3.pdf*

U.S. EPA. 2010p. *AgSTAR Program Accomplishments: New York*. Last updated 24 September. *http://www.epa.gov/agstar/projects/index.html#ny*

UTC Power. 2005. *PureCell™ 200 Heat & Power Solution*. Marketing brochure. *http://www.fuelcellmarkets.com/content/images/articles/PCell_Broch.pdf*

UTC Power. 2007. *Creating Clean Power with Free Fuel From Anaerobic Digester Gas With the PureCell® Model 200 Fuel Cell Powerplant*. 24 January.

Appendix A. Methods for Decentralized Wastewater Treatment Technologies Outcomes

A.1 Number of Systems

The ETV Program used two approaches to estimate the potential market for the verified decentralized wastewater treatment technology described in Chapter 2. According to estimates provided by Tetra Tech, under contract to EPA, current (as of 2010) new home construction in the United States averages approximately 500,000 units per year. Approximately 25% of new development (i.e., about 125,000 homes annually) currently uses individual and cluster wastewater treatment systems. Of this number, around 5% are served specifically by cluster systems. An average of five homes are served by each cluster (Tonning, 2010a). Using this approach, ETV calculated that the potential market for the verified technology is approximately 1,250 cluster systems per year. These estimates do not include cluster system installations that replace existing subdivision septic systems that are malfunctioning; this number is negligible because cluster systems generally are repaired rather than replaced if they malfunction (Tonning, 2010a).

In 1999, EPA estimated via modeling that there were about 353,000 large capacity septic systems (similar to cluster systems) in the United States, which represented approximately 0.3% of all U.S. homes at the time (U.S. EPA, 1999). Currently, there are approximately 128 million homes in the United States (U.S. Census Bureau, 2008). Assuming that these systems represent 0.3% of the 128 million homes, the ETV Program calculated that there are 384,000 potential/estimated large capacity septic systems in the United States. Housing stock is replaced at an annual rate of approximately 0.4% of the total number of homes each year (Tonning, 2010a). ETV assumed that these large capacity septic systems are installed at approximately the same rate as new home construction and calculated that 1,540 new systems are installed each year.

These two approaches led to respective estimates of 1,250 and 1,540 cluster systems installed annually in the United States. The ETV Program calculated the approximate average of these two estimates and performed pollutant reduction calculations assuming that 1,400 new cluster systems are installed in the United States annually and that each system serves an average of five homes. The total number of estimated homes ETV used for its calculations was 7,000. It should be noted that because of the current U.S. economy, new home construction has decreased by 50%; the potential market could be as high as 2,500 to 3,000 systems annually (12,500 to 15,000 homes) as the economy improves (Tonning, 2010b).

A.2 Pollutant Reduction

The ETV Program estimated pollutant reductions from actual application of the ETV-verified decentralized wastewater treatment technology at current and pending installations, as well as from potential application of the verified technology at 10% and 25% of the total market. Using assumptions regarding daily water use, nitrogen concentration and reduction, biochemical oxygen demand (BOD) concentration and reduction, and total suspended solids (TSS) concentration and reduction, the ETV Program calculated the annual pollutant reductions from potential application of the ETV-verified technology, when compared to the performance of traditional septic systems. These estimates assume average water usage of 179.2 gallons per day, per household, based on the following data: average flow of 70 gallons per person per day (U.S. EPA, 2009) and 2.56 people per household (U.S. Census Bureau, 2009). They assume minimum wastewater influent concentrations of 38 milligrams per liter (mg/L) for nitrogen, 230 mg/L for BOD, and 170 mg/L for TSS (the concentrations used in ETV verification testing). Based on technology performance observed during verification, these estimates assume mean total nitrogen (total Kjeldahl nitrogen and nitrite plus nitrate), BOD, and TSS reduction efficiencies of 88%, 98%, and 96%, respectively, achieved by the full treatment system. For these calculations, traditional septic systems are considered to be systems that discharge their effluent to soil, sand, or other media absorption fields for further treatment through biological processes, adsorption, filtration, and infiltration into underlying soils (U.S. EPA, 2002). Based on these parameters, these estimates assume the following treatment performance for traditional septic systems: total nitrogen removal rate of 80% (U.S. EPA, 2002) and BOD and TSS removal rates of 58% and 75%, respectively (Bounds, 1997). Because the calculations use minimum influent concentrations and are based on a conservative estimate of the total potential market, the estimates for pollutant reduction outcomes are conservative.

It also is important to note that, for four of the five current and pending installation sites detailed in the case study, pollution reduction estimates as compared to the performance of traditional septic system may be conservative. According to the vendor, nitrogen impairment in each of these areas is significant enough that construction would not have been approved without the availability of the ETV-verified decentralized wastewater treatment technology or an alternative treatment technology of equivalent performance (Smith, 2010). The casino site located in Great Falls, Montana, did not have the same nitrogen impairment issues; calculations of pollutant reductions at this site as compared to traditional technology are actual.

Based on the assumptions above, the ETV Program used the following equation to calculate pollutant reductions:

$$R_{TOTAL} = R_{TECH} - R_{TRAD}$$

Where:

- R_{TOTAL} is the total pollution reduction in tons per year.
- R_{TECH} is the pollution reduction in tons per year achieved by the verified system.
- R_{TRAD} is the pollution reduction in tons per year achieved by a traditional system.

For the current and pending installation sites outlined in the case study, R_{TECH} and R_{TRAD} were each calculated with the following equation:

$$R = (W \times PC \times \%PR)$$

Where:

- R is the total pollution reduction in tons per year for either the verified system or traditional system.
- W is the combined (annual or 3-year) amount of water handled by the system converted to liters.
- PC is the minimum influent pollutant concentration converted to tons per liter.
- %PR is the percent pollution reduction observed in the verified system or traditional system.

For the potential market penetration scenarios outlined in the case study, R_{TECH} and R_{TRAD} were each calculated with the following equation:

$$R = (W \times PC \times \%PR) \times \%MP$$

Where:

- R is the total pollution reduction in tons per year for either the verified system or traditional system.
- W is the combined annual amount of water handled by the system converted to liters.
- PC is the minimum influent pollutant concentration converted to tons per liter.
- %PR is the percent pollution reduction observed in the verified system or traditional system.
- %MP is the percent market penetration (i.e., number of systems) for the verified decentralized wastewater treatment system.

Average daily reductions were calculated with one of the following equations:

$$R_{AVGDAILY} = (R/1095) \times 2000$$

Where:

- $R_{AVGDAILY}$ is the daily average reduction in pounds per day.
- R is the total pollution reduction in tons per year.
- 1095 is the number of days the installed sites operated for the calculated R.
- 2000 is the pounds per ton conversion factor.

$$R_{ANNUALAVGDAILY} = (R/365) \times 2000$$

Where:

- $R_{ANNUALAVGDAILY}$ is the daily average reduction in pounds per day.
- R is the total pollution reduction in tons per year.
- 365 is the number of days in a year.
- 2000 is the pounds per ton conversion factor.

A.3 References

Bounds TR. 1997. Design and Performance of Septic Tanks. *In*: Bedinger MS, Johnson AI, and Fleming JS. *Site Characterization and Design of Onsite Septic Systems*. Philadelphia: American Society for Testing Materials.

Smith C. 2010. E-mail communication. International Wastewater Systems, Inc. 6 January.

Tonning B. 2010a. E-mail communication. Tetra Tech. 17 March.

Tonning B. 2010b. Personal communication. Tetra Tech. March.

U.S. Census Bureau. 2008. *American Housing Survey for the United States: 2007*. H-150-07. September. *http://www.census.gov/hhes/www/housing/ahs/ahs07/ahs07.html*

U.S. Census Bureau. 2009. *Current Population Survey, 2008 Annual Social and Economic Supplement: Table AVG1*. January. *http://www.census.gov/population/socdemo/hh-fam/cps2008/tabAVG1.xls*

U.S. EPA. 1999. *The Class V Underground Injection Control Study. Volume 5: Large-Capacity Septic Systems*. Office of Ground Water and Drinking Water. EPA/816-R-99-014e. September.

U.S. EPA. 2002. *Onsite Wastewater Treatment Systems Manual*. Office of Water. EPA/625-R-00-008. February.

U.S. EPA. 2009. *Indoor Water Use in the United States*. Last updated 16 January. *http://www.epa.gov/watersense/pubs/indoor.htm*

Appendix B. Methods for Waste-to-Energy Technologies Outcomes

As outlined in Chapter 3, ETV has verified the performance of two biogas processing systems, four distributed generation energy systems, and two biomass co-fired boilers. All eight systems were operated onsite using either landfill gas, anaerobic digester gas generated from animal waste or municipal wastewater sludge, or solid biomass. The technologies used to process and generate power from methane (CH_4) or other gaseous waste streams—the gas processing and distributed generation energy systems—are generally applicable to more than one sector. ETV estimated market scenarios and potential outcomes, including emission reductions, electrical generation, and cost benefits, associated with use of ETV-verified technologies by sector or application (see Chapter 3, Section 3.3). Because technology performance could be affected by the characteristics of the influent waste stream, ETV calculated outcomes based on the verified performance of technologies tested at each application.

B.1 Distributed Generation Systems

B.1.1 Animal Feeding Operations

There are several parameters that are necessary for animal feeding operations to be considered economically feasible candidates for biogas recovery system installation. One parameter is size; dairy operations with more than 500 cows and heifers and swine operations with more than 2,000 sows are good candidates for anaerobic digestion and biogas use. The potential for manure-produced biogas is highest for manure that is collected and stored as a liquid, slurry, or semisolid. Therefore, viable dairy operations include those that use flushed or scraped freestall barns and drylots for manure collection, and viable swine operations include those that use houses with flush, pit recharge, or pull-plug pit systems. Given these parameters, EPA AgSTAR estimates that 2,600 dairy operations and 5,600 swine operations in the United States are potential candidates for anaerobic digestion and manure biogas production, for a total potential market of 8,200 operations (U.S. EPA, 2006). The ETV Program used the above total number of facilities as the basis for its market penetration scenarios.

To estimate emissions reductions associated with use of ETV-verified technologies at animal feeding operations, the ETV Program used a range of verification results for two technologies tested in this application. The upper bound estimates refer to those obtained using verification results for the Martin Machinery Caterpillar Model 379 (200 kilowatt [kW]) engine/generator set with integrated combined heat and power (CHP) system tested at Patterson Farms (Auburn, New York). The lower bound estimates refer to those obtained using verification results for the Martin Machinery Caterpillar Model 3306 ST (100 kW) engine, generator, and heat exchanger tested at Colorado Pork (Lamar, Colorado). For both technologies, Southern Research Institute estimated annual emissions offsets for carbon dioxide (CO_2) and nitrogen oxides (NO_x) by comparing emissions rates of the onsite distributed generation/CHP systems observed during an extended monitoring period of the verification test with documented emissions from baseline electrical power generation technology (e.g., from nationwide or state/regional power grids) (Southern Research Institute, 2004b, 2007). The verification results for the Caterpillar Model 379 engine include estimated reductions in CO_2 equivalent emissions associated with the use of waste-generated CH_4 as fuel; the verification results for the Caterpillar Model 3306 ST engine do not include these additional reductions. Therefore, the upper bound estimates for annual emissions reductions include reductions from capture and use of the biogas; the lower bound estimates do not. Verification results used to calculate both upper and lower bound estimates for ETV's emissions reductions outcomes do not include additional reductions associated with the recovery and use of waste heat. Estimating these additional reductions would have required significant resources to conduct baseline greenhouse gas emissions assessments for standard waste management practices and was beyond the scope of the ETV verification. Therefore, verification results include emissions reductions from electricity generation only.

Annual emissions reductions estimated for the two internal combustion engines based on verification testing at animal feeding operations are presented in Exhibit B.1-1.

Exhibit B.1-1

Estimated Annual Emissions Reductions for ETV-Verified Technologies at Animal Feeding Operations

Technology[A]	Annual Emissions in Verified Application (lb/kWh)[B]		Grid Emissions (lb/kWh)[C]		Estimated Annual CO_2 Equivalent Emissions Reductions from Capture/Use of Biogas (lbs)	Estimated Annual Emissions Reductions (lbs)[D]	
	NO_x	CO_2	NO_x	CO_2		NO_x	CO_2
Martin Machinery Caterpillar Model 379 Engine/Generator with Integrated Heat Recovery	0.0213	1.43	0.00296	1.39	14,300,000	-29,300	14,300,000
Martin Machinery Caterpillar Model 3306 ST Engine/Generator and Heat Exchanger	0.012	1.97	0.00655	2.02	NE[E]	-740	6,000

[A] The ETV Program does not compare technologies. Order of appearance of technologies in this table does not necessarily reflect technology performance results.

[B] Based on emissions performance during an extended monitoring period of the verification test.

[C] Based on estimated U.S. regional annual emissions for equivalent fossil fuel grid power.

[D] Annual emissions reductions are based on electrical generation only and do not include additional benefits that may be realized through recovery and use of waste heat.

[E] NE = Not estimated; reductions in CO_2 equivalent emissions associated with the use of waste-generated CH_4 as fuel were not estimated for the Caterpillar Model 3306 ST engine.

The ETV Program also verified the performance of a third technology, the Capstone Microturbine Corporation, Capstone Model C30 microturbine system at the Colorado Pork facility; however, because of testing delays, extended monitoring did not occur and annual emissions offset analyses could not be performed. As such, emissions reductions associated with use of the Capstone Model C30 microturbine are not included in the below outcomes calculations.

For the potential emissions reductions, energy generation, and cost benefit outcomes calculations, the ETV Program assumed that the verified technologies would be operating at full load (i.e., 100% of system capacity or maximum power command verified during ETV testing) at all facilities. This assumption is based on the understanding that the most optimal economics result when a system is serving as base-load supply and operating at or near full capacity at all times. Many systems are being designed to operate at maximum thermal utilization (full load); in these cases, maximum system efficiency is achieved (Hansen, 2010a). For the Martin Machinery Caterpillar Model 379, verification results presented in Chapter 3 were achieved at 100% system capacity, or 200 kW. ETV also assumed that the biogas streams and the CHP requirements of potential installations would be comparable to the facility used during verification. For the Martin Machinery Caterpillar Model 3306 ST, verification results presented in Chapter 3 were achieved at 45% system capacity, or 45 kW of 100 kW total capacity. At the time of verification, the configuration of the engine's fuel input jets and the low heating value of the input biogas restricted the engine's power output to approximately 45 kW; this is lower than the manufacturer's recommended capacity for this system (100 kW). This system was an early attempt at digester gas utilization and was tested based on concurrence from all sponsoring parties that the equipment was ready for verification. The ETV Greenhouse Gas Technology Center believes that the verification helped identify issues associated with performance of the system and demonstrated that the system, when operating at such a reduced load, did not exhibit optimal performance (Hansen, 2010b). Emissions reductions from application of the Model 3306 ST could be higher at sites with configurations designed to maximize power output.

Based on the assumptions above, the ETV Program used the following equation to calculate CO_2 (or CO_2 equivalent) emissions reductions from animal feeding operations:

$$R_{TOTAL} = R_{AFO} /2000 \times \%MP$$

Where:

- R_{TOTAL} is the total CO_2 reduction in tons per year.
- R_{AFO} is the annual CO_2 emissions reduction in pounds per year for the ETV-verified internal combustion engine(s) tested at animal feeding operations as calculated by Southern Research Institute during verification.
- 2000 is the pounds per ton conversion factor.
- %MP is the percent market penetration (i.e., number of facilities) for the ETV-verified internal combustion engine(s) based on AgSTAR market estimates.

To calculate the energy generation and cost benefit estimates for animal feeding operations, the ETV Program used the above assumptions and an average electricity price of $0.10 per kilowatt-hour (kWh). This average electricity price is based on the average retail price to ultimate consumers in all end-use sectors in the 50 states and the District of Columbia between January 2008 and June 2010 (U.S. Department of Energy, 2010). ETV used the following equation to calculate the estimated energy generation cost benefits:

$$EG_{ANNUAL} = E_{AFO} \times 8760 \times \%MP \times 0.001$$

Where:

- EG_{ANNUAL} is the annual electricity generation in megawatts (MW) per year.
- E_{AFO} is the maximum power output in kW per hour for the ETV-verified internal combustion engine(s) tested at animal feeding operations as observed during verification.
- 8760 is the hours per year conversion factor.
- %MP is the percent market penetration (i.e., number of facilities) for the ETV-verified internal combustion engine(s) based on AgSTAR market estimates.
- 0.001 is the kW to MW conversion factor.

The corresponding cost benefit was calculated as follows:

$$CB_{ANNUAL} = EG_{ANNUAL} \times 1000 \times 0.10$$

Where:

- CB_{ANNUAL} is the annual cost benefit in dollars.
- EG_{ANNUAL} is the annual electricity generation in MW per year.
- 1000 is the MW to kW conversion factor.
- 0.10 is the average electricity price in dollars per kWh.

B.1.2 Wastewater Treatment Facilities

Analyses conducted by the EPA CHP Partnership indicate that wastewater treatment facilities with influent flow rates less than 5 million gallons per day (MGD) typically do not produce enough biogas from anaerobic digestion to make CHP technically and economically feasible (U.S. EPA, 2007). The 2004 EPA Clean Watersheds Needs Survey identified a total of 1,066 wastewater treatment facilities in the United States with flow rates greater than 5 MGD, making them potential candidates for distributed generation anaerobic digestion and biogas utilization. According to EPA, 544 of these wastewater treatment facilities currently produce biogas using anaerobic digesters. Of these, only 106 facilities utilize the biogas produced by their anaerobic digesters to generate electricity and/or thermal energy (U.S. EPA, 2004, as cited in U.S. EPA, 2007), for an additional potential market of 438 facilities that could install distributed generation waste-to-energy technologies. The ETV Program used this additional market potential as the basis for its market penetration scenarios. ETV estimates that more of the 1,066 facilities with flow rates suitable for anaerobic digestion and CHP could install ETV-verified technologies; however, treatment process modifications would most likely be required. Emissions reductions outcomes for the ETV-verified technologies could be even greater if market scenarios are based on the total number of treatment facilities with flow rates suitable for performing anaerobic digestion.

To estimate emissions reductions associated with use of ETV-verified technologies at wastewater treatment facilities, the ETV Program used the verification results for the technology tested in this application—the PureCell™ Model 200, manufactured by UTC Power and tested at the Red Hook Water Pollution Control Plant (Brooklyn, New York). For this system, Southern Research Institute estimated annual emissions offsets for CO_2 and NO_x by comparing emissions rates observed during an extended monitoring period of the verification test with documented emissions from baseline electrical power generation for the Red Hook plant without the fuel cell in place (e.g., from the state power grid). Use of the PureCell™ Model 200 fuel cell at the Red Hook plant provided an added environmental benefit by offsetting emissions from the flare. Southern Research Institute estimated the additional reductions in emissions associated with flare offset (Southern Research Institute, 2004a).

Exhibit B.1-2

Estimated Annual Emissions Reductions for ETV-Verified Technologies at a Wastewater Treatment Facility

Technology	Annual Emissions in Verified Application (tons)		Baseline Emissions (Red Hook Plant without PureCell™ Model 200) (tons)[A]						Estimated Annual Emissions Reductions (tons)[B]	
			Grid Emissions		Flare Emissions		Total Emissions			
	NO_x	CO_2	NO_x	CO_2	NO_x	CO_2	NO_x	CO_2	NO_x	CO_2
UTC PureCell™ Model 200	0.088	1,040	1.63	1,050	0.282	1,390	1.91	2,440	1.82	1,430

[A] Based on estimated annual emissions for equivalent fossil fuel grid power in the State of New York.

[B] Estimated reductions based on expected PC25C availability of 97% and an average measured power output of 166 kW.

Annual emissions reductions estimated for the fuel cell based on verification testing at a wastewater treatment facility are presented in Exhibit B.1-2.

Again, the ETV Program assumed that the verified technology would be operating at full load (i.e., 100% of system capacity or maximum power command verified during ETV testing) at all facilities (i.e., at 100% system capacity, or 200 kW for the PureCell™ Model 200). ETV also assumed that the biogas streams and CHP requirements of potential installations would be comparable to the facility used during verification.

Based on the assumptions above, the ETV Program used the following equation to calculate CO_2 (or CO_2 equivalent) and NO_x emissions reductions from wastewater treatment facilities:

$$R_{TOTAL} = R_{WWT} \times \%MP$$

Where:

- R_{TOTAL} is the total CO_2 or NO_x reduction in tons per year.
- R_{WWT} is the annual CO_2 or NO_x emissions reduction in tons per year for the ETV-verified fuel cell tested at the wastewater treatment facility as calculated by Southern Research Institute during verification.
- %MP is the percent market penetration (i.e., number of facilities) for the ETV-verified fuel cell based on Clean Watersheds Needs Survey market estimates.

To calculate the energy generation and cost-benefit estimates for wastewater treatment facilities, the ETV Program used the above assumptions and an average electricity price of $0.10/kWh:

$$EG_{ANNUAL} = E_{WWT} \times 8760 \times \%MP \times 0.001$$

Where:

- EG_{ANNUAL} is the annual electricity generation in MW per year.
- E_{WWT} is the maximum power output in kW per hour for the ETV-verified fuel cell tested at the wastewater treatment facility as observed during verification.
- 8760 is the hours per year conversation factor.
- %MP is the percent market penetration (i.e., number of facilities) for the ETV-verified fuel cell based on Clean Watersheds Needs Survey market estimates.
- 0.001 is the kW to MW conversion factor.

The corresponding cost benefit was calculated as follows:

$$CB_{ANNUAL} = EG_{ANNUAL} \times 1000 \times 0.10$$

Where:

- CB_{ANNUAL} is the annual cost benefit in dollars.
- EG_{ANNUAL} is the annual electricity generation in MW per year.
- 1000 is the MW to kW conversion factor.
- 0.10 is the average electricity price in dollars per kWh.

B.1.3 Landfills

The EPA Landfill Methane Outreach Program estimates that there are approximately 518 landfills already collecting landfill gas for energy recovery in the United States (U.S. EPA, 2010a). EPA also estimates that an additional 520 landfills are good candidates for landfill gas energy projects (U.S. EPA, 2010b); the ETV Program used this additional number of landfills as the basis for its market penetration scenarios. The ETV Program verified the performance of the International Fuel Cells Corporation, PC25 200 kW Fuel Cell (an older version of the fuel cell discussed above for application at a wastewater treatment facility) at landfills in Penrose, California and Groton, Connecticut. Annual emissions reductions, however, were not estimated as part of these verifications. As such, quantitative data are not available to estimate the potential emissions reductions associated with the market scenarios for ETV-verified technologies at landfills. Additionally, according to EPA, processing of landfill gas for fuel cell usage is not the most cost-effective option on a kW basis; it is more common to use landfill gas in internal combustion engines or boilers (Goldstein, 2010). Internal combustion engines are the most commonly used waste-to-energy technology for landfill gas applications (used in more than 70% of current landfill gas energy recovery projects in the United States) because of their relatively low cost, high efficiency, and good size match with the gas output of most landfills. The ETV Program estimated potential energy generation and cost benefits outcomes from use of ETV-verified technologies at landfills based on the range of verification results for the PC25 200 kW Fuel Cell at the two testing locations. Other ETV-verified distributed generation technologies described in Chapter 3, however, may be better candidates for landfill gas recovery. Additional energy generation and cost benefits, as well as emissions reductions, could be realized.

To calculate the energy generation and cost benefit estimates for landfills, the ETV Program used the above assumptions and an average electricity price of \$0.10/kWh:

$$EG_{ANNUAL} = E_{LFG} \times 8760 \times \%MP \times 0.001$$

Where:

- EG_{ANNUAL} is the annual electricity generation in MW per year.
- E_{LFG} is the maximum power output in kW per hour for the ETV-verified fuel cell tested at landfills as observed during verification.
- 8760 is the hours per year conversation factor.
- %MP is the percent market penetration (i.e., number of facilities) for the ETV-verified fuel cell based on the Landfill Methane Outreach Program market estimates.
- 0.001 is the kW to MW conversion factor.

The corresponding cost benefit was calculated as follows:

$$CB_{ANNUAL} = EG_{ANNUAL} \times 1000 \times 0.10$$

Where:

- CB_{ANNUAL} is the annual cost benefit in dollars.
- EG_{ANNUAL} is the annual electricity generation in MW per year.
- 1000 is the MW to kW conversion factor.
- 0.10 is the average electricity price in dollars per kWh.

B.2 Co-Fired Boilers

Data generated during the verification testing of biomass co-fired boilers allowed calculation of CO_2 emission rates while firing straight coal and blended fuel. Wood-based fuel and renewaFUEL wood pellets, however, are comprised of biogenic carbon—meaning that they are part of the natural carbon balance and will not add to atmospheric concentrations of CO_2. As a result, combustion of these fuels emits no creditable CO_2 emissions under international greenhouse gas accounting methods developed by the Intergovernmental Panel on Climate Change and adopted by the International Council of Forest and Paper Associations. By analyzing the heat content of coal and wood, total boiler heat input for the test periods, and boiler efficiency, Southern Research Institute determined that approximately 90% of the heat generated during co-firing test periods was attributable to the verified technology. Southern Research Institute therefore estimated that the CO_2 emissions offset during testing was approximately 90% or 148 pounds per million British thermal units (MMBtu) at this co-firing blend (Southern Research Institute, 2008). The ETV Program estimated emissions reductions outcomes—annual CO_2 emissions offset—for biomass co-firing at Minnesota Power's Boiler 5. According to the facility, they have been co-firing woody biomass since 1980, and continue to do so (Tolrud, 2010). The ETV Program did not estimate emissions reductions outcomes for the second verification testing site at the University of Iowa because this facility is no longer co-firing with the same fuel (renewaFUEL pellets) used during the verification test. The facility does report that they are experimenting with co-firing other types of biomass (e.g., poplar wood chips and oat hulls) (Milster, 2010).

The annual CO_2 offset was calculated using the following equation:

$$O_{ANNUAL} = O_{CALCULATED} \times GR \times A \times H/2000$$

Where:

- O_{ANNUAL} is the annual CO_2 offset in tons.
- $O_{CALCULATED}$ is the CO_2 emissions offset in MMBtu calculated by the Southern Research Institute for the ETV-verified fuel (Southern Research Institute, 2008).
- GR is the average boiler generating rate in MMBtu per hour as reported in the verification report (Southern Research Institute, 2008).
- A is the assumed availability for the boiler as reported in the verification report (Southern Research Institute, 2008).
- H is the hours per year the boiler is in operation as reported in the verification report (Southern Research Institute, 2008).
- 2000 is the pounds per ton conversion factor.

B.3 References

Goldstein R. 2010. E-mail communication. U.S. EPA Landfill Methane Outreach Program. June.

Hansen T. 2010a. E-mail communication. Southern Research Institute. 10 August.

Hansen T. 2010b. E-mail communication. Southern Research Institute. 21 September.

Milster, PF. 2010. E-mail communication. University of Iowa. 10 March.

Southern Research Institute. 2004a. *Environmental Technology Verification Report: Electric Power and Heat Generation Using UTC Fuel Cells' PC25C Power Plant and Anaerobic Digester Gas*. Prepared by Greenhouse Gas Technology Center, Southern Research Institute, Under a Cooperative Agreement with U.S. Environmental Protection Agency. SRI/USEPA-GHG-VR-26. September.

Southern Research Institute. 2004b. *Environmental Technology Verification Report: Swine Waste Electric Power and Heat Production—Martin Machinery Internal Combustion Engine*. Prepared by Greenhouse Gas Technology Center, Southern Research Institute, Under a Cooperative Agreement with U.S. Environmental Protection Agency and Under Agreement With Colorado Governor's Office of Energy Management and Conservation. SRI/USEPA-GHG-VR-22. September.

Southern Research Institute. 2007. *Environmental Technology Verification Report: Electric Power and Heat Production Using Renewable Biogas at Patterson Farms*. Prepared by Greenhouse Gas Technology Center, Southern Research Institute, Under a Cooperative Agreement with U.S. Environmental Protection Agency and Under Agreement With New York State Energy Research and Development Authority. SRI/USEPA-GHG-VR-43. September.

Southern Research Institute. 2008. *Environmental and Sustainable Technology Evaluation—Biomass Co-Firing in Industrial Boilers—Minnesota Power's Rapids Energy Center*. Prepared by Greenhouse Gas Technology Center, Southern Research Institute, Under a Cooperative Agreement with U.S. Environmental Protection Agency. EPA Contract No. EP-C-04-056. Work Assignment No. 2-8-101. April.

Tolrud D. 2010. E-mail communication. Minnesota Power. 10 March.

U.S. Department of Energy. 2010. *Electric Power Monthly*. 19 July. *http://www.eia.doe.gov/electricity/ epm/table5_3.html*

U.S. EPA. 2004. *Clean Watersheds Needs Survey Dataset*. *http://www.epa.gov/cwns/cwns2004db.mdb*

U.S. EPA. 2006. *Market Opportunities for Biogas Recovery Systems: A Guide to Identifying Candidates for On-Farm and Centralized Systems*. EPA-430-8-06-004. August.

U.S. EPA. 2007. *Opportunities for and Benefits of Combined Heat and Power at Wastewater Treatment Facilities*. Office of Air and Radiation, Combined Heat and Power Partnership. EPA-430-R-07-003. April.

U.S. EPA. 2010a. *An Overview of Landfill Gas Energy in the United States*. Landfill Methane Outreach Program. May.

U.S. EPA. 2010b. *Landfill Methane Outreach Program*. Last updated 9 September. *http://www.epa.gov/lmop/index.htm*

Appendix C. Recent Examples of ETV Outcomes for Environmental Policy, Regulation, Guidance, and Decision-Making

In addition to the outcomes reported for the technology areas featured in Chapters 2 and 3 of this document, this appendix provides recent examples of how ETV data, reports, protocols, and other information have been used in regulation, permitting, purchasing, and other similar activities for innovative technologies in other environmental areas.

C.1 Water Programs

The EPA Office of Water referenced nine ETV verification reports and two verification protocols in the *National Primary Drinking Water Regulations: Long Term 2 Enhanced Surface Water Treatment Rule* (LT2ESWTR). Additionally, EPA defined a set of test conditions that must be met for an acceptable challenge test to be used for compliance with the LT2ESWTR. These conditions provide a framework for the challenge test. States may develop additional testing requirements (40 CFR Parts 9, 141, and 142). EPA's *Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual* (April 2010) identifies the ETV *Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants* as containing sections that provide guidance for developing and conducting a bag and cartridge filter challenge test for LT2ESWTR (U.S. EPA, 2010a).

U.S. states use ETV-verified performance information in drinking water regulations and guidance. In 2009, NSF International, in cooperation with the Association of State Drinking Water Administrators, conducted a survey of U.S. state drinking water agencies. The survey showed that 35 states reported that they recognize ETV reports for drinking water treatment systems, mostly through policy, and 31 states responded that they can allow for reduced pilot testing of drinking water treatment systems for those products with acceptable ETV reports (NSF International, 2010).

The Massachusetts Department of Environmental Protection's (MassDEP) Drinking Water Regulations state that ETV verification reports can be used to qualify new drinking water treatment devices or equipment for approval, potentially with reduced pilot testing (MassDEP, 2007, 2009).

A memorandum (dated May 27, 2008) from J. Wesley Kleene, Director of the Office of Drinking Water (ODW), Virginia Department of Health, to all ODW staff addresses design features, process control and compliance monitoring, and permitting procedures of arsenic removal treatment systems. The memorandum states that test kits may be used for operational control monitoring and refers staff to the arsenic test kits that have been verified by ETV—a Web link to the verification reports is included (Kleene, 2008).

Utah Administrative Code R309-535-12, *Point-of-Use and Point-of-Entry Treatment Devices* (effective July 1, 2010) states that "...devices used shall only be those proven to be appropriate, safe, and effective as determined through testing and compliance with protocols established by EPA's Environmental Technology Verification Program (ETV) or the applicable ANSI/NSF Standard(s)." Code R309-535-13 cites the ETV Program as a source of performance testing and data for new treatment processes and equipment (Utah, 2010). The Utah Department of Environmental Quality Web Site also states: "A number of treatment processes have undergone rigorous testing under the EPA's Environmental Technology Verification Program (ETV). If a particular treatment process is a 'verified technology', it may be accepted in Utah without further pilot plant testing" (State of Utah, 2010).

The Washington State Department of Health's *Water Systems Design Manual* provides guidelines and criteria for design engineers who prepare plans and specifications for small public water systems serving fewer than 500 residential connections. The design manual states that manufacturers of alternative technologies for surface water treatment may develop testing protocols that demonstrate adequate treatment performance by using ETV protocols (State of Washington, 2009).

The National Primary Drinking Water Regulations: Revisions to the Total Coliform Rule; Proposed Rule states that EPA is considering an approach under which vendors of currently approved methods for compliance monitoring of total coliform in water would have the option of participating in ETV verification or an alternative evaluation equivalent in scope and rigor to the ETV Program. Based on the verification results, EPA's Office of Ground Water and Drinking Water would judge the appropriateness of each analytical method and determine if these methods should continue to be approved for future monitoring under this regulation (40 CFR Parts 141 and 142, 2010).

As referenced in the *Guidelines Establishing Test Procedures for the Analysis of Pollutants Under the Clean Water Act; National Primary Drinking Water Regulations; and National Secondary Drinking Water Regulations; Analysis and Sampling Procedures; Final Rule*, ETV reports and data were used during EPA's decision to retain Syngenta Method AG-625 as an approved method for atrazine, subject to certain conditions (40 CFR Parts 122, 136, et al.).

On May 26, 2010, Nancy Stoner, Deputy Assistant Administrator for the EPA Office of Water, testified before the U.S. House of Representatives Subcommittee on Domestic Policy of the Committee on Oversight and Government Reform. The topic of discussion was mercury in dental amalgam and specifically, EPA's actions to reduce releases of dental amalgam and other sources of mercury. Portions of Ms. Stoner's presentation concerned technologies for separating amalgam from dental office wastewater, and she cites an ETV verification report, among others, as evidence that separator technology is highly effective (Stoner, 2010). ETV's verification organization for the Water Quality Protection Center, NSF International, has been asked to participate in a symposium on dental amalgam separation in October 2010. In September 2010, EPA announced that it will propose a rule in 2011, and issue a final rule in 2012, to protect waterways by reducing mercury waste from dental offices (U.S. EPA, 2010b).

The California State Lands Commission Marine Invasive Species Program's *Ballast Water Treatment Technology Testing Guidelines* are based on the draft ETV *Generic Protocol for the Verification of Ballast Water Treatment Technologies*, which was developed as a joint effort by the ETV Water Quality Protection Center and the U.S. Coast Guard (Dobroski, et al., 2008).

The Maryland Department of the Environment has formed a Best Available Technology (BAT) Review Team to determine whether onsite sewage-disposal nitrogen-reducing technologies should be considered BAT and eligible for grants from the Chesapeake Bay Restoration Fund. Technology approval is based on data obtained from third-party verification of the technology. The team has adopted an ETV protocol as the baseline for verifying the performance of nitrogen-reducing onsite distribution systems. Systems that have been verified by ETV or another third-party standard at least as stringent as ETV's are considered grant eligible and receive a conditional BAT approval until they have undergone additional field testing by the State of Maryland (Maryland Department of the Environment, 2010).

ETV verification information, including links to verification reports, protocol, and ETV's verification organization's (NSF International) Web site, were included among posts on February 3, 2009, to a forum dedicated to RCC Holdings Corporation (RCCH) on InvestorsHub.com. The information was posted as part of a series of message board posts discussing stock for RCCH, formerly International Wastewater Systems. International Wastewater Systems Model 600 Sequencing Batch Reactor System, a decentralized wastewater treatment system, was verified by ETV in 2006 (see Chapter 2). InvestorsHub is a forum (message board) for investors to gather and share market insights in a dynamic environment using an advanced discussion platform. ETV and verification are mentioned in multiple posts of the message board discussion of RCCH (InvestorsHub, 2010).

A press release issued by Hydro International on March 19, 2010, states that the Public Works Department in Marietta, Georgia, has approved the use of the ETV-verified Hydro Up-Flo Filter and Downstream Defender systems for stormwater treatment projects. According to the press release, Marietta "added the products to its list of approved Water Quality Proprietary Units based on a series of exhaustive performance tests by the New Jersey Corporation for Advanced Technology and the U.S. EPA Environmental Technology Verification programs" (Hydro International, 2010).

C.2 Air and Energy Programs

The EPA Office of Inspector General's Evaluation Report, *EPA Needs to Improve Its Efforts to Reduce Air*

Emissions at U.S. Ports, to the EPA Office of Air and Radiation (OAR), states the need for independent verification of engine retrofit devices to promote voluntary emission reductions and references the ETV Program as having fulfilled this role. In the response from OAR, they state, "We agree that the ETV Program was a good compliment to the Office of Transportation and Air Quality's own verification program and that it enhanced our program when it was fully funded" (U.S. EPA, 2009a).

A memorandum (dated September 26, 2007) from Steve Page, Director of EPA's Office of Air Quality Planning and Standards (OAQPS), to EPA Regional Air Division Directors states that OAQPS will consider use of the ETV baghouse filtration protocol in future regulations, recommends that regions consider opportunities to employ protocols in state and local regulatory programs, and suggests the use of filter media tested under the ETV protocol (Page, 2007).

The South Coast Air Quality Management District's (AQMD) *Rule 1156, Further Reductions of Particulate Emissions from Cement Manufacturing Facilities* (adopted November 4, 2005; amended March 6, 2009) states, "In lieu of annual testing, any operator who elects to use all (ETV) verified filtration products in its baghouses shall conduct a compliance test every five years" (State of California, 2009b). AQMD's *Rule 1155, Particulate Matter Control Devices* (adopted December 4, 2009) requires the installation and use of ETV-verified filtration products by baghouse facility operators to meet particulate matter emission standards if established emission limits are exceeded by the facility (State of California, 2009a).

The Ventura County (California) Air Pollution Control District's *Rule 74.9, Stationary Internal Combustion Engine Revisions* (effective January 1, 2006) requires that screening analyses "be performed using a portable analyzer either verified by the Environmental Protection Agency (ETV) or approved in writing by the Air Pollution Control Officer." The rule also includes a link to a list of ETV-verified analyzers on ETV's Web Site (Ventura County Air Pollution Control District, 2005).

The California Air Resources Board's *Report to the Legislature on Gas-Fired Power Plant NO_x Emission Controls and Related Environmental Impacts* includes information on the installation status of the Xonon Cool Combustion™ catalytic combustor, manufactured by Catalytica Energy Systems, and references ETV verification of nitrogen oxides (NO_x) emissions reductions (State of California, 2004).

EPA OAQPS and states have used ETV information in guidance and regulations for outdoor wood-fired hydronic heaters (OWHHs). In 2007, OAQPS launched a voluntary program to promote the manufacture and sale of cleaner hydronic heaters (U.S. EPA, 2008). In June 2008, ETV published a protocol for verifying OWHH performance (RTI International, 2008). EPA OAQPS also provided technical and financial support for the development of a model rule to aid states and local agencies that choose to regulate emissions from OWHHs. The *Outdoor Hydronic Heater Model Regulation*, which became available in January 2007, was developed by the Northeast States for Coordinated Air Use Management and required testing by ETV as part of the certification procedures (Northeast States for Coordinated Air Use Management, 2007).

A number of states also established regulations for OWHHs. Under the Vermont Agency of Natural Resources *Adopted Rule 5-204, Outdoor Wood-Fired Boilers* (effective October 1, 2009), certification testing requirements stated that manufacturers must demonstrate that an outdoor wood-fired boiler complies with applicable emission limits set forth in the rule and provide written test results; before submitting a test report for certification, it must first be reviewed and approved by the ETV Program, the EPA Hydronic Heater Program, or another agent approved by the state (State of Vermont, 2009). The MassDEP has promulgated regulation *310 CMR 7.26(50-54), Outdoor Hydronic Heaters* (wood-fired boilers) (effective December 26, 2008), that identified ETV as a source for emission test data for certification (MassDEP, 2008). The Maine Department of Environmental Protection's Final Regulation, *Chapter 150: Control of Emissions from Outdoor Wood Boilers* (adopted July 4, 2008) also mentioned ETV as a possible means of testing for outdoor wood boilers to obtain state certification for meeting applicable particulate emission standards (Maine Department of Environmental Protection, 2008).

Under Texas Administrative Code *Title 30 Rule 114.315, Low Emission Diesel, Approved Test Methods* (effective May 17, 2006), diesel fuel additives and formulations that have been verified by ETV and by the EPA Office of Transportation and Air Quality's Voluntary Diesel Retrofit Program to reduce NO_x emissions by at least 5.78% as compared to base diesel fuel with properties as described for nationwide average fuel in the ETV's *General Verification Protocol for Determination of Emissions Reductions Obtained by Use of Alternative or Reformulated Liq-*

uid Fuels, Fuel Additives, Fuel Emulsions, and Lubricants for Highway and Nonroad Use Diesel Engines and Light Duty Gasoline Engines and Vehicles (RTI International, 2003), may be approved by the Texas Commission on Environmental Quality as an alternative diesel fuel under the Texas Low Emission Diesel (commonly known as TxLED) Program without need for further testing (Texas Commission on Environmental Quality, 2006, 2010). Additionally, Texas' New Technology Research and Development Program provides grants to expedite the commercialization of new and innovative emission reduction technologies that will help to improve air quality in Texas. Grants are awarded and administered by the Texas Environmental Research Commission through the Houston Advanced Research Center. In 2006, ETV was one of two verification programs specified in Texas Environmental Research Commission New Technology Research and Development solicitations for grant applications; these grants provided funding to help support verification (Texas Environmental Research Commission, 2010).

An entry in the Oil and Gas Lawyer Blog entitled "TCEQ Answers Rep. Lon Burnam's Questions on Investigation of Air Quality" and dated December 18, 2009, references ETV verification of COMM Engineering, USA's Eductor Vapor Recovery Unit. Specifically, the blog entry reports that State Representative Lon Burnam questioned the Texas Commission on Environmental Quality concerning its investigations of emissions of methane and volatile organic compounds from oil and gas operations in the Barnett Shale area and in Texas in general. The blog reports that Representative Burnam asked the commission how long it would take a producer to recover the cost of installing a vapor recovery unit for a typical well in Texas. The commission referred Burnam to the ETV verification, which demonstrates that the cost of a vapor recovery unit could typically be recovered between 3 and 19 months, depending on the price of natural gas. It states, "The Environmental Technology Verification Program at EPA evaluated the Eductor Vapor Recovery Unit (EVRU) from COMM Engineering. The $108,000 EVRU recovered 175 Mscf/day. Assuming a prices value of $5.46 per Mscf, the total value of recovered gas was estimated at $650,000 per year for an approximate two month payback" (Oil and Gas Lawyer Blog, 2009).

ETV reports and data were used to inform the development of the *Update of Continuous Instrumental Test Methods; Final Rule* (40 CFR Part 60), for measuring air pollutant emissions from stationary sources.

In 2007, the American Society for Testing and Materials (ASTM) approved ASTM standard D7270-07, *Standard Guide for Environmental and Performance Verification of Factory-Applied Liquid Coatings*. With the help of one of its stakeholders, ETV worked with ASTM Committee D01 on Paint and Related Coatings, Materials, and Applications and its Subcommittee D01.55 (Factory Applied Coatings on Preformed Products) to develop this ASTM standard, which is based on the *Environmental Technology Verification Coatings and Coating Equipment Program, UV-Curable Coatings—Generic Verification Protocol* (Concurrent Technologies Corporation, 2003).

The U.S. Green Building Council's *LEED® for Schools—for New Construction and Major Renovations* (U.S. Green Building Council, 2007) includes methods for calculating indoor air emissions from furniture, one of which references an ETV protocol. The guidelines state that classroom furniture and furnishings must meet indoor air emissions limits, which were determined using a procedure based on the *Environmental Technology Verification Large Chamber Test Protocol for Measuring Emissions of Volatile Organic Compounds and Aldehydes* (Research Triangle Institute, 1999).

C.3 Land and Toxics Programs

The EPA Office Pollution Prevention and Toxics' Lead Renovation, Repair, and Painting Program requires ETV testing or equivalent approval for lead paint test kits. The ETV Program is referenced in *Lead; Renovation, Repair, and Painting Program; Final Rule* (40 CFR Part 745), which includes a lead test kit recognition program. The recognition program references ETV as the testing organization that will be used to evaluate the test kits. ETV is in the process of verifying the performance of lead in paint test kits under an Environmental and Sustainable Technology Evaluation (ESTE) project. Additionally, in 2009, the State of Wisconsin requested information on the test plan for the verification testing under this project for consideration for inclusion in state regulations regarding lead in paint test kits.

The EPA Office of Pesticide Programs (OPP) is using ETV and its pesticide spray drift research, which is being conducted under an ESTE project, to develop pesticide risk assessment and labeling requirements. OPP intends to use verified drift-reduction technologies in its pesticide risk assessments and registration decisions (*Daily*

Environment Report, 2007). The ESTE spray drift project is discussed in the draft pesticide registration notice for pesticide spray drift entitled "Pesticide Registration Notice 2008-X Draft: Pesticide Drift Labeling" (U.S. EPA, 2009b).

In 2007, the U.S. Virgin Islands Waste Management Authority (VIWMA) issued a solicitation for waste-to-energy solid waste management facilities to process and dispose of solid waste on the island of St. Croix. VIWMA was seeking alternative solid waste disposal options that would provide maximum diversion of waste from landfills through proven technologies that generate energy, recover resources, and provide emissions control. The solicitation required that proposals demonstrate a successful record of technology performance. Specifically, the solicitation stated that ETV verification could be submitted as an alternative to a 5-year successful technology track record (ETVoice, 2007).

C.4 Other Areas

The Virginia Department of Environmental Quality, on its Web site, includes information on technology demonstration and verification programs, as well as other technology inventories and information resources. The site includes, among its resources, information on the ETV Program and links to the ETV Web Site (Virginia Department of Environmental Quality, 2009).

Acronyms and Abbreviations Used in This Appendix:

AQMD	Air Quality Management District
ASTM	American Society for Testing and Materials
BAT	Best Available Technology
ESTE	Environmental and Sustainable Technology Evaluation
EVRU	Eductor Vapor Recovery Unit
IWS	International Wastewater Systems
LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
MassDEP	Massachusetts Department of Environmental Protection
NO_x	nitrogen oxides
OAQPS	Office of Air Quality Planning and Standards
OAR	Office of Air and Radiation
ODW	Office of Drinking Water
OPP	Office of Pesticide Programs
OWHH	outdoor wood-fired hydronic heaters
RCCH	RCC Holdings Corporation
TxLED	Texas Low Emission Diesel
VIWMA	Virgin Islands Waste Management Authority

C.5 References

40 CFR Parts 122, 136, et al. 2007. *Code of Federal Regulations Title 40—Protection of the Environment. Chapter 1: Environmental Protection Agency.. Part 122: Guidelines Establishing Test Procedures for the Analysis of Pollutants Under the Clean Water Act; National Primary Drinking Water Regulations; and National Secondary Drinking Water Regulations; Analysis and Sampling Procedures; Final Rule*. 12 March.

40 CFR Parts 141, 142. 2010. *Code of Federal Regulations Title 40—Protection of the Environment. Chapter 1: Environmental Protection Agency. Parts 141 and 142: National Primary Drinking Water Regulations: Revisions to the Total Coliform Rule; Proposed Rule*. 14 July.

40 CFR Part 60. *2006. Federal Regulations Title 40—Protection of the Environment. Chapter 1: Environmental Protection Agency. Part 60: Update of Continuous Instrumental Test Methods; Final Rule*. 14 August.

40 CFR Part 745. 2008. *Lead; Renovation, Repair, and Painting Program; Lead Hazard Information Pamphlet; Notice of Availability; Final Rule*. 22 April.

40 CFR Parts 9, 141, and 142. 2006. *National Primary Drinking Water Regulations: Long Term 2 Enhanced Surface Water Treatment Rule*. 5 January.

Concurrent Technologies Corporation. 2003. *Environmental Technology Verification Coatings and Coating Equipment Program, UV-Curable Coatings—Generic Verification Protocol*. Prepared by the National Defense Center for Environmental Excellence and Submitted by Current Technologies Corporation Under a Cooperative Agreement. DAAE30-98-C-1050. 26 September.

Daily Environment Report. 2007. *Interview with J. Ellenberger, OPP*. 21 May.

Dobroski N, Scianni C, Gehringer D, and Falkner M. 2008. *Ballast Water Treatment Technology Testing Guidelines*. Prepared by the California State Lands Commission, Marine Invasive Species Program. 10 October.

ETVoice. 2007. *Virgin Islands to Consider ETV Verification in Selection Criteria for Solid Waste Management Facility*. July. *http://www.epa.gov/etv/etvoice0707.html*

Hydro International. 2010. *Marietta, Georgia Approves Use of Hydro International's Stormwater Treatment Products*. Press Release. 17 March.

InvestorsHub. 2010. RCC Holdings Corporation (RCCH) Message Board. *http://investorshub.advfn.com/boards/board.aspx?board_id=10562*. Last accessed 13 August.

Kleene WJ. 2008. "Memorandum from J. Wesley Kleene Ph.D. (P.E. Director) to the Office of Drinking Water Staff Concerning *Permits & Project Review—Procedures for Arsenic Removal Treatment Systems*. 28 May.

Maine Department of Environmental Protection. 2008. *Control of Emissions from Outdoor Wood Boilers: Final Regulation*. November.

Maryland Department of the Environment. 2010. *Bay Restoration Fund (BRF) Best Available Technology for Removing Nitrogen from Onsite Systems*. *http://www.mde.maryland.gov/water/cbwrf/osds/brf_bat.asp*. Last accessed 13 August.

Massachusetts Department of Environmental Protection (MassDEP). 2007. *BRP WS 27 Permits for New Technology and Third-Party Approval: Instructions and Supporting Materials*. Bureau of Resources Protection—Water Supply. June.

MassDEP. 2008. *310 CMR 7.26: Outdoor Hydronic Heaters*. November.

MassDEP. 2009. *310 CMR 22.00: The Massachusetts Drinking Water Regulations. Section 4: Construction, Operation, and Maintenance of Public Water Systems. Paragraph 8: New Product or Technology*. December.

Northeast States for Coordinated Air Use Management. 2007. *Outdoor Hydronic Heater Model Regulation*. 29 January.

NSF International. 2010. *Survey of ASDWA Members Use of NSF Standards and ETV Reports*. March.

Oil and Gas Lawyer Blog. 2009. TCEQ *Answers Rep. Lon Burnam's Questions on Investigation of Air Quality*. 18 December. *http://www.oilandgaslawyerblog.com/2009/12/tceq-answers-rep-lon-burnams-q.html*

Page SD. 2007. "Memorandum from Stephen D. Page (Office of Air Quality Planning and Standards) to Regional Air Division Directors Concerning *Use of New ASTM Performance Verifications for Baghouse Media*." 26 September.

RTI International. 2003. *Generic Verification Protocol for Determination of Emissions Reductions Obtained by Use of Alternative or Reformulated Liquid Fuels, Fuel Additives, Fuel Emulsions, and Lubricants for Highway and Non-Road Use Diesel Engines and Light-Duty Gasoline Engines and Vehicles*. Prepared by RTI International Under a Cooperative Agreement with U.S. Environmental Protection Agency. CR829434-01-1. September.

RTI International. 2008. *Generic Verification Protocol for Determination of Emissions from Outdoor Wood-Fired Hydronic Heaters*. Prepared by RTI International Under a Cooperative Agreement with U.S. Environmental Protection Agency. CR831911-01-1. June.

State of California. 2004. *Report to the Legislature on Gas-Fired Power Plant NO_x Emission Controls and Related Environmental Impacts*. Air Resources Board. May.

State of California. 2009a. *Rule 1155: Particulate Matter Control Devices*. South Coast Air Quality Management District. 4 December.

State of California. 2009b. *Rule 1156: Further Reductions of Particulate Emissions From Cement Manufacturing Facilities*. South Coast Air Quality Management District. 6 March.

State of Utah. 2010. *Construction Approval Process: Project Notification—Plan Approval—Operating Permit*. Department of Environmental Quality. *http://www.drinkingwater.utah.gov/plan_review_intro.htm*. Last accessed 13 July.

State of Vermont. 2009. *Final Rule 5-204: Outdoor Wood-Fired Boilers*. Agency of Natural Resources. October.

State of Washington. 2009. *Water System Design Manual*. Department of Health. December.

Stoner N. 2010. *Testimony Before the House of Representatives, Subcommittee on Domestic Policy of the Committee on Oversight and Government Reform*. May 26.

Texas Commission on Environmental Quality. 2006. *Texas Administrative Code Title 30 Rule 114.315, Low Emission Diesel, Approved Test Methods*. 17 May.

Texas Commission on Environmental Quality. 2010. *Regulatory Guidance RG-000 Draft: Questions and Answers Regarding the Texas Low Emission Diesel Fuel (TxLED) Regulations*. July.

Texas Environmental Research Commission. 2010. *Texas Environmental Research Commission New Technology Research and Development Request for Grant Applications. http://www.tercairquality.org/ NewTechnologyResearchDevelopmentNTRD/FundingOpportunities/RequestsforGrantApplications/tabid/781/Default.aspx*. Last accessed 13 August.

U.S. EPA. 2008. *Hydronic Heater Program Phase 2 Partnership Agreement between the Office of Air Quality Planning and Standards and the U.S. Environmental Protection Agency*. Final Agreement. October 15.

U.S. EPA. 2009a. *EPA Needs to Improve Its Efforts to Reduce Air Emissions at U.S. Ports: Evaluation Report*. Office of Inspector General. Report No. 09-P-0125. 23 March.

U.S. EPA. 2009b. *Draft Pesticide Registration Notice 2009-X: Additional Information and Questions for Commenters*. Office of Pesticide Programs. October.

U.S. EPA. 2010a. *Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual*. Office of Water. EPA 815-D-09-001. April.

U.S. EPA. 2010b. *EPA Will Propose Rule to Protect Waterways by Reducing Mercury From Dental Office /Existing Technology Is Available to Capture Dental Mercury*. Press Release. 27 September. *http://yosemite.epa.gov/opa/admpress.nsf/e77fdd4f5afd88a3852576b3005a604f/a640db2ebad201cd852577ab00634848!OpenDocument*

U.S. Green Building Council. 2007. *LEED® for Schools—for New Construction and Major Renovations*. November.

Ventura County Air Pollution Control District. 2005. *Compliance Assistance Advisory: Rule 74.9: Stationary Internal Combustion Engine Revisions*. 8 November.

Virginia Department of Environmental Quality. 2009. *Innovative Technology: Technology Verifications and Inventories*. Last updated 8 January. *http://www.deq.state.va.us/export/sites/default/innovtech/dem2.html*

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