Environmental Technology Verification (ETV) Program Case Studies: Demonstrating Program Outcomes, Vol. II

EPA/600/R-06/082

Environmental Technology Verification (ETV) Program Case Studies

Demonstrating Program Outcomes Volume II

EPA United States
Environmental Protection
Agency

Cover Background image from the NASA Web site at http://visibleearth.nasa.gov

EPA/600/R-06/082
September 2006

Environmental Technology Verification (ETV) Program Case Studies:

Demonstrating Program Outcomes

Volume II

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Notice

Development of this document was funded by the United States Environmental Protection Agency's (EPA's) Environmental Technology Verification (ETV) Program under contract number 68-C-02-067 to Science Applications International Corporation. ETV is a public/private partnership conducted, in large part, through competitive cooperative agreements with nonprofit research institutes. This document has been subjected to the Agency's review and has been approved for publication as an EPA document. Mention of trade names, products, or services does not convey, and should not be interpreted as conveying, official EPA approval, endorsement, or recommendation. The use of company- and/or product-specific sales information, images, quotations, or other outcomes-related information does not constitute the endorsement of any one verified company or product over another, nor do the comments made by these organizations necessarily reflect the views of the U.S. EPA.

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 ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both 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 to link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

Acknowledgements

The ETV Program wishes to thank the verification organization partners, external peer reviewers, ETV center project officers, EPA program office staff, and other EPA personnel who reviewed or contributed to the case studies throughout the development process. The following individuals were instrumental in ensuring that the information presented in the case studies was technically accurate, consistent with the Agency's current understanding of the underlying issues, summarized fairly, and, in the case of projected outcomes, estimated in a reasonable manner:

- *Baghouse Filtration Products:* Michael Kosusko, EPA National Risk Management Research Laboratory (NRMRL); John Wasser, EPA NRMRL; Andrew Trenholm, RTI International; John Bosch, EPA Office of Air Quality Planning and Standards (OAQPS); Thomas Logan, EPA OAQPS
- *Continuous Emission Monitors (CEMs) for Mercury:* Robert Fuerst, EPA National Exposure Research Laboratory (NERL); Thomas Kelly, Battelle; Thomas Logan, EPA OAQPS; William Maxwell, EPA OAQPS; Robin Segall, EPA OAQPS
- *Fuel Cells:* David Kirchgessner, EPA NRMRL; Timothy Hansen, Southern Research Institute; Richard Adamson, Southern Research Institute; Kimberly Crossman, EPA CHP Partnership
- *Microturbine/Combined Heat and Power (CHP) Technologies:* David Kirchgessner, EPA NRMRL; Timothy Hansen, Southern Research Institute; Richard Adamson, Southern Research Institute; Kimberly Crossman, EPA CHP Partnership; Luis Troche, EPA Office of International Affairs (OIA) (formerly with the CHP Partnership)
- *Microfiltration (MF) and Ultrafiltration (UF) for Removal of Microbiological Contaminants:* Jeff Adams, EPA NRMRL; Bruce Bartley, NSF International; Hiba Shukairy, EPA Office of Ground Water and Drinking Water (OGWDW); Dan Schmelling, EPA OGWDW
- *Nanofiltration for Removal of Disinfection Byproduct (DBP) Precursors:* Jeff Adams, EPA NRMRL; Bruce Bartley, NSF International; Hiba Shukairy, EPA OGWDW; Jimmy Chen, EPA OGWDW; John Abraham, EPA NRMRL; Ray Smith, EPA NRMRL
- *Immunoassay Test Kits for Atrazine in Water:* Robert Fuerst, EPA NERL; Amy Dindal, Battelle; Herb Brass, EPA OGWDW (retired); Kent Sorrell, EPA OGWDW; Patricia Fair, EPA OGWDW; Pritidhara Mohanty, EPA OGWDW; Diane Sherman, EPA Office of Pesticide Programs (OPP); Mary Frankenberry, EPA OPP; Thuy Nguyen, EPA OPP
- *Ultraviolet (UV) Disinfection for Secondary Wastewater Effluent and Water Reuse:* Raymond Frederick, EPA NRMRL; Thomas Stevens, NSF International; Rodney Frederick, EPA Office of Wetlands, Oceans, and Watersheds (OWOW)
- *All Case Studies:* Teresa Harten, EPA NRMRL; Evelyn Hartzell, EPA NRMRL; Robert Olexsey, EPA NRMRL; Alva Daniels, EPA NRMRL; JoAnn Lighty, University of Utah; Linda Benevides, Massachusetts Executive Office of Environmental Affairs; Arleen O'Donnell, Massachusetts Department of Environmental Protection; David Noonan, Massachusetts Department of Environmental Protection.

Table of Contents

Acronyms and Abbreviations

AA	atomic absorption
acfm	actual cubic feet per minute
AE	atomic emission
AF	atomic fluorescence
AMS Center	ETV's Advanced Monitoring Systems Center
APCT Center	ETV's Air Pollution Control Technology Center
ASDWA	Association of State Drinking Water Administrators
ASERTTI	Association of State Energy Research and Technology Transfer Institutions
BAT	best available technology
CAMR	Clean Air Mercury Rule
CEM	continuous emission monitor
CHP	combined heat and power
cm w.g.	centimeters water gauge
CO	carbon monoxide
CO_2	carbon dioxide
DBP	disinfection byproduct
DBPR	Disinfectants and Disinfection Byproducts Rule
DG	distributed generation
DOE	Department of Energy
DWS Center	ETV's Drinking Water Systems Center
EA	Economic Analysis
EPA	Environmental Protection Agency
ETV	EPA's Environmental Technology Verification Program
g/dscm	grams per dry standard cubic meter
GC/MS	gas chromatography/mass spectrometry
GHG Center	ETV's Greenhouse Gas Technology Center
HAA5	the sum of five haloacetic acids
IEEE	Institute of Electrical and Electronics Engineers
IPCC	Intergovernmental Panel on Climate Change
IQ	intelligence quotient
IRED	Interim Reregistration Eligibility Decision
ISO	International Standards Organization
kW	kilowatts
lbs/kWh	pounds per kilowatt-hour
LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MF	microfiltration
MGD	million gallons per day
mL	milliliters
MW	megawatts
NAAQS	National Ambient Air Quality Standards
NOAA	National Oceanic and Atmospheric Administration

NO_X	nitrogen oxides
OAQPS	EPA's Office of Air Quality Planning and Standards
OH	Ontario Hydro
PAFC	phosphoric acid fuel cell
PCI	PCI Membrane Systems Inc.
PEM	polymer electrolyte membrane fuel cell
PM	particulate matter
PM_{10}	fine PM with a nominal aerodynamic diameter of 10 micrometers or less
$PM_{2.5}$	fine PM with a nominal aerodynamic diameter of 2.5 micrometers or less
ppb	parts per billion
PSWA	Pittsburgh Sewer and Water Authority
RIA	Regulatory Impact Analysis
SCAQMD	South Coast Air Quality Management District
SIP	State Implementation Plan
SO_2	sulfur dioxide
Texas CEQ	Texas Commission on Environmental Quality
THCs	total hydrocarbons
TMDL	Total Maximum Daily Load
TTHM	total trihalomethane
UF	ultrafiltration
UV	ultraviolet
WQP Center	ETV's Water Quality Protection Center
µg/L	micrograms per liter
$µg/m^3$	micrograms per cubic meter
µg/scm	micrograms per standard cubic meter

I.

Introduction and Summary

1.1

Purpose

This document is the second volume in a collection of case studies that document actual and project estimated (or potential) outcomes and benefits of the U.S. Environmental Protection Agency's (EPA's) Environmental Technology Verification (ETV) Program. The first volume (U.S. EPA, 2006f) was published in January 2006 and can be found at *http://www.epa.gov/etv/sitedocs/program-index.html.*

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 five nonprofit research institutes listed in Exhibit 1.1-1, although some verifications are performed under contracts. The ETV Program, through its cooperative agreement recipients, develops testing protocols and publishes detailed performance results in the form of verification reports and statements, which can be found at *http://www.epa.gov/etv/verifications/verification-index.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 guidelines. By providing credible performance information about new and improved, commercially ready environmental technologies, ETV verification can help vendors 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 to the public. In measuring performance, GPRA distinguishes between "output" measures and "outcome" measures. Output measures assess a program's activities in their simplest form, such as counting the number of projects completed. Outcome measures assess the results of these activities compared to their intended purpose, for example, by quantifying the benefits of those projects (GPRA, 1993).

Historically, the ETV Program has measured its performance in terms of outputs, for example, the number of technologies verified and testing protocols developed. ETV is expanding its approach to include outcomes, such as pollution reductions attributable to the use of ETV technologies and subsequent health or environmental impacts. These case studies highlight how the program's outputs have translated into actual outcomes and predict potential outcomes based on market penetration scenarios. The program also will use 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 predicting environmental outcomes and human health benefits. Therefore, many of the outcomes quantified in these case studies are potential outcomes, and should be treated as estimates only. Also, in general, these estimates were calculated by assuming a straight-line relationship between pollutant reductions and reductions in health effects estimated in publicly available resources, for example, regulatory impact analyses. In most cases, this estimation method is likely a simplification of the actual relationship between pollutant reductions and health effects. It also probably simplifies the relationship between pollutant reductions and ambient concentrations, and the relationship between ambient concentrations and health effects. In general, these estimates also do not account for localized impacts, which are likely to be observed under lower market penetration scenarios.
- Vendors of ETV-verified technologies are not required to track their sales or report the effects 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 potential market for a given technology or technology group and applied scenarios, for example, 10% and 25% of this market, to project the number of applications for the technology category. Where sales information is available, however, ETV has incorporated this information into its market penetration scenarios (see, for example, the case study in Section 2.4).
- The outcomes presented here were not produced during the verification tests themselves. Instead, the ETV Program has calculated these outcomes by combining the verified performance results (which can be found at *http://www.epa.gov/etv/verifications/verification-index.html*) with data from publicly available sources such as 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 are merely intended to highlight benefits or other outcomes that could be attributed to verification and verified technology use.
- The ETV Program does not compare technologies. Therefore, when a case study discusses a group of similar verified technologies, it summarizes performance results in the form of a range or without identifying the specific vendor associated with a given result. When results are listed in a tabular format, the vendor and product names are not mentioned and the results are listed in a random order. Specific results for all verified technologies can be found at *http://www.epa.gov/etv/verifications/verification-index.html*.
- 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 make the final decisions on the content of the verification reports, which are considered 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 verification data have been collected, analyzed, and presented in a manner that is consistent with EPA's quality assurance guidelines.
- Verification organization partners, the ETV center EPA project officers, and appropriate program office and other EPA personnel have reviewed the case studies throughout the development process. These reviews were performed to ensure that the information presented in the case studies was technically accurate, consistent with the Agency's current understanding of the underlying issues, summarized fairly, and, in the case of outcomes, estimated in a reasonable manner. Vendors were also provided with an opportunity to review the pre-final versions of the case studies.

- Three of the eight case studies presented here were initially based on draft case studies (U.S. EPA, 2002a; NSF, 2004; Battelle, 2004a) that were developed by EPA ETV Program staff and verification partners. These case studies include text and other information found in the draft documents.

- 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 information does not constitute the endorsement of any one verified company or product over another, nor do the comments made by these organizations necessarily reflect the views of the U.S. EPA.

EXHIBIT 1.1–1

ETV CENTERS AND VERIFICATION ORGANIZATIONS

ETV Center/Pilot	Verification Organization	Technology Areas and Environmental Media Addressed
ETV Advanced Monitoring Systems (AMS) Center	Battelle	❖ Air, water, and soil monitoring ❖ Biological and chemical agent detection in water
ETV Air Pollution Control Technology (APCT) Center	RTI International	❖ Air pollution control
ETV Drinking Water Systems (DWS) Center	NSF International	❖ Drinking water treatment ❖ Biological and chemical agent treatment in water
ETV Greenhouse Gas Technology (GHG) Center	Southern Research Institute	❖ Greenhouse gas mitigation and monitoring
ETV Water Quality Protection (WQP) Center	NSF International	❖ Storm and waste water control and treatment ❖ Biological and chemical agent wastewater treatment
ETV Pollution Prevention (P2) Coatings and Coating Equipment Pilot (CCEP)	Concurrent Technologies Corporation (CTC)	❖ Pollution prevention for coatings

1.2

Organization and Scope

This document includes case studies of eight selected ETV-verified technologies or technology groups. Section 2 presents four "Air and Energy Technology" case studies. Section 3 presents four "Water Technology" case studies. One of the case studies is an update of a case study originally published in the first volume of this document (U.S. EPA, 2006f). Section 4 is a complete list of references and the document concludes with a set of appendices that provide a detailed discussion of the methods used to estimate outcomes in several of the case studies.

Exhibit 1.2-1 lists the eight case studies, shows the ETV center that verified each, and identifies the priority environmental topics and significant pollutants addressed by each.

Each case study begins with a summary of actual and estimated outcomes, followed by three sections. The first section, "Environmental, Health, and Regulatory Background," describes: (1) the pollutant or environmental issue the technology is designed to address, (2) the human health and environmental impacts associated with the pollutant or issue, and (3) regulatory programs or voluntary initiatives under which the technology can be applied. The second section, "Technology Description," describes the technology, identifies what makes the technology innovative, and summarizes the performance results as verified by ETV. The third section, "Outcomes," presents, in detail, the ETV Program's estimates of outcomes from verification and from implementing the technology. These outcomes include:

- Pollutant (or emissions) reduction outcomes, such as pounds of pollutant removed nationwide by actual or projected applications of the technology
- Environmental and human health outcomes, such as cases of disease or death avoided, nationwide, by actual or projected applications of the technology
- Resource conservation outcomes, such as the types of natural or man-made resources that the technology can conserve
- Economic and financial outcomes, such as the economic value of avoided cases of disease or cost savings to users of the technology
- Regulatory compliance outcomes, such as the number of facilities that the technology can assist in complying with a regulation
- 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 due to ETV verification or scientific uncertainties that can be addressed by verification.

Within each outcome category, the ETV Program made every effort to quantify, that is, place a numerical value on, the outcome. Where

EXHIBIT 1.2–1

CASE STUDIES, PRIORITY ENVIRONMENTAL TOPICS, AND SIGNIFICANT POLLUTANTS

Case Study and Section Number	ETV Center (1)	Priority Environmental Topics	Significant Pollutants
Air and Energy Technologies			
2.1 Baghouse Filtration Products	APCT	Industrial emissions, children's health	Fine particulate matter (PM2.5)
2.2 Continuous Emission Monitors (CEMs) for Mercury	AMS	Industrial emissions, children's health	Mercury
2.3 Microturbine/Combined Heat and Power (CHP) Technologies	GHG	Greenhouse gases, waste-to-energy, community development	Carbon dioxide, nitrogen oxides, carbon monoxide, total hydrocarbons
2.4 Microturbine/Combined Heat and Power (CHP) Technologies (2)	GHG	Greenhouse gases, waste-to-energy, community development	Carbon dioxide, nitrogen oxides, sulfur dioxide, methane, carbon monoxide, particulate matter, ammonia, total hydrocarbons
Water Technologies			
3.1 Microfiltration (MF) and Ultrafiltration (UF) for Removal of Microbiological Contaminants	DWS	Small drinking water systems	*Cryptosporidium* and *Cryptosporidium*-sized particles
3.2 Nanofiltration for Removal of Disinfection Byproduct (DBP) Precursors	DWS	Small drinking water systems	Trihalomethanes and haloacetic acids
3.3 Immunoassay Test Kits for Atrazine in Water	AMS	Drinking water compliance, watershed protection	Atrazine
3.4 Ultraviolet (UV) Disinfection for Secondary Wastewater Effluent and Water Reuse	WQP	Watershed protection, community development	Pathogenic organisms, such as E. coli and enterococci

(1) APCT = Air Pollution Control Technology Center; GHG = Greenhouse Gas Technology Center; CCEP = Coatings and Coating Equipment Pilot; AMS = Advanced Monitoring Systems Center; DWS = Drinking Water Systems Center; WQP = Water Quality Protection Center

(2) Updated from the case study originally presented in the first volume of this document (U.S. EPA, 2006f)

insufficient data were available to quantify an outcome, the case studies present information about that outcome and describe its projected significance qualitatively.

Each case study is written to stand on its own, so that readers interested in only one technology category (or a few categories) can direct their attention to the section(s) of interest without needing to review the entire document. For this reason, each case study spells out acronyms (other than EPA and ETV) on first use within that case study, even if those acronyms have been used in previous case studies. To further aid readers, each case study also includes its own acronyms list at the end of the section. For readers who wish to review all the case studies together, a complete acronyms list is included at the beginning of this document.

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 above, the ETV Program examined a number of 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 and provides examples of the most significant quantifiable actual and projected outcomes. Exhibit 1.3-1 lists the eight case studies, with the types of outcomes identified in each. It also indicates which of the outcomes the ETV Program was able to quantify.

Exhibit 1.3–1

Types of Outcomes Identified for Each Case Study

Case Study and Section Number	Pollutant or Emissions Reduction	Environmental & Human Health	Resource Conservation	Financial & Economic	Regulatory	Technology Acceptance & Use	Scientific Advancement
Air and Energy Technologies							
2.1 Baghouse Filtration Products	Q	X		X	Q	X	X
2.2 Continuous Emission Monitors (CEMs) for Mercury	X(1)	X(1)		X	Q	X	X
2.3 Fuel Cells	Q	X	Q	X		X	
2.4 Microturbine/Combined Heat and Power (CHP) Technologies (2)	Q	X	X	X		X	X
Water Technologies							
3.1 Microfiltration (MF) and Ultrafiltration (UF) for Removal of Microbiological Contaminants		Q		Q	Q	X	X
3.2 Nanofiltration for Removal of Disinfection Byproduct (DBP) Precursors		Q		Q	Q	X	
3.3 Immunoassay Test Kits for Atrazine in Water	X(1)	X(1)		Q	X	X	X
3.4 Ultraviolet (UV) Disinfection for Secondary Wastewater Effluent and Water Reuse	X	X	Q	X	Q	X	X

Blank = ETV did not identify this type of outcome
X = ETV identified this type of outcome, but was not able to quantify its potential impact
Q = ETV identified this type of outcome and was able to quantify its potential impact
(1) ETV estimates that information provided by the monitors ultimately can assist in reduction of emissions or pollutant releases, with environmental and human health benefits
(2) Revised from the case study originally presented in the first volume of this document (U.S. EPA, 2006f)

Examples of some of the significant outcomes from those identified in Exhibit 1.3-1 include the following:

- The ETV-verified baghouse filtration products would result in human health and environmental benefits, including up to 68 avoided cases of premature mortality per year, with an economic value of up to $450 million per year,[1] assuming 25% market penetration. California has adopted a rule (Rule 1156) that provides incentives for cement manufacturing facilities to use the ETV-verified baghouse fabrics to control particulate emissions. EPA's Office of Air Quality Planning and Standards (OAQPS) is preparing a memorandum to encourage EPA regional offices and other agencies to consider adopting similar regulations.
- ETV verification of mercury continuous emissions monitors (CEMs) has helped inform the development to the Clean Air Mercury Rule (CAMR) and resulted in improvements in monitors by the participating vendors. The verified monitors, or monitors improved as a result of testing, could be applied at approximately 340 utilities that EPA estimates would use CEMs to meet monitoring requirements under the CAMR. The information provided by the verified monitors will ultimately assist in achieving mercury emissions reductions, with associated human health, environmental, and economic benefits.
- The ETV-verified fuel cells would reduce carbon dioxide (CO2) emissions by 41,000 tons per year and nitrogen oxide (NOX) emissions by 270 tons per year, with associated climate change and environmental and human health benefits, assuming annual sales continue at the same rate as in 2005 over the next five years. Many of the fuel cells would utilize renewable fuels, such as anaerobic digester gas, resulting in reductions in the consumption of natural resources.
- The ETV-verified microturbine/combined heat and power (CHP) technologies would reduce CO2 emissions by up to 150,000 tons per year and NOX emissions by up to 530 tons per year, with associated climate change and environmental and human health benefits, assuming annual sales continue at the same rate as in 2005 over the next five years.
- The ETV-verified microfiltration (MF) and ultrafiltration (UF) technologies would prevent up to 13,000 cases of cryptosporidiosis per year and up to two premature deaths per year associated with these cases, with an associated economic value of up to $19 million per year,[2] assuming 25% market penetration. States such as Utah and Massachusetts are willing to use ETV verification data to approve technology use at the state level.
- The ETV-verified nanofiltration technology could prevent up to 20 cases of bladder cancer per year, with an associated economic value of up to $110 million per year,[3] assuming 25% market penetration.[4] States such as Utah and Massachusetts are willing to use ETV verification data to approve technology use at the state level.
- The ETV-verified immunoassay test kits for atrazine in water would result in national sampling-cost savings of up to $5,000,000 per year,[5] assuming the test kits partially replace conventional methods in model sampling programs at up to 960 community surface water systems and up to 2,500 watersheds (representing 25% market penetration). ETV data will contribute to EPA's future decision to modify or withdraw one of the approved analysis methods used for drinking water compliance.

---

[1] In 1990 dollars.

[2] In year 2003 dollars.

[3] In year 2003 dollars.

[4] In 71 FR 388, EPA acknowledges that causality has not yet been established between chlorinated water and bladder cancer and that the actual number of cases attributable to disinfection byproducts could be zero. Therefore, the actual number of cases avoided and associated economic value could be as low as zero.

[5] In late 1990s dollars.

- The ETV-verified UV disinfection technologies would result in the capacity to recycle up to 140 million gallons of water per day, with associated human health, environmental, and economic benefits, assuming 25% market penetration in Florida and California alone.

2.

Air and Energy Technology Case Studies

2.1

Baghouse Filtration Products

The ETV Air Pollution Control Technology (APCT) Center, operated by RTI International (RTI) under a cooperative agreement with EPA's National Risk Management Research Laboratory, has verified the performance of 16 technologies for reducing emissions of fine particulate matter ($PM_{2.5}$), and has an additional verification in progress. These technologies use fabric filters to remove particulate matter (PM) from stationary emission sources. Fabric filters, or baghouses, are widely used for controlling PM from a variety of industrial sources such as utility and industrial boilers, metals and mineral processing facilities, and grain milling (U.S. EPA, 2003d, 2003k, 2003l). ETS, RTI's subcontractor during the verifications, estimates that there are more than 100,000 baghouses in the United States, of which 10,000 are medium to large (McKenna, 2006).[6] $PM_{2.5}$ contributes to serious public health problems in the U.S., including premature mortality and respiratory problems, and has other environmental impacts, including reduced visibility. To help address the public health effects of $PM_{2.5}$, EPA has established National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$. In April 2005, EPA identified that there were 39 areas of the country that exceed the current NAAQS for $PM_{2.5}$. These areas are required to meet the NAAQS for $PM_{2.5}$ by no later than April 2010, although EPA can grant extensions to this date of up to five years in certain cases. States are required to prepare State Implementation Plans (SIPs) by April 2008 to describe how these areas will meet the standards (U.S. EPA, 2006b; 70 FR 65984).

Verification has increased awareness of technologies that could be used to reduce $PM_{2.5}$ at the state, local, and user level, with the following benefits:

- California has adopted a rule (Rule 1156) that provides incentives for cement manufacturing facilities to use the ETV-verified baghouse fabrics to control particulate emissions. By reducing the required compliance testing frequency from annually to every five years, this rule can provide a significant cost savings to users of the verified technologies. EPA's Office of Air Quality Planning and Standards (OAQPS) is preparing a memorandum to encourage EPA regional offices and other agencies to use the ETV protocol and to consider adopting similar regulations.
- ASTM International has adopted the ETV baghouse filtration testing protocol as its standard, promoting standardization and consistency in performance evaluation for these technologies. The International Standards Organization (ISO), a worldwide voluntary standards organization, has also proposed the ETV testing protocol as their

---

[6] For purposes of these statistics, ETS considers baghouses of 50,000 to 250,000 acfm to be medium and those above 250,000 acfm to be large.

standard. It is progressing through the ISO adoption and approval process.

- Industry sources suggest that verification data can assist facilities in selecting technologies and state and local agencies in evaluating permit applications. One vendor reports that ETV verification facilitated the permitting process for at least one customer and other vendors report that ETV data have helped them compete in the marketplace. Vendors also have continued to participate in additional rounds of testing to maintain their verified status and verify new products.

Based on the analysis in this case study and 25% market penetration, the ETV Program also estimates that:

- Ninety large facilities (out of 358 large facilities)[7] would apply the ETV-verified baghouse filtration products, reducing $PM_{2.5}$ emissions by a total 7,600 tons per year. This estimate only counts large facilities in 39 areas of the country that exceed the NAAQS for $PM_{2.5}$. The total number of facilities with the potential to apply the technologies, and the associated pollutant reductions, would be much greater.[8]
- The $PM_{2.5}$ reductions at 90 facilities would result in human health and environmental benefits, including up to 68 avoided cases of premature mortality per year, with an economic value of up to $450 million per year.[9]

2.1.1 Environmental, Health, and Regulatory Background

PM is a generic term for a variety of solids or liquid droplets over a wide range of sizes. Two mechanisms account for the presence of atmospheric PM: primary emission and secondary formation. Primary particles are emitted directly into the air as a solid or liquid particle. Secondary particles form in the atmosphere as a result of chemical reactions among precursors such as sulfate, ammonia, and nitrate species. Airborne PM with a nominal aerodynamic diameter of 2.5 micrometers is considered to be fine PM or $PM_{2.5}$ (70 FR 65984). Both primary emission and secondary formation are significant contributors to atmospheric $PM_{2.5}$.

In 2002, U.S. sources emitted an estimated 6.8 million short tons of $PM_{2.5}$. Most of these emissions originated from uncontrolled, fugitive sources such as agriculture, wildfires, and dust. Stationary point sources, however, also contributed a significant portion of total $PM_{2.5}$ emissions. These stationary point sources include stationary non-residential fuel combustion (approximately 900,000 short tons of $PM_{2.5}$), mineral products (approximately 200,000 short tons), and other industrial processes (approximately 200,000 short tons) (U.S. EPA, 2005g). The ETV-verified baghouse technologies can be used for the control of emissions from many of these stationary point sources. Based on data from U.S. EPA (2003d, 2003k, and 2003l), the following industry categories are amenable to baghouse technology for $PM_{2.5}$ control:

- Combustion of coal and wood in electric utility, industrial, and commercial/institutional facilities
- Ferrous and non-ferrous metals processing
- Asphalt manufacturing
- Grain milling
- Mineral products.

These industry categories account for 13% of national $PM_{2.5}$ emissions (see Appendix A).

Atmospheric PM results in detrimental human health and environmental effects. Health effects associated with exposure to elevated $PM_{2.5}$ levels include the following: premature mortality, aggravation of respiratory and cardiovascular disease, lung disease, decreased lung function, asthma attacks, and cardiovascular problems. The elderly, people with heart and lung disease, and children are particularly sensitive to $PM_{2.5}$ (70

---

[7] Large facilities are those that emit more than 100 tons per year of $PM_{2.5}$.

[8] ETV used this conservative estimate of the number of facilities because it includes the facilities most likely to require increased control under the NAAQS for $PM_{2.5}$.

[9] In 1990 dollars.

FR 65984). $PM_{2.5}$ results in visibility impairment associated with regional haze by scattering or absorbing light. Hazardous trace metals such as arsenic, cadmium, nickel, selenium, and zinc from combustion processes tend to concentrate preferentially in the fine PM fractions in primary emission sources. Reductions in $PM_{2.5}$ can have the added benefit of reducing emissions of hazardous metals (70 FR 65984; Mycock et al., 2002).

EPA is responsible under the Clean Air Act for setting NAAQS for pollutants considered harmful to public health and the environment. EPA established the first NAAQS for PM in 1971 and has revised these standards as new scientific information became available. Initially, EPA issued standards for “total suspended particulate.” In 1987, the NAAQS were revised to address PM with a nominal aerodynamic diameter of 10 micrometers (PM_{10}) or less to protect against human health effects from deposition of these smaller particles in the lower respiratory tract. EPA later established NAAQS for $PM_{2.5}$ in 1997 and presently has standards for both PM_{10} and $PM_{2.5}$ (U.S. EPA, 2004b). These standards include an annual average of 15 micrograms per cubic meter (µg/m^3) and a 24-hour standard of 65 µg/m^3. Finally, in January 2006, to further improve public health across the country, EPA proposed to revise the NAAQS for $PM_{2.5}$. The proposed rule would lower the 24-hour standard to 35 µg/m^3,[10] while retaining the annual standard at its current level. The proposal also solicits comment on alternative levels for the standards (71 FR 2620).

In April 2005, EPA identified 39 areas of the country, with a population of 90 million (representing about 30% of the U.S. population), that exceed the current NAAQS for $PM_{2.5}$. These areas are known as “non-attainment” areas. These areas are required to meet the NAAQS for $PM_{2.5}$ by no later than April 2010, although EPA can grant extensions to this date of up to five years in certain cases. States are required to prepare State Implementation Plans (SIPs) by April 2008 to describe how these areas will meet the standards (U.S. EPA, 2006b; 70 FR 65984). In November 2005, EPA issued a proposed rule identifying the requirements that states must meet in preparing these SIPs (70 FR 65984).

> “Baghouses and their accompanying filter media have long been one of the leading particulate control technologies for industrial sources. Increasing emphasis on higher removal efficiencies has helped the baghouse to be continually more competitive when compared to the other generic PM control devices to the point where it is now the control option of choice for most industrial applications. The development of new and improved filter media has further enhanced baghouse capability to control fine PM over an expanded range of industrial applications.”
> —ETS and RTI, 2001e

2.1.2 Technology Description

Fabric filter, or baghouse, technology has long been used for controlling particulate emissions from industrial stationary sources. Baghouses are capable of reducing emissions of various particulate sizes (e.g., total PM, PM_{10}, $PM_{2.5}$), as well as hazardous air pollutants present in particulate form. There are two principal types of baghouses, pulse jet and reverse air. In a typical pulse jet baghouse application, flue gas passes through a fabric where particulate is retained as a result of sieving and other mechanisms. Fabric is typically in the shape of a cylindrical bag, with gas flowing from the outside to the inside prior to being emitted to the atmosphere. As particles build up, the differential pressure (pressure drop) increases. Periodically, the particulate material is removed from the filter using techniques such as rapid pulse cleaning, where a pulse of compressed air is forced through the filter from the clean gas side to dislodge the dust (U.S. EPA, 2003d). A reverse air baghouse is similar except gas flows from the inside to the outside of the bag and the direction of airflow is reversed to clean the bags (U.S. EPA, 2003k).

The ETV Program has verified the performance of 16 baghouse filtration products designed primarily to reduce $PM_{2.5}$ emissions,

---

[10] The annual standard is based on the three-year average of annual mean $PM_{2.5}$ concentrations. The 24-hour standard is based on the three-year average of the 98th percentile of 24-hour $PM_{2.5}$ concentrations.

Installing a fabric swatch in the test apparatus

and has an additional verification in progress. All of the verified products are commercial fabrics used in baghouse emission control devices. The verification reports (ETS and RTI, 2000a, 2000b, 2000c, 2000d, 2000e, 2000f, 2000g, 2000h, 2000i, 2001a, 2001b, 2001c, 2001d, 2002, 2005, 2006) can be found at *http://www.epa.gov/etv/verifications/vcenter5-2.html*. Due to the evolving nature of these products and their markets, the baghouse filtration products verification statements are valid for three years from the date of verification. Exhibit 2.1-1 identifies the verified technologies.

During verification testing, each baghouse filtration product underwent the following:

- A conditioning period of 10,000 rapid pulse cleaning cycles
- A recovery period of 30 normal filtration cycles
- A six-hour performance test period.

During all three periods, the products were subjected to a continuous and constant

Exhibit 2.1–1

ETV-Verified Baghouse Filtration Products

Technology Name	Verification Date	Description
Air Purator Corporation, Huyglas® 1405M	September 2000	An expanded polytetrafluoroethylene film applied to a glass felt for use in hot-gas filtration.
Albany International Corporation, Primatex™ Plus I	September 2000	A polyethylene terephthalate filtration fabric with a fine fibrous surface layer.
BASF Corporation, AX/BA-14/9-SAXP® 1405M	September 2000	A Basofil filter media
BHA Group, Inc. QG061®	September 2000	A woven-glass-base fabric with an expanded, microporous polytetrafluoroethylene membrane, thermally laminated to the filtration/dust-cake surface
BHA Group, Inc. QP131®	September 2001	A polyester needlefelt substrate with an expanded, microporous polytetrafluoroethylene membrane, thermally laminated to the filtration/dust-cake surface
BWF America, Inc. Grade 700 MPS Polyester®	June 2002	A micro-pore-size, high-efficiency, scrim-supported felt fabric
BWF America, Inc. Grade 700 MPS Polyester® Felt	September 2005	A micro-pore-size, high-efficiency, scrim-supported felt fabric
Inspec Fibres 5512BRF®	September 2000	A scrim-supported needlefelt.
Menardi-Criswell 50-504®	September 2000	A singed microdenier polyester felt
Polymer Group, Inc. DURAPEX™ PET	September 2001	A non-scrim-supported 100% polyester, non-woven fabric
Standard Filter Corporation Capture® PE16ZU®	September 2000	A stratified microdenier polyester non-woven product
Tetratec PTFE Technologies Tetratex® 8005	September 2000	A polyester scrim-supported needlefelt with an expanded polytetrafluoroethylene membrane
Tetratec PTFE Technologies Tetratex® 6212	September 2001	A polyester needlefelt with an expanded polytetrafluoroethylene membrane
W.L. Gore & Associates, Inc. L4347®	September 2000	An expanded polytetrafluoroethylene membrane/polyester felt laminate
W.L. Gore & Associates, Inc. L4427®	September 2001	A membrane/polyester felt laminate
W.L. Gore & Associates, Inc. L3560®	July 2006	A membrane/fiberglass fabric laminate

Sources: ETS and RTI, 2000a, 2000b, 2000c, 2000d, 2000e, 2000f, 2000g, 2000h, 2000i, 2001a, 2001b, 2001c, 2001d, 2002, 2005, 2006.

dust loading. The performance parameters verified included the following: filter outlet $PM_{2.5}$ concentration, filter outlet total mass concentration, pressure drop, filtration cycle time, and mass gain on the filter fabric.

Exhibit 2.1-2 summarizes some of the performance data for the individual baghouse filtration products. Because the ETV Program does not compare technologies, the performance results shown in Exhibit 2.1-2 do not identify the vendor associated with each result and are not in the same order as the list of technologies in Exhibit 2.1-1. The ETV Program found that the baghouse filtration products resulted in outlet $PM_{2.5}$ concentrations of less than $2x10^{-6}$ to $38x10^{-5}$ grams per dry standard cubic meter (g/dscm), and total particulate concentrations of less than $2x10^{-6}$ to $42x10^{-5}$ g/dscm. The residual pressure drop ranged from 2.45 to 15.0 centimeters water gauge (cm w.g.), and residual pressure drop increase ranged from 0.18 to 7.84 cm w.g.

UNDERSTANDING RESIDUAL PRESSURE DROP AND RESIDUAL PRESSURE DROP INCREASE

The process of cleaning the bags in a baghouse is cyclic and involves a periodic pulse of compressed air to remove dust collected on the bags. The "residual pressure drop" is the pressure drop measured across the bag fabric just after the bag cleaning and is the result of the resistance to flow created by the fabric and any remaining dust on the fabric. After cleaning, the pressure drop across the fabric increases to a predetermined value as dust is removed from the dirty gas stream and collects on the fabric surface. This predetermined value is the "residual pressure drop increase." At this point the bags are cleaned again and the cycle is completed. The residual pressure drop and the amount the pressure increases during a cleaning cycle are important parameters for the user of the verification data to understand the context of the emissions performance results. (Trenholm and McKenna, 2006)

EXHIBIT 2.1–2

PERFORMANCE OF ETV-VERIFIED BAGHOUSE FILTRATION PRODUCTS[11]

Technology	Outlet Particle Concentration (g/dscm x 10-6)		Residual Pressure Drop,(cm w.g.)	Residual Pressure Drop Increase (cm w.g.)
	$PM_{2.5}$	Total Mass		
		Membrane Fabrics		
A	50	120	8.46	1.16
B	5.1	23.2	7.38	0.79
C	13	22	4.92	0.42
D	4.7	11.5	5.83	0.41
E	15	23	9.36	1.22
F	2	2	6.2	0.56
G	6.8	38	6.21	0.44
H	<2	<2	2.45	0.18
		Non-membrane Fabrics		
I	32	68	6.98	1.72
J	19	70	15.0	7.84
K	42.3	67.6	13.3	5.25
L	9.4	19	14.6	6.03
M	270	270	10.5	4.32
N	10.4	16.1	6.75	1.11
O	380	420	11.8	5.1
P	19.8	19.8	4.1	0.34

Values rounded to three or fewer significant figures.
Sources: ETS and RTI, 2000a, 2000b, 2000c, 2000d, 2000e, 2000f, 2000g, 2000h, 2000i, 2001a, 2001b, 2001c, 2001d, 2002, 2005, 2006.

---

[11] Because the ETV Program does not compare technologies, the performance results shown in Exhibit 2.1-2 do not identify the vendor associated with each result and are not in the same order as the list of technologies in Exhibit 2.1-1.

2.1.3 Outcomes

ETS, RTI's subcontractor during the verifications, estimates that there are more than 100,000 baghouses in the United States, of which 10,000 are medium to large (McKenna, 2006).[12] For this analysis, however, ETV has limited its estimate of the market for the ETV-verified baghouse filtration products to large stationary sources located in areas of the country that exceed the NAAQS for $PM_{2.5}$ (i.e., non-attainment areas). Accordingly, the ETV Program used data from a technical background document for EPA's proposed rule outlining SIP requirements for $PM_{2.5}$ (U.S. EPA, 2005h) to estimate the potential market for the verified filtration products. This document estimated that there were 358 facilities that each emit more than 100 tons per year of $PM_{2.5}$ located in non-attainment areas.

As discussed below under "Technology Acceptance and Use Outcomes," there is a robust market for baghouse filtration products. Because the ETV Program does not have access to a comprehensive set of sales data for the ETV-verified technologies, the ETV Program used a conservative market estimate and two market penetration scenarios, 10% and 25% of the potential market, to estimate pollutant reduction outcomes. Exhibit 2.1-3 lists the estimated number of facilities that would apply the ETV-verified technologies based on these market penetration scenarios. Because this analysis only considers large facilities located in non-attainment areas, the number of facilities with the potential to apply the technologies is much larger. Specifically, the estimates do not include smaller facilities, facilities in areas that meet the NAAQS, or new facilities that could apply the ETV-verified technologies. The estimates also do not include facilities that would require additional control if EPA's proposed revisions to the NAAQS (71 FR 2620) are finalized.

EXHIBIT 2.1–3

PROJECTED NUMBER OF LARGE FACILITIES IN NON-ATTAINMENT AREAS THAT WOULD APPLY ETV-VERIFIED BAGHOUSE FILTRATION PRODUCTS

Market Penetration	Number of Facilities
10%	36
25%	90

Pollutant Reduction Outcomes

U.S. EPA (2005h) estimated that the 358 facilities included in ETV's market estimate emitted 381,400 tons of $PM_{2.5}$ in 2001. Pollutant reductions from the application of baghouse technologies vary based on a number of factors, including gas velocity, particle concentration, particle characteristics, and cleaning mechanism. Design efficiencies for new baghouse devices are between 99% and 99.9%, whereas older models have actual operating efficiencies between 95% and 99.9% (U.S. EPA, 2003d, 2003k, 2003l). Also, although removal efficiency was not a parameter in the verification tests, data in the verification reports indicate that the ETV-verified technologies removed greater than 99.99% of $PM_{2.5}$ under the test conditions. The ETV results accurately reflect $PM_{2.5}$ penetration of the media, but overall baghouse efficiencies are a function of both media penetration and leaks through components of the baghouse other than the bags. According to an EPA OAQPS expert, however, it is possible that ETV-verified filtration products would cause fewer bag malfunctions and remove more $PM_{2.5}$ over a longer period of time than conventional products (Bosch, 2006).

Exhibit 2.1-4 shows estimated $PM_{2.5}$ reductions from application of the ETV-verified technologies at large facilities in non-attainment areas and two market penetration scenarios, 10% and 25%. To estimate these reductions, ETV used data from U.S. EPA (2005g, 1999b,

EXHIBIT 2.1–4

ESTIMATED POLLUTANT REDUCTIONS AT LARGE FACILITIES IN NON-ATTAINMENT AREAS FROM ETV-VERIFIED BAGHOUSE FILTRATION PRODUCTS

Market Penetration	Annual $PM_{2.5}$ Reduction (tons per year)
10%	3,000
25%	7,600

Values rounded to two significant figures

---

[12] For purposes of these statistics, ETS considers baghouses of 50,000 to 250,000 acfm to be medium and those above 250,000 acfm to be large.

and 1993) to estimate that baghouse technologies account for approximately 8% of total nationwide $PM_{2.5}$ emissions from point sources and applied this percentage to the 381,400 tons emitted by large facilities in non-attainment areas. ETV then assumed that these facilities have existing baghouses with a removal efficiency of 95% and that applying ETV-verified filtration products would increase their efficiency to 99.9%. There is substantial uncertainty involved in applying these assumptions, because data are not available to estimate overall baghouse removal efficiency using the ETV-verified filtration products or the efficiency of existing baghouses at the selected facilities. The resulting estimates likely are conservative (low) because some of the facilities might not have existing controls in place. They also do not account for additional reductions that would occur if EPA's proposed revisions to the NAAQS (71 FR 2620) are finalized. Finally, with approximately 100,000 baghouses in the United States, the total number of facilities with the potential to apply the technologies is much larger. Using the same assumptions and national emissions data from U.S. EPA (2005g), ETV estimates that pollutant reductions could be up to 43,000 tons per year at 25% market penetration if the ETV-verified filtration products were applied nationwide. Appendix A describes the methods and assumptions used in these estimates in greater detail.

Human Health and Environmental Outcomes

Based on data from EPA's Regulatory Impact Analysis (RIA) for the 1997 NAAQS (U.S. EPA, 1997b), the ETV Program estimated the human health outcomes that would be associated with the $PM_{2.5}$ reductions shown in Exhibit 2.1-4. Appendix A describes the methods and assumptions used in these estimates in greater detail, but the estimates assume a straight-line relationship between pollutant reductions and reductions in health effects estimated in the RIA. This assumption is most likely a simplification of the actual relationship between these two factors for a number of reasons discussed in Appendix A.

Exhibit 2.1-5 shows the estimated human health outcomes based on the methods described in Appendix A. These outcomes include avoided cases of premature mortality, acute and chronic illnesses, hospital visits, and lost work days. Exhibit 2.1-5 includes upper- and lower-bound estimates because the RIA presents both upper- and lower-bound data. The estimates likely are conservative (low) because they are based on the conservative estimates of pollutant reductions, which only account for pollutant reductions at large facilities in non-attainment areas. ETV estimates that the number of premature deaths avoided would be up to 380 per year in the upper bound at 25% market penetration if the ETV-verified filtration products were applied nationwide.

In addition to the benefits shown in Exhibit 2.1-5, there are other, unquantified health

Exhibit 2.1–5

ESTIMATED HUMAN HEALTH OUTCOMES FROM ETV-VERIFIED BAGHOUSE FILTRATION PRODUCTS AT LARGE FACILITIES IN NON-ATTAINMENT AREAS

$PM_{2.5}$-Related Outcomes Per Year	Market Penetration	
	10%	25%
Upper Bound		
Premature Deaths	11	68
Chronic Bronchitis	52	330
Hospital Admissions—all respiratory (all ages)	4.0	25
Hospital Admissions—congestive heart failure	1.5	9.1
Hospital Admissions—ischemic heart disease	1.7	10
Acute Bronchitis	14	87
Lower Respiratory Symptoms	210	1,300
Upper Respiratory Symptoms	42	260
Work Loss Days	2,200	14,000
Minor Restricted Activity Days	18,000	110,000
Lower Bound		
Premature Deaths	2.3	14
Chronic Bronchitis	31	200
Hospital Admissions—all respiratory (all ages)	2.5	16
Hospital Admissions—congestive heart failure	0.8	5.2
Hospital Admissions—ischemic heart disease	0.8	5.2
Acute Bronchitis	8.4	52
Lower Respiratory Symptoms	120	780
Upper Respiratory Symptoms	25	160
Work Loss Days	1,300	8,300
Minor Restricted Activity Days	11,000	68,000

Values rounded to two significant figures

> "[The NAAQS for $PM_{2.5}$] means that owners/operators of new or existing baghouses will have to consider fine particulate removal effectiveness when making decisions on purchasing filter media. Credible information on the performance of filter media, at reasonable cost, will assist them in their selection process. Such information will also provide valuable guidance for consultants and state and local agencies reviewing baghouse permit applications."
> —ETS and RTI, 2001e

benefits associated with reductions in $PM_{2.5}$, including avoided changes in pulmonary function, morphological changes, altered host defense mechanisms, cases of cancer, cases of other chronic respiratory diseases, and cases of infant mortality (U.S. EPA, 1997b). $PM_{2.5}$ reductions can also result in nonhealth-related environmental benefits, including improved visibility and avoided damage to materials and ecosystems. The ETV Program's estimates under "Economic and Financial Outcomes," below, include visibility benefits and consumer cleaning cost savings, which are the avoided costs of cleaning households that would otherwise be soiled by $PM_{2.5}$ and represent part of the value of avoided damage to materials.

Regulatory Compliance Outcomes

As discussed in Section 2.2.1, EPA has identified 39 areas of the country, with a total population of 90 million, that exceed the NAAQS for $PM_{2.5}$. Although controls on other pollutants, such as those required under the 2005 Clean Air Interstate Rule, will help some areas meet the $PM_{2.5}$ standards, EPA anticipates that many states will require emission controls on large stationary sources of $PM_{2.5}$ (70 FR 65984). The ETV-verified baghouse filtration products can be used to meet these requirements. In addition, the verification data can assist facilities and state and local agencies in evaluating the technologies' effectiveness for meeting these requirements (see quote at top left). The availability of ETV data also has facilitated the permitting process for users (see quote at bottom left).

> "At least one customer ... made his work with permitting easier by running our materials through the ETV testing process ..."
> —Clint Scoble, BWF America (Scoble, 2006)

ETV also supports state and local air pollution rules. On November 4, 2005, the California South Coast Air Quality Management District (SCAQMD) adopted Rule 1156, which encourages the use of ETV-verified baghouse fabrics to control particulate emissions from cement manufacturing facilities. Paragraph (e)(7) of the rule allows facilities that use ETV-verified products in their baghouses to reduce the frequency of compliance testing from annually to every five years (SCAQMD, 2005; Pham, 2006). EPA's OAQPS plans to issue a memorandum to EPA regional air divisions (see quote top of next page) that:

- Outlines the advantages of the ETV and ASTM protocols for baghouse filtration products
- Indicates that EPA will consider ETV protocols in future federal regulations wherever appropriate
- Requests that regional offices encourage and aid state and local pollution control agencies to use the ETV protocol
- Encourages the adoption of rules similar to that issued by SCAQMD (Bosch, 2006).

Economic and Financial Outcomes

In addition to personal and societal impacts, the human health outcomes discussed above also have an economic benefit. The ETV Program estimated the nationwide economic benefits associated with the human health outcomes shown in Exhibit 2.1-5 based on the upper- and lower-bound economic estimates provided in the RIA for the 1997 NAAQS (U.S. EPA, 1997b). Based on the same data, ETV also included benefits associated with visibility improvements and consumer cleaning cost savings.

Exhibit 2.1-6 presents the economic estimates.[13] Appendix A presents the assumptions

---

[13] These estimates are subject to the same limitations discussed for the human health outcomes. However, they likely are conservative (low), as discussed in Appendix A. For example, they are in 1990 dollars.

EXHIBIT 2.1–6

ESTIMATED ECONOMIC BENEFITS FROM ETV-VERIFIED BAGHOUSE FILTRATION PRODUCTS AT LARGE FACILITIES IN NON-ATTAINMENT AREAS

	Million dollars per years	
Market Penetration	**Lower Bound**	**Upper Bound**
10%	13	72
25%	81	450

Values rounded to two significant figures

used in this analysis in greater detail. As for human health outcomes, these economic estimates likely are conservative (low) because they only account for pollutant reductions at large facilities in non-attainment areas. ETV estimates that the economic benefits would be up to $2.5 billion per year in the upper bound at 25% market penetration if the ETV-verified filtration products were applied nationwide. Additional economic benefits could result from the prevention of other human health and environmental outcomes discussed above.

In addition, rules like SCAQMD's Rule 1156 could have significant financial benefits for users of the verified products. Reducing compliance tests from annual to every five years could save each user $5,000 per avoided compliance test, or $20,000 per five year cycle (Bosch, 2006). Also, as discussed in "Technology Acceptance and Use Outcomes," filters that produce lower pressure drops could reduce facility operating costs for the user.

Scientific Advancement Outcomes

The development of the ETV protocol for baghouse filtration products has promoted standardization and consistency in performance evaluation. The ETV protocol has been adopted as ASTM D6830 "Characterizing the Pressure Drop and Filtration Performance of Cleanable Filter Media" (U.S. EPA, 2004a). ISO, a worldwide voluntary standards organization, also has proposed the ETV testing protocol as their standard and it is progressing through the ISO adoption/approval process.

In addition, the development of the protocol and publication of verification results has provided and will continue to provide valuable scientific information to facilities, vendors, and state and local agencies (see quote below). For example, over the last three years the ASTM method has been used for over 100 tests. These tests have been used to screen media during early stage development of new media and as a quality control test for commercial lots of fabric (McKenna, 2006).

> "We plan to . . . issue a memorandum from Steve Page, our OAQPS Director, to all EPA Regional Offices and State Directors which endorses the use of verified baghouse filter-media and encourages its future use in both permits and in new/revised regulations wherever appropriate."
>
> "Other air pollution monitoring and control technologies have also been verified by ETV and we hope to soon expand their applicability and use by permitting authorities and regulators nationwide."—John Bosch, EPA OAQPS (Bosch, 2006)

Technology Acceptance and Use Outcomes

In 2005, fabric filter industry sales to one industry sector, the U.S. power plant industry, were expected to be $630 million. Vendors have found the ETV data useful in competing in this robust

> "Industry, vendors, new technology developers, state regulators, and environmentalists … all worked together to generate the protocols …. It benefited industry, because it reduced the risk for applications of technology. They were able to see real results, not vendor projected results—results that were tested to minimize the risk and allow them to move forward at a much more rapid pace. It benefited the developers by promoting technology acceptance. The education process and the balanced protocol development gave them a truly beneficial test to determine what their technology could or could not do. It benefited the state regulators because the testing provided data on performance, applications, and operation and maintenance. It made it a little easier to obtain permits."—Robert Bessette, President of the Council of Industrial Boiler Owners (U.S. EPA, 2004a)

> "Gore successfully used the program to win business in the marketplace. Customers greatly appreciate the credible and high quality data from U.S. EPA."—Wilson Poon, W.L. Gore and Associates (Poon, 2002)

market (see quote next page). For example, ETV verification results contributed to purchasing decisions in the following two instances:

- A steel producer used the ETV verification test data in replacing its 2,000 fabric filter bags used for reducing its electric arc furnace emissions. The facility used the ETV data in selecting a verified fabric filter that would provide a lower pressure drop, resulting in a lower operating cost.
- An electrical power generator used the ETV verification test data in replacing its 9,000 fabric filter bags. The facility used the ETV data to identify differences in performance, in particular pressure drop, associated with candidate technologies, and ultimately selected an ETV-verified technology based on the verification data (Mycock et al., 2002).

Also, some of the vendors participating in the program have submitted materials for multiple rounds of testing, for example, upon development of a new product. In one case, a vendor "re-verified" the same product after the initial verification expired.[14] The continuing participation of the vendors suggests that they are benefiting from the program.

ACRONYMS USED IN THIS CASE STUDY:

acfm	actual cubic feet per minute	PM	particulate matter
APCT	ETV's Air Pollution Control Technology Center	PM_{10}	fine PM with a nominal aerodynamic diameter of 10 micrometers or less
cm w.g.	centimeters water gauge	$PM_{2.5}$	fine PM with a nominal aerodynamic diameter of 2.5 micrometers or less
g/dscm	grams per dry standard cubic meter	RIA	Regulatory Impact Analysis
ISO	International Standards Organization	SCAQMD	South Coast Air Quality Management District
NAAQS	National Ambient Air Quality Standards	SIP	State Implementation Plan
OAQPS	EPA's Office of Air Quality Planning and Standards	$\mu g/m^3$	micrograms per cubic meter

---

[14] The baghouse filtration products verification statements are valid for three years from the date of verification.

2.2

Continuous Emission Monitors (CEMs) for Mercury

The ETV Program's Advanced Monitoring Systems (AMS) Center, operated by Battelle under a cooperative agreement with EPA, has verified the performance of seven continuous emission monitors (CEMs) for measuring mercury emissions. Mercury is a toxic, persistent pollutant that, after deposition from the atmosphere, accumulates in the food chain, particularly in fish. Mercury can cause adverse neurological health effects, particularly in the unborn children of mothers who eat food with significant mercury accumulation. To help address the health effects of mercury, EPA recently issued the Clean Air Mercury Rule (CAMR). This rule requires coal-fired power plants, the largest source of human-generated mercury emissions in the U.S., to reduce mercury emissions. The rule also will require power plants to monitor their emissions using technologies like those verified by the ETV Program.

Based on the analysis in this case study, ETV verification of mercury CEMs has:

- Contributed to advancing mercury monitoring technology and resulted in improvements in monitors by the participating vendors
- Helped inform the development of the CAMR and could assist in future rule refinements
- Helped small vendors compete in the marketplace
- Involved significant collaboration with state agencies (e.g., Massachusetts) and other federal agencies (e.g., the Department of Energy). This collaboration resulted in the sharing of scientific expertise among the agencies and enabled smaller vendors to participate in the tests.

The ETV Program also projects the following benefits:

- ETV-verified mercury CEMs or monitors improved as a result of testing could be applied at the approximately 340 utilities that EPA estimates would use CEMs to meet monitoring requirements under the CAMR.
- The verified monitors could be applied at other facilities (e.g., incinerators), by state agencies, or in research efforts addressing mercury chemistry or control.
- The information provided by the verified monitors will ultimately assist in achieving mercury emissions reductions, with associated human health, environmental, and economic benefits.

2.2.1 Environmental, Health, and Regulatory Background

EPA estimates that total annual global mercury emissions, including both natural and human-generated, range from roughly 4,400 to 7,500 tons per year. Human-generated emissions in the U.S. account for about 3% of this total (U.S. EPA, 2005e). Coal-fired power plants are the largest source of human-generated mercury emissions in the U.S., accounting for about 40% of nationwide emissions in 2003 (U.S. EPA, 2005e; 2005f).

Mercury is "a toxic, persistent pollutant that accumulates in the food chain." (U.S. EPA, 2005e) Although concentrations in the air usually are low (i.e., a few nanograms per cubic meter), mercury reacts slowly in the atmosphere and can be transported thousands of miles before it is deposited to water or soil. When atmospheric mercury reaches rivers, lakes, and estuaries, it can be transformed into methyl mercury, a highly toxic form that accumulates in fish tissue. Consumption of fish that have accumulated mercury is the primary route of human exposure to methyl mercury and represents a particular concern for women of childbearing age. Developing fetuses are sensitive to the toxic effects of methyl mercury, and children exposed to methyl mercury before birth can be at increased risk for adverse neurobehavioral effects, such as poor performance on tasks that measure attention, fine motor function, language skills, visual-spatial abilities and verbal memory (U.S. EPA, 2005e; Battelle, 2004a). Consumption of fish or other food containing high levels of mercury can also pose a risk to adults, with effects including failure of muscle control, blurred vision, slurred speech, hearing difficulties, blindness, deafness, and death (U.S. EPA, 2005f).

To help address the risks associated with mercury emissions from coal-fired power plants, EPA issued the CAMR on March 18, 2005. The CAMR limits mercury emissions from new and existing coal-fired power plants and creates a market-based cap-and-trade program that will reduce nationwide utility emissions of mercury. Under a cap-and-trade program, coal-fired power plants that reduce emissions more than required receive allowances. They can then trade these allowances to sources that are unable to meet the requirement, or bank them for future use. This approach represents an economically more efficient method for reducing total emissions than a traditional technology standard and emissions limit. The ability to trade creates financial incentives for sources to use innovative, low-cost methods to reduce emissions and improve the performance of emission control equipment. The ability to bank allowances for future use also can result in early reductions of mercury (U.S. EPA, 2005e).

A cap-and-trade program, like that under the CAMR, must include stringent monitoring of emissions to ensure that reductions occur, allow for tracking progress, and lend credibility to the trading component of the program. Therefore, the CAMR requires coal-fired utilities that emit more than 29 pounds of mercury per year to collect mercury emission data continuously. To collect this data, the utilities can use either CEMs like those verified by the ETV Program or another long-term mercury sampling method, a sorbent trap monitoring approach. The CAMR sets performance requirements for these monitoring technologies, including standards for monitoring total mercury with CEMs (70 FR 28606). These requirements include the following:

- Initial and daily calibration error tests with a performance specification of 5.0% of span for the initial daily test with an alternate specification for span values of 10 micrograms per standard cubic meter (µg/scm) of an absolute difference less than or equal to 1.0 µg/scm
- Initial and quarterly 3-point linearity tests with a performance specification of 10% of the reference concentration with an alternate specification for span values of 10 µg/scm of an absolute difference less than or equal to 1.0 µg/scm
- An initial cycle time test with a maximum of a 15-minute cycle time
- Initial and annual relative accuracy test audits with a requirement to achieve a relative accuracy of 20.0% or less with an alternate specification for stack concentrations less than 5.0 µg/scm of an absolute difference less than or equal to 1.0 µg/scm
- An initial bias test
- Initial and weekly system integrity tests with a performance specification of 5.0% of span.

2.2.2 Technology Description

CEMs for mercury are a relatively new technology category. They offer an advantage over conventional laboratory techniques (e.g., the Ontario Hydro or "OH" method) in that they can provide real-time or near real-time monitoring results. Because they provide continuous results or frequent results through sequential readings at intervals of several minutes, they avoid the delay, labor, and cost associated with laboratory methods.

Typically, CEMs determine elemental mercury vapor by atomic absorption (AA), atomic fluorescence (AF), or plasma atomic emission (AE). CEMs also use aqueous reagents or heated catalysts to reduce oxidized forms of mercury to elemental mercury for detection, allowing measurement of total mercury. Although some CEMs measure total mercury only, others allow separate measurement of the elemental and oxidized forms (Battelle, 2004a).

The seven CEMs for mercury that have been verified to date by the ETV Program include examples of each of these detection and reduction approaches, some reporting on a continuous basis and some on a semi-continuous basis. Exhibit 2.2-1 identifies the ETV-verified monitors and provides a description of each. The verification reports (Battelle, 2001a, 2001b, 2001c, 2001d, 2003a, 2003b, 2003c, 2003d, 2003e) can be found at *http://www.epa.gov/etv/verifications/vcenter1-11.html.*

Verification testing was conducted in two rounds. In the first round, four of the technologies were tested under conditions simulating (a) coal-fired flue gas and (b) municipal incinerator flue gas. The tests took place at a pilot-scale incinerator in Research Triangle Park, North Carolina, over a three-week period. In the second round, five technologies (including two of the technologies tested in the first phase) were evaluated at a full-scale waste incinerator in Oak Ridge, Tennessee. The testing took place over several weeks of continuous operation. In addition, the ETV Program is currently conducting a third round of testing at a coal-fired power plant (the box next page identifies CEM and sorbent-based sampling technologies included in this third round).

In each round of verification testing, the Ontario Hydro (OH) method was used as the reference method for establishing the performance of the tested technologies. The performance parameters verified included the following: accuracy relative to the OH method, correlation

Exhibit 2.2–1

ETV-Verified CEMs for Mercury (First Two Rounds of Testing)

Technology	Description
Envimetrics, Argus-Hg 1000 Mercury CEM	Uses AE spectroscopy with a proprietary catalytic converter that reduces molecular forms of mercury to atomic mercury. Total mercury can be measured during automatic operation, or both total and elemental mercury can be measured when manually operated.
Nippon Instruments Corporation, DM-6/DM-6P Mercury CEM	Uses cold vapor AA with a catalytic process to measure total mercury.
Nippon Instruments Corporation, AM-2 Elemental Mercury CEM	Uses cold vapor AA, with a distilled water scrubbing trap for removal of any oxidized mercury species, to measure elemental mercury.
Nippon Instruments Corporation, MS-1/DM-5 Mercury CEM (verified in 2001 and 2003)	Uses cold vapor AA to provide separate and continuous measurements of elemental and oxidized mercury, which are separated using a wet scrubbing and chemical reaction system.
Ohio Lumex, Ltd., Lumex Mercury CEM	Uses cold vapor AA to provide separate and continuous measurements of elemental and total mercury, with catalytic pyrolysis to decompose oxidized mercury to elemental mercury for total mercury measurement.
OPSIS AB, HG-200 Mercury CEM	Uses a double-beam photometer to measure total or elemental mercury, with a thermo-catalytic converter that forms elemental mercury from any oxidized mercury compounds to measure total mercury.
PS Analytical, Ltd., Sir Galahad II Mercury CEM (verified in 2001 and 2003)	Uses AF to provide separate and continuous measurement of elemental and total mercury, with a proprietary aqueous reagent to convert oxidized mercury to elemental mercury for total mercury measurement.

Sources: Battelle, 2001a, 2001b, 2001c, 2001d, 2003a, 2003b, 2003c, 2003d, 2003e.

with that method, precision (i.e. repeatability), bias, calibration/zero drift, response time, interferences, data completeness, and other operational factors.

MERCURY MONITORING TECHNOLOGIES INCLUDED IN THE THIRD ROUND OF ETV VERIFICATION

- Tekran Instruments, mercury CEM
- Thermo, mercury CEM
- Environmental Supply Company, mercury sorbent trap
- Apex Instruments, mercury sorbent trap

Exhibit 2.2-2 summarizes some of the performance data for the verified technologies. Because the ETV Program does not compare technologies, the performance results shown in Exhibit 2.2-2 do not identify the vendor associated with each result and are *not* in the same order as the list of technologies in Exhibit 2.2-1.

The ETV Program found that the average relative accuracy for the monitors ranged from 11.2% to 76.5%. A result of 0% indicates perfect accuracy relative to the reference mercury concentration. The relative precision ranged from 1.8% to 43.3%. A result of 0% indicates perfect precision. With one exception, monitor bias ranged from –7% to 14.6%. The response times,

EXHIBIT 2.2–2

PERFORMANCE OF ETV-VERIFIED CEMS FOR MERCURY[15]

Technology	Average Relative Accuracy	Relative Precision	Response Time (95%)	Bias	Correlation (slope, intercept, r^2) (1)	Data Completeness
First Round						
A	58.2 to 71% (total mercury)	2.5 to 27%	30 to 100 seconds	-44.5 to -20.5%	Slope: not reported Intercept: not reported r^2: 0.621	Not estimated
B	14 to 23% (elemental mercury)	3 to 40.3%	One 13-minute cycle	07%	Slope: 0.885 Intercept: -0.212 r^2: 0.973	100%
C-Phase I	20.6 to 32.8% (total mercury)	1.8 to 24.7%	One 5- to 6-minute cycle	-4.9 to -0.3%	Slope: 0.681 Intercept: 2.492 r^2: 0.978	100%
D-Phase I	13.2 to 39.1% (total mercury)	3.7 to 23.9%	35 to 50 seconds	-7%	Slope: 0.607 Intercept: 3.92 r^2: 0.938	100%
Second Round						
C-Phase II	59.8% (total mercury)	8.9 to 15.9%	One 5- to 6-minute cycle	2.8 to 6.9%	Slope: 0.4973 Intercept: 6.8904 r^2: 0.875	88.3%
D-Phase II	11.2% (total mercury)	9.2 to 17.3%	2 to 3 minutes	0.0 to 6.6%	Slope: 0.899 Intercept: 2.4969 r^2: 0.987	97.7%
E	76.5% (overall)	10.1 to 22.1%	One 7-minute cycle	0.3 to 14.6%	Slope: 0.3404 Intercept: 9.4121 r^2: 0.8393	92.7%
F	20.3% (overall)	9.1 to 10.9%	2 minutes	0.0 to 13.6%	Slope: 0.8347 Intercept: 3.5033 r^2: 0.953	97.5%
G	76.3% (overall)	12.5 to 43.3%	One 5-minute cycle	Not evaluated	Slope: 0.3559 Intercept: 8.1695 r^2: 0.935	65.8%

(1) Correlation data shown are for total mercury, except technology B, where results shown are for elemental mercury.

Sources: Battelle, 2001a, 2001b, 2001c, 2001d, 2003a, 2003b, 2003c, 2003d, 2003e.

---

[15] Because the ETV Program does not compare technologies, the performance results shown in Exhibit 2.2-2 do not identify the vendor associated with each result and are *not* in the same order as the list of technologies in Exhibit 2.2-1.

which measure instrument response to a sudden change in mercury concentration, ranged from 30 seconds to within approximately 13 minutes. The ETV Program used linear regression analysis to evaluate correlation of the monitor results to the OH method results. For total mercury, the slope values ranged from 0.3404 to 0.899; the intercept values ranged from 2.492 to 9.4121 micrograms per dry standard cubic meter; and the r^2 values ranged from 0.621 to 0.987.[16] A higher r^2 value indicates a higher correlation with the standard test method over the range of concentrations tested. The price of the monitors ranged from $30,000 to $70,000 at the time of testing (Battelle, 2001a, 2001b, 2001c, 2001d, 2003a, 2003b, 2003c, 2003d, 2003e).

2.2.3 Outcomes

The market for the ETV-verified CEMs includes coal-fired utilities that must continuously monitor mercury emissions (i.e., those that emit more than 29 pounds of mercury per year) to meet CAMR requirements. Accordingly, the ETV Program used data from a technical background document for the CAMR (U.S. EPA, undated) to estimate this market. This document estimated that 342 of the 685 facilities required to monitor continuously would choose CEMs, as opposed to another technology. The ETV Program used this estimate to represent the potential market for the verified monitors.

Regulatory Compliance Outcomes

As noted in Section 2.2.1, CAMR mandates certain performance testing and standards for CEMs. Although the ETV verification tests and test conditions[17] were not identical to those required by the final rule, nor are the results all in a form directly comparable to those of the rule's performance specification, some comparisons to the CAMR requirements are possible. Firstly, six of the seven ETV-verified CEMs provide total mercury results, as required by the rule. Secondly, the verified CEMs either provide real-time monitoring data or have cycle times of 3 to 13 minutes, which is less than the CAMR maximum 15 minute cycle time. Finally, when tested on simulated coal-fired flue gas, two of the monitors provided relative accuracy for total mercury of 13.2% and 20.6%, respectively, close to or better than the relative accuracy required by the CAMR.

One of the test locations for mercury CEM verification

Since these results meet or very nearly meet the CAMR requirement, it is possible that at least some of the ETV-verified monitors, or similar monitors improved by the vendors as a result of ETV testing, could be used to meet the CAMR monitoring requirements. It also is important to note that the ETV Program is conducting a third round of CEM testing at a coal-fired power plant, under conditions that more closely simulate those experienced when the monitors are used for rule compliance (U.S. EPA, 2004a; Battelle, 2004a). Depending upon how well the monitors perform during this third round, these monitors could also be candidates to meet the CAMR requirements. Therefore, any of the 342 coal-fired utilities discussed above ultimately could use ETV-verified CEMs to comply with the CAMR.[18]

In addition to these facilities, other facilities could use the verified technologies to meet other regulatory requirements. Such facilities include

---

[16] Slope and intercept are measures of the relationship between analyzer response and the reference method value. The degree to which the slope deviates from one and the intercept deviates from zero are indicators of the monitor's accuracy. The r^2 is a measure of how well observed data fit a linear relationship. Values of r^2 range from 0 to 1, with higher values indicating a better fit. Thus, a higher r^2 value indicates a higher correlation with the standard test method over the range of concentrations tested.

[17] Most notably, the monitors were tested on incinerator flue gas and simulated (not actual) coal-fired gas.

[18] U.S. EPA (undated) estimated 342 of 685 utilities would use CEMs, while the rest would use sorbent traps. While all 685 ultimately could use ETV-verified technologies, to be conservative, ETV chose 342 as its estimate of the number of facilities that could use ETV-verified CEMs.

municipal and hazardous waste incinerators that emit mercury. State regulatory agencies also could use the monitors to investigate specific sources. The verification data can assist facilities and state and local agencies in evaluating the technologies' effectiveness in these applications. For example, in issuing a recent permit for a cement facility, the Florida Department of Environmental Protection required the facility to install a mercury CEM. The permit requires that the CEM either meet the state's performance standard or be ETV verified (Florida Department of Environmental Protection, 2006).

Pollutant Reduction, Environmental, Human Health, and Economic Outcomes

As discussed in Section 2.2.1, monitoring data are integral to achieving reductions under a cap-and-trade program like that established under the CAMR. The CAMR, when fully implemented, will reduce utility mercury emissions from 48 tons per year to 15 tons per year (U.S. EPA, 2005e). These reductions would result in human health benefits such as preventing intelligence quotient (IQ) losses in children of people consuming recreationally caught fish. EPA estimated the economic value of avoiding these IQ losses at $200,000 to $3 million per year in 1999 dollars, depending on the assumptions applied and the discount rate. EPA also noted that there would be non-quantifiable benefits that include avoiding adverse cardiovascular and ecosystem effects (70 FR 28606). The use of ETV-verified CEMs ultimately will assist with successful mercury emissions reductions, with significant environmental, human health, and economic benefits.

> "U.S. EPA has organized and conducted test programs for the purposes of evaluating continuous mercury emissions monitoring systems at both a pilot plant level as well as at commercially operating power plants. Since initially participating in the U.S. EPA-ETV Program, Horiba-NIC has been an active participant in these test programs …. Horiba's instrument has benefited from design improvements as a result of each of the testing programs …."—Dean Masropian, Horiba Instruments, Inc. (ICAC, 2005)

Scientific Advancement Outcomes

ETV verification of mercury CEMs has led to improvements in monitoring technology. For example, two vendors (Envimetrics, Inc. and Ohio Lumex) participated in ETV verification with newly developed commercial CEMs, and reported that the field testing had been highly valuable and informative. These and other vendors used the test results to improve their CEMs (see quote below left) (Battelle, 2004a; U.S. EPA, 2004a; ICAC, 2005). For another vendor, the ETV test results contributed to the development of another mercury CEM technology, a system using a dry catalyst to convert oxidized mercury to elemental mercury (Stockwell, 2006).

ETV verification results also contributed to the scientific and technology analyses that EPA performed in support of the CAMR. ETV test results were included in the EPA studies of the state of monitoring technology that informed rule development (U.S. EPA, 2003b; U.S. EPA, 2003c). The State of Massachusetts also used the data from the first two rounds of ETV testing in its evaluation of the feasibility of mercury control. The state concluded that monitors were commercially available and able to meet the desired 20% relative accuracy standard, thus contributing to the overall conclusion that mercury control is feasible and to the state's decision to develop its own mercury standard (Massachusetts, 2002). Massachusetts finalized this standard in 2004, including a requirement that facilities install CEMs by January 1, 2008 (Massachusetts, 2004).

In addition, the final CAMR requires measurement of total vapor phase mercury, but does not require separate monitoring of speciated mercury emissions (i.e., elemental mercury or oxidized mercury). In issuing the rule, however, EPA stated that it is important to understand and monitor the speciation profile of Hg emissions. EPA stated its commitment to test speciated mercury monitoring technologies and, if these technologies are adequately demonstrated, to consider a proposed rulemaking to reflect changes in the monitoring requirements within four to five years after program implementation (70 FR 28606). Because several of the ETV-verified monitors provide speciated mercury data, the ETV verification program will help inform the study associated with this potential regulation.

ETV verification for mercury CEMs has involved significant collaboration with other state and federal agencies, which has helped to improve the technical quality of the tests as well as the utility of the results. For the first round, the Massachusetts Department of Environmental Protection provided co-funding. The second round of testing was conducted at a U.S. Department of Energy (DOE) facility, and involved partnership with DOE, who provided major support to conduct the test at their site. DOE also worked with the vendors, helped to design the test/quality assurance plan, and helped to review the verification reports. As discussed above, the ETV Program is performing a third round of testing at a coal-fired utility. The Connecticut Department of Environmental Protection provided $50,000 in cost-share for this test, and the Illinois Clean Coal Institute has funded the AMS Center with $170,000 to support the test. This funding will be used to offset testing costs so that smaller vendors can participate in the test (U.S. EPA, 2004a).

Technology Acceptance and Use Outcomes

ETV verification has resulted in sales of mercury CEMs, assisting small U.S. companies to compete in the marketplace (see quote top right). The vendor quoted also stated that, since they are a small company, ETV verification gave them an opportunity to have a level playing field on which to compete (U.S. EPA, 2004a). Another mercury CEM vendor, represented by Horiba Instruments, Inc., reports that participation in ETV testing has led directly to sales of several units, including a sale to the operator of the waste incinerator that was used as the test site for the second round of ETV verification. Negotiations are also in progress with a major utility, and state agencies have inquired about use of the CEM to investigate specific sources. This vendor routinely calls attention to the ETV test results in discussions with prospective customers, and has publicized the ETV performance results in presentations at major mercury-related conferences (Battelle, 2004).

> "Envimetrics has found the ETV Program to be very valuable in the whole process of developing instrumentation. Envimetrics started out as an SBIR [Small Business Innovative Research] company using EPA research grants to develop their technology. They then received some state funding for commercialization. The last piece of the puzzle was for the ETV Program to provide them feedback and exposure for their product … for a small company, one cannot buy the kind of exposure that one gets by participating in the ETV Program."
> —Philip Efthimion, Envimetrics (U.S. EPA, 2004a)

ACRONYMS USED IN THIS CASE STUDY:

AA	atomic absorption	CEM	continuous emission monitor
AE	atomic emission	DOE	Department of Energy
AF	atomic fluorescence	IQ	intelligence quotient
AMS Center	ETV's Advanced Monitoring Systems Center	OH	Ontario Hydro
CAMR	Clean Air Mercury Rule	µg/scm	micrograms per standard cubic meter

2.3
Fuel Cells

The ETV Program's Greenhouse Gas Technology (GHG) Center, operated by Southern Research Institute under a cooperative agreement with EPA, has verified the performance of two fuel cell technologies that generate electricity at the point of use. Fuel cells can reduce emissions of carbon dioxide (CO_2), methane, nitrogen oxides (NO_X), carbon monoxide (CO), and total hydrocarbons (THCs). CO_2 and methane are greenhouse gases linked to global climate change. CO, THCs, and the various compounds in the NO_X family, as well as derivatives formed when NO_X reacts in the environment, cause a wide variety of health and environmental impacts.

Available sales data indicate that a capacity of 15 megawatts (MW) of ETV-verified fuel cells have been installed in the United States since the verifications were completed. Based on the analysis in this case study, the estimated benefits of these existing installations include the following:

- Emissions reductions of 17,000 tons per year of CO_2 and 120 tons per year of NO_X, with associated climate change, environmental, and human health benefits. At least 29% of the fuel cells are installed in combined heat and power (CHP) applications, potentially providing emissions reductions in addition to those estimated here.
- Increased utilization of renewable fuels, such as anaerobic digester gas, resulting in reductions in the consumption of natural resources. Systems that utilize anaerobic digester gas represent 2 MW of the currently installed capacity and contribute 14,000 tons per year of the CO_2 reductions estimated above.
- Potential reductions in emissions of other greenhouse gases and pollutants, with additional environmental and human health benefits.

As the capacity of fuel cells installed increases, emission reductions and other benefits also will increase. In fact, based on the analysis in this case study and assuming annual sales continue at the same rate as in 2005, the ETV Program estimates the total installed capacity of ETV-verified fuel cells will reach 34 MW in the next five years,[19] with the following benefits:

- Emissions reductions of 41,000 tons per year of CO_2 and 270 tons per year of NO_X, with associated climate change, environmental, and human health benefits. The percent of fuel cells installed in CHP applications would increase to at least 38%, resulting in even greater additional emissions reductions.
- Utilization of renewable fuels would increase, resulting in additional reductions in natural resource consumption. Systems that utilize anaerobic digester gas represent 5 MW of

---

[19] This estimate includes the 15 MW that the ETV Program estimates have already been installed. It represents 134 fuel cells total.

the estimated future capacity and would contribute 36,000 tons per year of the CO_2 reductions estimated above.

- Increasing reductions in emissions of other greenhouse gases and pollutants, with additional environmental and human health benefits.

In addition, vendors and users estimate that fuel cell installations can result in cost savings for the user. Fuel cells also can provide reliable backup power to emergency services facilities and shelters in the event of a natural disaster or other event.

2.3.1 Environmental, Health, and Regulatory Background

EPA estimates that, in 2002, the United States emitted almost 6.4 billion tons of CO_2 and nearly 22 million tons of NO_X.[20] Electricity generation is the largest single source of CO_2 emissions, accounting for 39% of the total. Electricity generation also contributes significantly to NO_X emissions, accounting for 21% of the total (U.S. EPA, 2004e). A variety of other pollutants also are emitted during electricity generation, including CO 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.

CO_2 is the primary greenhouse gas emitted by human activities in the United States. Its concentration in the atmosphere has increased 31% since pre-industrial times. As a greenhouse gas, CO_2 contributes to global climate change. The Intergovernmental Panel on Climate Change (IPCC) has concluded that global average surface temperature has risen 0.6 degrees centigrade in the 20th century, with the 1990s being the warmest decade on record. Sea level has risen 0.1 to 0.2 meters in the same time. Snow cover has decreased by about 10% and the extent and thickness of northern hemisphere sea ice has decreased significantly (IPCC, 2001a). Climate changes resulting from emissions of greenhouse gases, including CO_2 and methane, can have adverse outcomes including the following:

- More frequent or severe heat waves, storms, floods, and droughts
- Increased air pollution
- Increased geographic ranges and activity of disease-carrying animals, insects, and parasites
- Altered marine ecology
- Displacement of coastal populations
- Saltwater intrusion into coastal water supplies.

Each of these outcomes can result in increased deaths, injuries, and illnesses (U.S. EPA, 1997a). Many of these impacts, however, 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 increased precipitation and evaporation, more intense rainstorms, and drier soils (U.S. EPA, 2000a).

The various compounds in the NO_X family (including nitrogen dioxide, nitric acid, nitrous oxide, nitrates, and nitric oxide) and derivatives formed when NO_X reacts in the environment cause a variety of health and environmental impacts. These impacts include the following:

- Contributing to the formation of ground-level ozone (or smog), which can trigger serious respiratory problems
- Reacting to form nitrate particles, acid aerosols, and nitrogen dioxide, which also cause respiratory problems
- Contributing to the formation of acid rain
- Contributing to nutrient overload that deteriorates water quality
- Contributing to atmospheric particles that cause respiratory and other health problems, as well as visibility impairment
- Reacting to form toxic chemicals
- Contributing to global warming (U.S. EPA, 1998; U.S. EPA, 2003j).

Each of the other pollutants emitted during electricity generation also can have significant environmental and/or health effects.

---

[20] Values converted from gigagrams as reported in U.S. EPA (2004e).

THCs and CO can contribute to ground-level ozone formation, and CO can be fatal at high concentrations (U.S. EPA, 2000b; U.S. EPA, 2005n).

As discussed in detail in Section 2.3.2, fuel cells can reduce emissions of greenhouse gases or pollutants because they use hydrogen, or another fuel converted to hydrogen, to generate electricity, reducing the need to burn fossil fuels. Fuel cells can be used in vehicles and at stationary locations. Stationary fuel cells that generate electricity at the point of use are categorized as distributed generation (DG) technologies. These technologies also can employ heat recovery systems that capture excess thermal energy and use it to heat water and/or spaces. Systems that include this option are commonly termed CHP systems. As discussed in detail in Sections 2.3.2 and 2.3.3, DG and CHP technologies not only have the potential to reduce emissions, but also to conserve finite natural resources and utilize resources that would otherwise be wasted (e.g., anaerobic digester gas and landfill gas). In recognition of these benefits, EPA has established programs such as the CHP Partnership to encourage the use of CHP technologies, including those that use fuel cells. The CHP Partnership is a voluntary EPA-industry effort designed to foster cost-effective CHP projects. The goal of the partnership is to reduce the environmental impact of energy generation and build a cooperative relationship among EPA, the CHP industry, state and local governments, and other stakeholders to expand the use of CHP (U.S. EPA, 2005k).

One market sector targeted by the CHP Partnership is wastewater treatment facilities. Wastewater treatment facilities generate biogas from anaerobic digesters. This digester gas can be used as fuel for a DG technology like a fuel cell, instead of released to the atmosphere or burned using a flare, with a number of benefits for the facility and the environment (see box at right). DG technologies also offer an important security and safety benefit for wastewater treatment facilities. To help maintain public health, these facilities must operate, or come back on-line quickly, in the event of a power loss, such as a catastrophic event or natural disaster. DG technologies can continue to provide power to these and other critical facilities in the event of a utility failure caused by these emergencies (U.S. EPA, 2006g).

In a related effort, EPA and many states are developing and using output-based regulations for power generators. Output-based regulations establish emissions limits on the basis of units of emissions per unit of useful power output, rather than on the traditional basis of units of emissions per unit of fuel input. The traditional, input-based approach relies on the use of emissions control devices, whereas output-based regulations encourage energy efficiency. Currently a number of states, including Connecticut and Massachusetts, have developed output-based regulations that recognize the energy efficiency benefits of CHP projects. Regulated sources can use technologies like the ETV-verified fuel cells as part of their emissions control strategy to comply with these regulations. EPA also has developed resources, such as *Output-Based Regulations: A Handbook for Air Regulators* (U.S. EPA, 2004f), to assist in developing output-based regulations for power generators (U.S. EPA, 2005l).

States and localities also are undertaking efforts to promote the use of fuel cells. Based on data from Breakthrough Technologies Institute (2006), agencies in 43 states and the District of Columbia have undertaken activities supporting the use of stationary fuel cells.[21] These activities include the following: demonstration projects, long-term plans, research support, regulations or

> "CHP offers many benefits for wastewater treatment facilities because it:
>
> - Produces power at a cost below retail electricity
> - Displaces purchased fuels for thermal needs
> - Qualifies as a renewable fuel for green power programs
> - Enhances power reliability for the plant
> - Offers an opportunity to reduce greenhouse gas and other air emissions."
>
> —EPA's CHP Partnership Web site (U.S. EPA, 2006g)

---

[21] Excludes states whose activities are limited to fuel cell vehicles or the production of hydrogen fuel.

standards, education partnerships, procurement standards, and business incentives (Breakthrough Technologies Institute, 2006).

2.3.2 Technology Description

Fuel cells use hydrogen as the fuel in an electrochemical process, similar to what occurs in a battery, that generates electricity (U.S. EPA, 2002b; U.S. DOE, 2006a, 2006b). Unlike a battery, however, fuel cells can operate indefinitely, as long as the supply of fuel is maintained (U.S. EPA, 2002b). Fuel cells consist of two electrodes, a cathode and an anode, separated by an electrolyte (U.S. EPA, 2002b; U.S. DOE, 2006a, 2006b). In the ETV-verified fuel cells, 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, 2006a, 2006b). There are a number of different types of fuel cells, typically defined by the type of electrolyte used (U.S. EPA, 2002b; U.S. DOE, 2006b). The ETV-verified fuel cells include a polymer electrolyte membrane (PEM) fuel cell, in which a solid polymer membrane serves as the electrolyte, and a phosphoric acid fuel cell (PAFC), in which liquid phosphoric acid is the electrolyte (U.S. EPA, 2002b; Southern Research Institute, 1998, 2003c, 2004b).

Fuel cell technologies incorporate multiple stacks of paired electrodes. Many fuel cell technologies, including those verified by ETV, also incorporate a fuel processor or reformer. This system converts natural gas or another fuel, such as biogas, into a hydrogen-rich form for use by the fuel cell. Because only the fuel processing system involves combustion, fuel cells generate limited emissions (U.S. EPA, 2002b; U.S. DOE, 2006a). The primary byproducts of fuel cells are water and heat (U.S. DOE, 2006a, 2006b).

When used in stationary applications to generate electricity at the point of use, fuel cells 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 coupled with heat recovery systems that capture excess thermal energy to heat water and/or spaces, fuel cells also reduce the need to use conventional heating technologies such as boilers and furnaces. When well-matched to building or facility needs in a properly designed CHP application, fuel cells can increase operational efficiency and avoid power transmission losses, thereby reducing overall emissions and net fuel consumption.

Fuel cells also can be designed to operate using biogas from sources including animal waste, wastewater treatment plants, and landfills. Biogas is a renewable resource that otherwise goes unused because it is typically flared or vented to the atmosphere.

The first PEM and PAFC fuel cells were developed in the 1960s and 1970s, respectively (U.S. EPA, 2002b). Because they have seen limited commercialization, reliable performance data are needed on fuel cell technologies. The ETV Program responded by completing three verifications for two stationary fuel cell technologies (see Exhibit 2.3-1). One of these technologies is a small PEM fuel cell, sized for residential-scale use, that operated on natural gas in the ETV tests. The other is a larger PAFC technology, sized for commercial or institutional use. In the ETV tests, the latter technology operated on biogas from landfills and a wastewater treatment plant. Although none of the tests involved heat recovery in a CHP application, ETV did verify the potential for heat recovery in one of the tests, as discussed below.

During each test, the ETV Program verified power production and emissions performance. In one of the tests, ETV also verified potential heat production. In two of the tests (one for each technology), ETV verified power quality.

Power production tests measured electrical power output and electrical efficiency at selected loads. At full load under normal operations, electrical efficiencies ranged from 23.8% to 38.0%. In the test where potential heat production was verified, ETV measured heat production rate, potential thermal efficiency, and potential total system efficiency at selected loads. The potential thermal efficiency at full load and normal operation was 56.9%. ETV verified that, if the heat were recovered, potential total system efficiency would be 93.8%. In tests at less than full

EXHIBIT 2.3–1

ETV-VERIFIED FUEL CELL TECHNOLOGIES

Technology Name	Electricity Generating Capacity (kilowatts [kW])	Additional Information
Plug Power SU1 Fuel Cell System	5	Tested at a private residence in Lewiston, New York. Included a fuel reformulation system to operate using natural gas. Excess power generated by the fuel cell, but not used by the residence, was directed to the electric utility grid.
UTC Fuel Cells PC25™ Fuel Cell (1)	200	In 1998, tested at municipal solid waste landfills in California and Connecticut. Included a gas processing unit to operate using landfill gas. The electricity produced was directed to a local grid system and sold to utility companies. In 2003, tested at a wastewater treatment facility in Brooklyn, New York. Included a gas processing unit to operate using anaerobic digester gas. Power produced by the fuel cell offset the need to purchase electricity from the facility's local utility.

(1) UTC Fuel Cells was known as International Fuel Cells Corporation in 1998, when the first verification was completed. The technology has since been renamed as the PureCell ™ 200.

Sources: Southern Research Institute, 1998, 2003c, 2004b.

load, electrical efficiencies were lower, but thermal efficiencies were higher.

Power quality tests measured electrical frequency, voltage output, power factor, and voltage and current total harmonic distortion. Verified average voltage outputs were 121 volts (for the technology designed to produce 120 volts) and 488 volts (for the technology designed to produce 480 volts). Performance results for the other power quality parameters are available in the verification reports, which can be found at the links below.

Emissions tests measured emissions concentrations and rates at selected loads. Verified CO_2 emissions rates ranged from 1.31 to 1.66 pounds per kilowatt-hour (lbs/kWh). Verified NO_X emissions rates ranged from less than 6.97×10^{-7} to 0.013 lbs/kWh.[22] The ETV Program also verified concentrations and emissions rates for other pollutants and greenhouse gases, including CO, THCs, and methane. Two of the verification reports, one for each of the technologies, also estimated total annual CO_2 and NO_X reductions. For the technology tested at a residence, these reductions were calculated compared to emissions generated by electricity obtained from the grid. For the technology operating on anaerobic digester gas, the basis of comparison also considered the emissions that were eliminated by using the gas in the fuel cell system, instead of flaring it to the atmosphere. These estimates are presented in detail in Appendix B. More detailed performance data are available in the verification reports for each of the technologies (Southern Research Institute, 1998, 2003c, 2004b), which can be found at *http://www.epa.gov/etv/verifications/vcenter3-17.html* and *http://www.epa.gov/etv/verifications/vcenter3-14.html.*

2.3.3 Outcomes

The ETV Program used data from Fuel Cells 2000's Worldwide Stationary Fuel Cell Installation Database (Fuel Cells 2000, 2006) to estimate the number and capacity of ETV-verified fuel cells that have been installed in the United States since the verifications were completed. The ETV Program used these same data to estimate the number and capacity of ETV-verified fuel cells that could be installed in the near future. ETV extrapolated the number of fuel cells installed in year 2005 to each of the next five years and added this projection to the capacity currently installed.[23] Exhibit 2.3-2 shows the resulting estimates. Appendix B explains the derivation of these estimates in more detail. The ETV Program used these capacity estimates to estimate the emissions reduction outcomes shown below.

---

[22] CO_2 and NO_X emissions results summarized here encompass those from two of the verification reports and cover both technologies. In the other report, emissions rates were reported on the basis of operating hours, rather than kWh, and, thus, are not in a comparable form.

Exhibit 2.3–2

Projected Number and Capacity of ETV-Verified Fuel Cells Estimated to Be Installed

Total Installed	Number of Fuel Cells	Capacity (MW)
Currently	130	15
After Five Years	220	34

Values rounded to two significant figures

Emissions Reduction Outcomes

Emissions reductions from the application of fuel cell technology depend on a number of factors, including the electricity demand of the specific installation, the fuel cell emissions rates, and the emissions rates of the electric utility power plant that the fuel cell replaces. These factors vary geographically and by specific application. Given this variation, characterizing these factors for every potential ETV-verified fuel cell application is difficult. Therefore, ETV used estimates developed by Southern Research Institute for the test sites to extrapolate emissions reductions estimates for current and future installations. Appendix B describes the Southern Research Institute estimates and the method for using these estimates to project nationwide emissions reductions for the fuel cell capacities shown in Exhibit 2.3-2.

Exhibit 2.3-3 shows estimates of annual CO_2 and NO_X reductions generated using this method for the fuel cell capacity currently installed and the projected capacity after five years. In addition to the CO_2 and NO_X reductions shown in Exhibit 2.3-3, the ETV-verified fuel cells also have the potential to reduce other emissions, such as CO and THCs. As discussed in Section 2.3.1, the environmental and health effects of CO_2, NO_X, and other greenhouse gases and pollutants are significant. Therefore, the benefits of reducing these emissions also should be significant.

Exhibit 2.3–3

Estimated Emissions Reductions for ETV-Verified Fuel Cells[24]

	Annual Reduction (tons per year)	
Total Capacity Installed	CO_2	NO_X
Currently	17,000	120
After Five Years	41,000	270

Values rounded to two significant figures

Also, ETV-verified fuel cells can be and have been used in CHP installations. Based on data from the Fuel Cells 2000 database, at least 39 of the 134 fuel cells currently installed, or 29%, incorporate heat recovery for purposes including space heating and cooling and hot water. Projecting year 2005 CHP installations to each of the next five years results in a total of 85 of 224 fuel cells, or 38%, that incorporate heat recovery. These installations can further reduce emissions by replacing a conventional heat source, such as a hot water heater, boiler, or furnace. These conventional sources can emit significant quantities of CO_2, NO_X, and CO. Because the test sites did not incorporate heat recovery, the estimates in Exhibit 2.3-3 do not include these additional emissions reductions.

Resource Conservation Outcomes

In two of the verification tests, the fuel cells were powered by biogas—landfill gas in one test and anaerobic digester gas in the other. These waste fuels represent a renewable resource and using them results in the conservation of finite natural resources in the form of conventional fuels such as natural gas, oil, and coal. Currently, 10 of the 134 ETV-verified fuel cells operate on anaerobic digester gas, providing a generating capacity of 2 MW. After five years, ETV estimates these numbers would increase to 25 fuel cells with a capacity of 5 MW. These installations represent a significant use of a renewable resource. In addition, they account for most of the CO_2 emissions reductions estimated above: 14,000 tons per year currently and 36,000 tons per year after five years.[25]

---

23 As discussed in Appendix B, based on information from the vendor Web sites, ETV included fuel cells from the two vendors in its count even if the technology name was not specified or not identical to that used in the verification reports. The projection, however, does not include future installations of one of the technologies. The current and 2005 estimates also exclude short-term demonstration projects. Therefore, both the current estimate and future projection are likely to be conservative.

24 Reductions vary based on the source for grid power or thermal supply (hydroelectric, coal, etc.). Reductions here account for CO_2 emissions from the fuel reformer or gas processing units associated with the fuel cells.

25 As discussed in Southern Research Institute (2004b), a small portion of these CO_2 reductions are offset by increased emissions of methane, another greenhouse gas. The methane increase amounts to less than 1% of the CO_2 reduction in terms of greenhouse gas potential, or carbon equivalents.

Economic and Financial Outcomes

Section 2.3.2 reports the verified efficiencies of the ETV-tested fuel cell technologies. In general, these efficiencies compare favorably with those of separate heat and grid power applications, particularly when coupled with heat recovery in CHP applications. In addition, because they generate and use electricity onsite, fuel cells avoid losses associated with the transmission of electricity, which can be in the range of 4.7% to 7.8% (Southern Research Institute, 2001a, 2001b, 2003a, 2004b). In addition to the efficiency increases, systems that operate on biogas can result in cost savings for the user by using a "free" waste fuel rather than an expensive conventional fuel. While cost savings can vary depending on the configuration of the individual installation and the cost of electricity and fuels, these savings can be significant (see box at right).

Technology Acceptance and Use Outcomes

The large number of ETV-verified fuel cells currently installed (see Exhibit 2.3-2) provides evidence that the technology is becoming accepted. In addition to the emissions reduction and resource conservation benefits discussed above, another benefit that has contributed to this acceptance is the technologies' ability to provide reliable backup power in case of a natural disaster or other emergency. This benefit is particularly important for critical emergency services facilities and facilities that serve as emergency shelters. Examples of facilities that have benefited from ETV-verified fuel cells in this manner include the following:

- A high school in New York, where the fuel cell "will allow the high school to become an emergency shelter during community disasters" (Fuel Cells 2000, 2006)
- A high school in Connecticut that serves as a regional emergency shelter (Fuel Cells 2000, 2006; UTC Power, 2006a)
- A government office building in New York, where the fuel cell powers the state's regional emergency management office (Fuel Cells 2000, 2006)
- A police station in New York City's Central Park, a facility routinely affected by power shortages prior to installation, where the fuel cell provided uninterrupted power during the blackout of 2003 (UTC Power, 2006b).

Examples of Cost Savings from ETV-verified Fuel Cells

At two colleges in New Jersey:

- "Officials anticipate the plant will cut energy costs by over $81,000 annually, recovering the college's investment within four years."
- "Combined heat and power operating cost savings are estimated to be $259,000 per year."

At a hospital in Rhode Island:

- "Produces one-third of hospital's electricity during peak hours, saving $60,000–$90,000/year."

—Fuel Cells 2000 database (Fuel Cells 2000, 2006)

Acronyms used in this case study:

CHP	combined heat and power	kW	kilowatts
CO	carbon monoxide	lbs/kWh	pounds per kilowatt-hour
CO_2	carbon dioxide	MW	megawatts
DG	distributed generatio	NO_X	nitrogen oxides
GHG Center	ETV's Greenhouse Gas Technology Center	PAFC	phosphoric acid fuel cell
IEEE	Institute of Electrical and Electronics Engineers	PEM	polymer electrolyte membrane fuel cell
IPCC	Intergovernmental Panel on Climate Change	THCs	total hydrocarbons

2.4

Microturbine/Combined Heat and Power (CHP) Technologies

The ETV Program's Greenhouse Gas Technology (GHG) Center, operated by Southern Research Institute under a cooperative agreement with EPA, has verified the performance of six microturbine systems that generate electricity at the point of use. Several of the verified technologies also include heat recovery systems that capture excess thermal energy from the system and use it to heat water and/or spaces. Systems that include this option are commonly termed combined heat and power (CHP) systems. Microturbine systems, with or without heat recovery, can reduce emissions of carbon dioxide (CO_2), methane, and pollutants including nitrogen oxides (NO_X), sulfur dioxide (SO_2), carbon monoxide (CO), particulate matter (PM), ammonia, and total hydrocarbons (THCs). CO_2 and methane are greenhouse gases linked to global climate change. CO, SO_2, PM, ammonia, THCs, and the various compounds in the NO_X family, as well as derivatives formed when NO_X reacts in the environment, cause a wide variety of health and environmental impacts.

The ETV Program initially prepared this case study as part of the first volume of *ETV Program Case Studies: Demonstrating Program Outcomes* (U.S. EPA, 2006f). Following publication of that document, one of the technology vendors provided important new information on recent sales. Based on this new information, the ETV Program has updated the original case study and is presenting it in this volume.

Available sales data indicate that a capacity of 13 megawatts (MW) of ETV-verified microturbines[26] have been installed in CHP applications in the United States since the verifications were completed. Based on the analysis in this case study, the estimated benefits of these existing installations include the following:

- Emissions reductions of up to 36,000 tons per year of CO_2 and approximately 120 tons per year of NO_X, with associated climate change, environmental, and human health benefits
- Reduction in emissions of other greenhouse gases and pollutants, with additional environmental and human health benefits
- Reduction in natural resource consumption by utilizing renewable fuels (such as biogas) or by increasing efficiency (and reducing net fuel consumption) when well-matched to building or facility needs in a properly designed CHP application.

As the capacity of microturbines installed in CHP applications increases, emission reductions and other benefits also will increase. In fact, based on the analysis in this case study and assuming annual sales continue at the same rate as in 2005, the ETV Program estimates the total installed

---

[26] This estimate is based on sales from only one vendor and represents between approximately 190 and 220 installations (at 60 to 70 kW per installation).

capacity of ETV-verified microturbine/CHP systems will reach 55 MW in the next five years,[27] with the following benefits:

- Emissions reductions of up to 150,000 tons per year of CO_2 and up to 530 tons per year of NO_X, with associated climate change, environmental, and human health benefits
- Reduction in emissions of other greenhouse gases and pollutants, with additional environmental and human health benefits
- Additional reduction in natural resource consumption.

Other benefits of verification include the development of a well-accepted protocol that has advanced efforts to standardize protocols across programs. The Association of State Energy Research and Technology Transfer Institutions (ASERTTI), the Department of Energy (DOE), and state energy offices are adopting this protocol as a national standard protocol for field testing microturbines and CHP systems.

2.4.1 Environmental, Health, and Regulatory Background

EPA estimates that, in 2002, the United States emitted almost 6.4 billion tons of CO_2 and nearly 22 million tons of NO_X.[28] Electricity generation is the largest single source of CO_2 emissions, accounting for 39% of the total. Electricity generation also contributes significantly to NO_X emissions, accounting for 21% of the total (U.S. EPA, 2004e). A variety of other pollutants also are emitted during electricity generation, including CO, SO_2, 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.

CO_2 is the primary greenhouse gas emitted by human activities in the United States. Its concentration in the atmosphere has increased 31% since pre-industrial times. As a greenhouse gas, CO_2 contributes to global climate change. The Intergovernmental Panel on Climate Change (IPCC) has concluded that global average surface temperature has risen 0.6 degrees centigrade in the 20th century, with the 1990s being the warmest decade on record. Sea level has risen 0.1 to 0.2 meters in the same time. Snow cover has decreased by about 10% and the extent and thickness of northern hemisphere sea ice has decreased significantly (IPCC, 2001a). Climate changes resulting from emissions of greenhouse gases, including CO_2 and methane, can have adverse outcomes including the following:

- More frequent or severe heat waves, storms, floods, and droughts
- Increased air pollution
- Increased geographic ranges and activity of disease-carrying animals, insects, and parasites
- Altered marine ecology
- Displacement of coastal populations
- Saltwater intrusion into coastal water supplies.

Each of these outcomes can result in increased deaths, injuries, and illnesses (U.S. EPA, 1997a). Many of these impacts, however, 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 increased precipitation and evaporation, more intense rainstorms, and drier soils (U.S. EPA, 2000a).

The various compounds in the NO_X family (including nitrogen dioxide, nitric acid, nitrous oxide, nitrates, and nitric oxide) and derivatives formed when NO_X reacts in the environment cause a variety of health and environmental impacts. These impacts include the following:

- Contributing to the formation of ground-level ozone (or smog), which can trigger serious respiratory problems

---

[27] This estimate includes the 13 MW that the ETV Program estimates have already been installed. It represents between approximately 790 and 920 installations total. It is a conservative (low) estimate, as discussed in Appendix C.

[28] Values converted from gigagrams as reported in U.S. EPA (2004f).

- Reacting to form nitrate particles, acid aerosols, and nitrogen dioxide, which also cause respiratory problems
- Contributing to the formation of acid rain
- Contributing to nutrient overload that deteriorates water quality
- Contributing to atmospheric particles that cause respiratory and other health problems, as well as visibility impairment
- Reacting to form toxic chemicals
- Contributing to global warming (U.S. EPA, 1998; U.S. EPA, 2003j).

Each of the other pollutants emitted during electricity generation also can have significant environmental and/or health effects. For example, SO_2 contributes to the formation of acid rain and can cause a variety of other environmental and health effects (U.S. EPA, 2006h). THCs and CO can contribute to ground-level ozone formation, and CO can be fatal at high concentrations (U.S. EPA, 2000b; U.S. EPA, 2005n). PM can cause premature mortality and a variety of respiratory effects (70 FR 65984). Finally, ammonia can contribute to PM levels and result in a number of 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, 2004g).

As discussed in detail in Sections 2.4.2 and 2.4.3, distributed generation technologies can reduce emissions of CO_2, NO_X, and other greenhouse gases and pollutants (e.g., CO, methane from biogas, SO_2, PM, ammonia, and THCs), as well as conserve finite natural resources and utilize resources that would otherwise be wasted (e.g., biogas, landfill gas, and oilfield flare gas). In recognition of these benefits, EPA has established programs such as the CHP Partnership to encourage the use of CHP technologies, including those that use microturbines. The CHP Partnership is a voluntary EPA-industry effort designed to foster cost-effective CHP projects. The goal of the partnership is to reduce the environmental impact of energy generation and build a cooperative relationship among EPA, the CHP industry, state and local governments, and other stakeholders to expand the use of CHP (U.S. EPA, 2005k).

> "By installing a CHP system designed to meet the thermal and electrical base loads of a facility, CHP can increase operational efficiency and decrease energy costs, while reducing emissions of greenhouse gases that contribute to the risks of climate change."—EPA's CHP Partnership Web site (U.S. EPA, 2005k)

In a related effort, EPA and many states are developing and using output-based regulations for power generators. Output-based regulations establish emissions limits on the basis of units of emissions per unit of useful power output, rather than on the traditional basis of units of emissions per unit of fuel input. The traditional, input-based approach relies on the use of emissions control devices, whereas output-based regulations encourage energy efficiency. Currently a number of states, including Connecticut and Massachusetts, have developed output-based regulations that recognize the energy efficiency benefits of CHP projects. Regulated sources can use technologies like the ETV-verified microturbine/CHP systems as part of their emissions control strategy to comply with these regulations. EPA also has developed resources, such as *Output-Based Regulations: A Handbook for Air Regulators* (U.S. EPA, 2004f), to assist in developing output-based regulations for power generators (U.S. EPA, 2005l).

2.4.2 Technology Description

Electric utilities and others have used large- and medium-scale gas-fired turbines "to generate electricity since the 1950s, but recent developments have enabled the introduction of much smaller turbines, known as microturbines" (U.S. EPA, 2002a). Microturbines are well-suited to providing 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 (NREL, 2003). By generating electricity at the point of use, microturbines reduce the need to generate electricity from sources such as large electric utility plants. When coupled with heat recovery systems that capture excess thermal energy to heat water and/or spaces, microturbines also reduce the need to use conventional heating technologies such as boilers and furnaces, 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, microturbines can increase operational efficiency and avoid power transmission losses, thereby reducing overall emissions and net fuel consumption. Microturbines also can be designed to operate using biogas from sources including animal waste, wastewater treatment plants, and landfills. Biogas is a renewable resource that otherwise goes unused because it is typically flared or vented to the atmosphere.

Because they are relatively new, reliable performance data are needed on microturbine/CHP technologies. The ETV Program responded by verifying the performance of six microturbine technologies (see Exhibit 2.4-1), four of which include heat recovery. The verification reports (Southern Research Institute, 2001a, 2001b, 2001c, 2003a, 2003b, 2004a) can be found at *http://www.epa.gov/etv/verifications/vcenter3-3.html.* Residential, commercial, institutional, and industrial facilities were used as test sites. One of the technologies tested operated on biogas recovered from animal waste.

One of the ETV-verified microturbine/CHP technologies.

During each test, the ETV Program verified heat and power production, power quality, and emissions performance. Heat and power production tests measured electrical power output and electrical efficiency at selected loads. For systems with heat recovery, these tests also measured heat recovery rate, thermal efficiency, and total system efficiency at selected loads. At full load under normal operations, electrical efficiencies ranged from 20.4% to 26.2%. For systems with heat recovery, thermal efficiencies at full load and normal operation ranged from 7.2% to 47.2%. For these systems, total system efficiencies ranged from 33.4% to 71.8%.[29] In tests at less than full load, electrical efficiencies were lower, but thermal efficiencies were higher. In tests with enhanced heat recovery (as opposed to normal operations), thermal and total efficiencies were higher.

Power quality tests measured electrical frequency, voltage output, power factor, and voltage and current total harmonic distortion. Verified average voltage outputs ranged from 215 to 495 volts (for design voltages of 275 to 480 volts). Performance results for the other power quality parameters are available in the verification reports, which can be found at the link above.

Emissions tests measured emissions concentrations and rates at selected loads. Verified CO_2 emissions rates ranged from 1.34 to 3.90 pounds per kilowatt-hour (lbs/kWh). Verified NO_X emissions rates ranged from 4.67×10^{-5} to 4.48×10^{-3} lbs/kWh. The ETV Program also verified concentrations and emissions rates for other pollutants and greenhouse gases, including CO and THCs, and, for some of the technologies, methane, sulfate, total recoverable sulfur, total particulate matter, and ammonia. Three of the verification reports also estimated total CO_2 reductions compared to emissions generated by electricity obtained from the grid and heat obtained from a conventional technology, either for the test sites or for hypothetical sites. In two cases, total NO_X reductions were estimated in a similar manner. These estimates are presented in

---

[29] Note that the lower end of the range for thermal and total efficiency represents a site where efficiencies under "normal operating conditions" were low because of low space heating and dehumidification demand during testing. Excluding this site, the range of thermal efficiencies was 21% to 47.2% and the range of total efficiencies was 46.3% to 71.8%.

EXHIBIT 2.4–1

ETV-VERIFIED MICROTURBINE AND CHP TECHNOLOGIES

Technology Name	Electricity Generating Capacity (kilowatts [kW])	Includes Heat Recovery for CHP?	Additional Information
Mariah Energy Corporation Heat PlusPower™ System	30	Yes	Tested at a 12-unit condominium site that combines a street-level retail or office space with basement, and a one- or two-level residence above.
Ingersoll-Rand Energy Systems IR PowerWorks™ 70 kW Microturbine System	70	Yes	Tested at a 60,000 square-foot skilled nursing facility providing care for approximately 120 residents.
Honeywell Power Systems, Inc. Parallon® 75 kW Turbogenerator	75	No	Tested at a 55,000 square-foot university office building.
Honeywell Power Systems, Inc. Parallon® 75 kW Turbogenerator With CO Emissions Control	75	No	Same technology as above, but with installation of optional CO emissions control equipment.
Capstone 30 kW Microturbine System	30	Yes	Tested system operates on biogas recovered from animal waste generated at a swine farm.
Capstone 60 kW Microturbine CHP System	60	Yes	Tested at a 57,000 square-foot commercial supermarket.

Sources: Southern Research Institute, 2001a, 2001b, 2001c, 2003a, 2003b, 2004a.

detail in Appendix C. More detailed performance data are available in the verification reports for each of the technologies (Southern Research Institute, 2001a, 2001b, 2001c, 2003a, 2003b, 2004a).

2.4.3 Outcomes

Microturbine/CHP systems can be used at residential, commercial, institutional, and industrial facilities to provide electricity at the point of use and reduce the need to use conventional heating technologies. As discussed below under "Technology Acceptance and Use Outcomes," based on data from one vendor, 13 MW of ETV-verified microturbines have been installed for CHP applications in the United States since the verifications were completed. Because this estimate includes sales from only one vendor, it likely is conservative and represents the minimum capacity currently installed.

The ETV Program used these same data to estimate the capacity of ETV-verified microturbine/CHP systems that could be installed in the near future. The vendor reported 8.4 MW were installed during 2005. ETV extrapolated these 2005 sales to each of the next five years to estimate that an additional 42 MW could be installed during this period. Adding this projection to the capacity currently installed, results in a total installed capacity after five years of 55 MW, as shown in Exhibit 2.4-2. Appendix C explains the derivation of the estimates in Exhibit 2.4-2 in more detail.[30] The ETV Program used these capacity estimates to project the emissions reduction outcomes shown below.

EXHIBIT 2.4–2

PROJECTED CAPACITY OF ETV-VERIFIED MICROTURBINE/CHP SYSTEMS ESTIMATED TO BE INSTALLED

Total Capacity Installed	MW
Currently	13
After Five Years	55

Values rounded to two significant figures

Emissions Reduction Outcomes

Emissions reductions from the application of microturbine/CHP technology depend on a number of factors, including the electricity and heating demand of the specific application, the microturbine emissions rates, and the emissions rates of the conventional source that the

---

[30] As discussed in Appendix C, this is a conservative (low) estimate.

microturbine replaces, such as an electric utility power plant or hot water heater. These factors vary geographically and by specific application. Given this variation, characterizing these factors for every potential ETV-verified microturbine/CHP application is difficult. Therefore, this analysis uses model facilities developed by Southern Research Institute for the test sites to estimate emissions reductions for current and future installations. Appendix C describes the model sites and the method for using the model facilities to estimate nationwide emissions reductions for the microturbine capacities shown in Exhibit 2.4-2.

Exhibit 2.4-3 shows upper- and lower-bound estimates of annual CO_2 and NO_X reductions generated using this method for the microturbine capacity currently installed and the projected capacity after five years. The upper-bound estimates assume each ETV-verified microturbine/CHP installation is represented by the model site that achieves the greatest reduction for that compound. The lower-bound estimates assume each ETV-verified microturbine/CHP installation is represented by the model site that achieves the lowest reduction for that compound.

In addition to the CO_2 and NO_X reductions shown in Exhibit 2.4-3, the ETV-verified microturbine/CHP systems also have the potential to reduce emissions of other greenhouse gases, such as methane, and other pollutants, such as THCs. As discussed in Section 2.4.1, the environmental and health effects of CO_2, NO_X, nd other greenhouse gases and pollutants are significant. Therefore, the benefits of reducing these emissions also should be significant.

Resource Conservation, Economic, and Financial Outcomes

Section 2.4.2 reports the verified efficiencies of the ETV-verified microturbine technologies. In general, these efficiencies compare favorably with those of separate heat and grid power applications, particularly when coupled with heat recovery in CHP applications. In addition, because they generate and use electricity onsite, microturbines avoid losses associated with the transmission of electricity, which can be in the range of 4.7% to 7.8% (Southern Research Institute, 2001a, 2001b, 2003a, 2004b). Also, as shown in one of the verification tests, microturbines can be fueled by biogas, a renewable resource. The application of the ETV-verified microturbine/CHP systems can result in the conservation of finite natural resources and potentially result in cost savings for the user due to efficiency increases and the use of renewable or waste fuels rather than conventional fuels. At least one vendor reports significant sales of their ETV-verified biogas-fueled technology in the last year (see “Technology Acceptance and Use Outcomes”).

EXHIBIT 2.4–3

ESTIMATED EMISSIONS REDUCTIONS FOR ETV-VERIFIED MICROTURBINE/CHP SYSTEMS[31]

	Annual Reduction (tons per year)	
Total Capacity Installed	**CO_2**	**NO_X**
	Upper Bound	
Currently	36,000	120
After Five Years	150,000	530
	Lower Bound	
Currently	20,000	120
After Five Years	83,000	490
Values rounded to two significant figures		

---

[31] Reductions vary based on the source for grid power or thermal supply (hydroelectric, coal, etc.).

Technology Acceptance and Use Outcomes

According to recent reports, one verified vendor has sold 13 MW of ETV-verified microturbines for CHP applications in the United States since verification. U.S. sales in 2005 alone were approximately 8.4 MW (ETV Vendor, 2006). U.S. sales in 2005 represented approximately half of the vendor's global sales. Also, 11% of 2005 sales were for resource recovery applications, many of which used the ETV-verified biogas-fueled technology. This vendor projects increasing sales of ETV-verified microturbines during each of the next several years (ETV Vendor, 2005). Vendors also report that ETV verification has increased awareness of this technology, leading to marketing opportunities (see quotes at right).

Scientific Advancement Outcomes

Other benefits of verification include the development of a well-accepted protocol that has advanced efforts to standardize protocols across programs. This protocol, the "Generic Field Testing Protocol for Microturbine and Engine CHP Applications," was originally developed by Southern Research Institute for ASERTTI and was eventually adopted by the GHG Center and published as an ETV protocol. The protocol also is scheduled to be adopted by ASERTTI, DOE, and state energy offices as a national standard protocol for field testing.

> "People are skeptical of new technology, which is why Mariah Energy needed believable third-party verification. It may be years before we know the impact ETV had on sales, but it is already an important factor in discussions with our new customers, and ETV has opened doors we didn't anticipate it would. For example, new partnering organizations are using ETV data to make decisions on investing in our technology. Also, new opportunities to conduct field demonstrations have occurred, and we've been invited to testify at Senate hearings on clean high performance energy technology."—Paul Liddy, President and CEO of Mariah Energy (U.S. EPA, 2002a)
>
> "We are very proud of our ETV results. We cite them all the time, in fact most recently in our press release last week."
> —Keith Field, Director of Communications, Capstone Turbine Corporation (Field, 2005)

Acronyms used in this case study:

ASERTTI	Association of State Energy Research and Technology Transfer Institutions	kW	kilowatts
CHP	combined heat and power	lbs/kWh	pounds per kilowatt-hour
CO	carbon monoxide	MW	megawatts
CO_2	carbon dioxide	NO_X	nitrogen oxides
DOE	Department of Energy	PM	particulate matter
GHG Center	ETV's Greenhouse Gas Technology Center	SO_2	sulfur dioxide
IEEE	Institute of Electrical and Electronics Engineers	THCs	total hydrocarbons
IPCC	Intergovernmental Panel on Climate Change		

3.

Water Technology Case Studies

3.1

Microfiltration (MF) and Ultrafiltration (UF) for Removal of Microbiological Contaminants

The ETV Program's Drinking Water Systems (DWS) Center, operated by NSF International under a cooperative agreement with EPA, has verified the performance of three microfiltration (MF) systems and six ultrafiltration (UF) systems for removal of microbiological contaminants. The ETV-verified systems are easily transportable, making them ideal for small drinking water systems. The ETV tests described in this case study verified the performance of these technologies for the removal of *Cryptosporidium* and *Cryptosporidium*-sized particles.[32] *Cryptosporidium* is a known infectious pathogen that causes gastrointestinal infections and is potentially life threatening for susceptible populations. To help protect the public from the health effects of *Cryptosporidium*, EPA requires a minimum of 2-log (99%) removal of the pathogen from filtered drinking water systems that use surface water sources. EPA also has finalized the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). This rule adds *Cryptosporidium* treatment requirements for unfiltered drinking water systems and increases treatment requirements for filtered drinking water systems with the highest risk levels. As a result, certain drinking water systems must install treatment technologies similar to the MF and UF technologies verified by the ETV Program.

Based on the analysis in this case study and 25% market penetration, the ETV Program estimates that:

- The ETV-verified MF and UF technologies would assist up to 550 small drinking water systems (out of approximately 2,200 systems) in complying with the new standards for *Cryptosporidium*.
- At these systems, the technologies would prevent up to 13,000 cases of cryptosporidiosis per year and up to two premature deaths per year associated with these cases. The technologies also can prevent other negative human health effects, including those associated with co-occurring contaminants.
- The technologies would result in economic benefits of up to $19 million per year[33] due to the prevention of the above cases of cryptosporidiosis.

Verification has also increased awareness of the ETV-verified technologies and their benefits among state regulatory agencies and potential users. The following benefits have been or can be realized from the use of the ETV data:

---

[32] The ETV Program also has verified the performance of technologies other than MF and UF for removal of microbiological contaminants. This case study specifically covers MF and UF technologies that ETV verified for *Cryptosporidium* removal. Information on other technologies verified for removal of microbiological contaminants can be found at *http://www.epa.gov/etv/verifications/verification-index.html*.

[33] In year 2003 dollars.

- Twenty-five states reportedly use ETV verification data to reduce the frequency and/or length of site-specific pilot tests for drinking water treatment. The State of Utah's drinking water regulations identify the ETV Program as a source of performance verification data for permitting consideration. The State of Massachusetts has proposed changes to its regulations whereby, to obtain approval of a new drinking water technology in Massachusetts, a manufacturer must demonstrate that it has received a favorable review from third parties such as ETV or be piloted for multiple seasons. EPA's guidance manual for membrane filtration under the LT2ESWTR cites the ETV test plan as an example of a protocol that can be used to meet the testing requirements of the rule.
- Assuming 25% market penetration, up to 550 systems would use ETV data to reduce pilot testing requirements, saving up to $8.3 million in pilot testing costs.
- The reduction in pilot testing length also could lead to systems achieving the above health benefits sooner than would otherwise be possible.
- Based in part on the results of ETV testing, the City of Pittsburgh chose one of the verified technologies for full-scale installation, demonstrating that the technologies can be scaled up for application at large systems. This technology saved the City approximately $5 million compared to conventional treatment, and could reduce exposure to *Cryptosporidium*, with associated human health and economic benefits.

3.1.1 Environmental, Health, and Regulatory Background

In the United States, more than 14,000 public water systems serving approximately 180 million people rely on water sources that are susceptible to microbial pathogens (U.S. EPA, 2005a), including *Cryptosporidium, Giardia, E. coli,* and viruses. Human and animal fecal matter are common sources of these pathogens in drinking water, and all of them can cause a variety of gastrointestinal illnesses (e.g., diarrhea, vomiting, cramps) (U.S. EPA, 2003a). *Cryptosporidium* is of particular concern because it is resistant to standard drinking water disinfectants such as chlorine (U.S. EPA, 2005a).

Cryptosporidiosis, a gastrointestinal illness, is most often caused by consuming drinking water contaminated with *Cryptosporidium* oocysts. Common symptoms of cryptosporidiosis in humans include profuse diarrhea, dehydration, abdominal cramps, vomiting, and lethargy. Clinical symptoms, however, vary and can include renal failure and liver disease. Symptom severity depends upon immune system status. Patients with compromised immune systems, such as children, the elderly, AIDS patients, and cancer patients undergoing chemotherapy, are especially susceptible to infection and run a greater risk of prolonged illness from the infection and possibly death (U.S. EPA, 2001b).

EPA has promulgated several regulations designed to decrease exposure to microorganisms such as *Cryptosporidium*. Under the Safe Drinking Water Act, EPA has established a Maximum Contaminant Level Goal (MCLG) for *Cryptosporidium* of zero oocysts. MCLGs allow for a margin of safety and are non-enforceable public health goals. Current drinking water regulations require a minimum of 2-log (99%) removal of *Cryptosporidium* for all public water systems that use surface water sources and include filtration as part of their treatment process (67 FR 1812 and 63 FR 69478). To further reduce the incidence of disease associated with the presence of *Cryptosporidium* (and other pathogenic microorganisms) in drinking water, EPA finalized the LT2ESWTR in January of 2006. This rule is part of the "Microbial-Disinfectants/Disinfection Byproducts Cluster" rules. Major requirements of the rule include additional *Cryptosporidium* treatment techniques for filtered systems, and *Cryptosporidium* inactivation for unfiltered systems. Under the LT2ESWTR, filtered systems that are classified in higher risk treatment categories (or "bins") will be required to reduce *Cryptosporidium* levels by an additional 1-log to 2.5-log (90% to 99.7%). The LT2ESWTR also requires 2-log to 3-log (99% to 99.9%) inactivation of *Cryptosporidium* by all unfiltered systems. Approximately 1,900 to 2,900 drinking water systems will have to install treatment to meet the new requirements. Of these systems, EPA estimates that 76% (or about 1,400 to 2,200) are small systems that serve fewer than 10,000 people each (71 FR 654). Drinking water systems will begin monitoring programs under the rule between October 2006 and October 2008, depending on their size. They generally then will have three years after completing monitoring to comply with any additional treatment requirements (U.S. EPA, 2006a).

3.1.2 Technology Description

MF and UF technologies work under similar scientific principles: They both use membranes as mechanical barriers to remove contaminants. MF and UF technologies can achieve greater removals of microbiological contaminants than conventional filtration technologies (Cadmus and Pirnie, 2003). They are practical for drinking water systems of all sizes (U.S. EPA, 2005a). The ETV-verified systems are all skid-mounted or easily transportable technologies making them ideal for small drinking water systems. Additionally, the filtration systems are largely automated, thus requiring very little manual operation (NSF, 2000a, 2000b, 2000c, 2000d, 2000e, 2000f, 2000g, 2000h, 2001, 2002, 2003a, 2003b).

The ETV Program has completed 12 verification reports addressing the performance of nine technologies (three MF technologies and six UF technologies) for removing *Cryptosporidium* and/or *Cryptosporidium*-sized particles.[34] The verification reports (NSF, 2000a, 2000b, 2000c, 2000d, 2000e, 2000f, 2000g, 2000h, 2001, 2002a, 2003a, 2003b) can be found at *http://www.epa.gov/etv/verifications/vcenter2-6.html, http://www.epa.gov/etv/verifications/vcenter2-10.html, and http://www.epa.gov/etv/verifications/vcenter2-5.html.* The testing locations included surface water supplies in Pennsylvania, Oregon, Wisconsin, California, and New Hampshire. The tests took place over periods ranging from 30 to greater than 90 days. Each of the tests measured water quality results, microbial removal and/or microbial-sized particle removal, membrane flux and operation, cleaning efficiency, and membrane integrity. The tests also tracked operation and maintenance, usually examining power supply requirements, chemical consumption, and operational reliability (NSF, 2000a, 2000b, 2000c, 2000d, 2000e, 2000f, 2000g, 2000h, 2001, 2002a, 2003a, 2003b). Exhibit 3.1-1 identifies the ETV-verified technologies and provides a description of each.


One of the verified UF technologies

ETV testing results indicated that the technologies were capable of 4.1-log to 6.8-log removal of *Cryptosporidium* oocysts and 4.9-log to 5.8-log removal of *Giardia* cysts. Protozoa-size bacteria removals of 4-log were observed. In addition, ETV-verified UF systems showed MS-2 bacteriophage removal from 3.3-log to 5.8-log removal, indicating significant virus removal capabilities. Reported system feed or throughput

---

[34] The ETV Program also has verified the performance of technologies other than MF and UF for removal of microbiological contaminants. This case study specifically covers MF and UF technologies that ETV verified for *Cryptosporidium* removal. Information on other technologies verified for removal of microbiological contaminants can be found at *http://www.epa.gov/etv/verifications/verification-index.html.*

EXHIBIT 3.1–1

ETV-VERIFIED MF AND UF TECHNOLOGIES FOR MICROBIOLOGICAL REMOVAL

Technology Name	Description
	MF Technologies
Pall Corporation Microfiltration using Microza™ 3-inch Unit, Model 4UFD40004-45	A skid-mounted unit with pressure-driven hollow fibers of polyvinylidene fluoride and automated controls. Specifically targeted for applications with a low flow rate, such as package plants, small commercial operations, schools, campgrounds, swimming pools, or small communities (1).
Pall Corporation WPM-1 Microfiltration System	A skid mounted, stand-alone system with a hollow fiber type MF membrane made of polyvinylidene fluoride. Capable of operating in an automatic mode.
US Filter 3M10C Microfiltration Membrane System	A skid-mounted package plant containing three pressure vessels with hollow fiber membrane modules made of polypropylene and automated controls.
	UF Technologies
Aquasource North America Model A35 Ultrafiltration System (2)	A self-contained, skid-mounted system with two hollow fiber membrane modules made from a cellulose acetate derivative and automated controls.
F.B. Leopold Company Ultrabar Ultrafiltration System Utilizing a Mark III Membrane (60") Element	A self-contained, stand-alone system installed in a 20-foot long sea-going (watertight) container. Contains two hollow fiber membranes made of modified polyethersulfone. Capable of operating in an automatic mode.
Hydranautics HYDRAcap® Ultrafiltration Membrane System	Two hollow fiber membrane modules made of polyethersulfone, mounted on a transportable skid constructed of steel. Includes automatic and manual controls.
Ionics UF-1-7T Ultrafiltration Membrane system	Seven hollow fiber membrane modules made of polyacrylonitrile, inside an aluminum pressure vessel and mounted on a transportable skid. Includes automated controls.
Polymem UF120 S2 Ultrafiltration Membrane Model	A polyvinyl chloride pressure vessel containing 19 individual polysulfone hollow fiber membrane bundles. Tested using a skid-mounted custom membrane pilot plant supplied by others.
ZENON Environmental Systems, Inc. ZEEWEED® ZW-500 Ultrafiltration System (3)	A stand-alone system with hollow fiber membranes made of a proprietary polymeric compound. Capable of operating in an automatic mode.

(1) EPA defines a small system as a system the serves a community of less than 10,000 people. This may or may not agree with how the vendors define systems of this size. For clarification, please contact the vendor contact listed on the front page of the verification statement posted at *http://www.epa.gov/etv/verifications/vcenter2-6.html.*

(2) Verified in May 2000 and September 2000

(3) Verified in August 2000 and June 2001 for *Cryptosporidium* removal. Also verified in August 2000 in combination with coagulation for removal of *Cryptosporidium*-sized particles.

Sources: NSF, 2000a, 2000b, 2000c, 2000d, 2000e, 2000f, 2000g, 2000h, 2001, 2002a, 2003a, 2003b.

flow rates ranged from 1 to 60 gallons per minute (NSF, 2000a, 2000b, 2000c, 2000d, 2000e, 2000f, 2000g, 2000h, 2001, 2002a, 2003a, 2003b).

3.1.3 Outcomes

The most likely market for the ETV-verified MF and UF technologies includes small drinking water systems serving less than 10,000 people that will have to install or modify treatment units to comply with the new *Cryptosporidium* removal requirements of the LT2ESWTR. Therefore, the ETV Program used data from the LT2ESWTR (71 FR 654) to estimate the market for the technologies. The result of this analysis, which is described in more detail in Appendix D, is a potential market of approximately 1,400 to 2,200 systems. It is a conservative (low) estimate of the market, because, as shown by the example discussed below under "Technology Acceptance and Use Outcomes," the technologies also can be scaled up for use by larger systems.

Reports from a technology vendor, discussed below under "Technology Acceptance and Use Outcomes," provide some evidence of market penetration. Because the ETV Program does not have access to comprehensive sales data for the ETV-verified technologies, the ETV Program used two market penetration scenarios, 10% and 25% of the potential market, to conservatively estimate health, economic, and regulatory compliance outcomes. Exhibit 3.1-2 lists the number of systems that are projected to apply

EXHIBIT 3.1–2

PROJECTED NUMBER OF SYSTEMS THAT WOULD APPLY THE ETV-VERIFIED MF AND UF TECHNOLOGIES

Market Penetration	Number of Systems	Population Served (number of people)
Lower Bound		
10%	140	220,000
25%	360	560,000
Upper Bound		
10%	220	340,000
25%	550	860,000

Values rounded to two significant figures

the ETV-verified technologies based on these market penetration scenarios. Exhibit 3.1-2 includes upper- and lower-bound estimates of the number of systems and population served because the LT2ESWTR included a range of estimates, based on differing data sources, of the number of systems serving less than 10,000 people. ETV's upper-bound estimate corresponds to the high end of the range presented in the LT2ESWTR and the lower-bound estimate corresponds to the low end.

Environmental and Health Outcomes

The human health benefits of removing *Cryptosporidium* from drinking water include the prevention of cases of cryptosporidiosis and related incidences of premature death. The ETV Program estimated the number of cryptosporidiosis cases and related deaths (see Exhibit 3.1-3) that could be avoided by using the ETV-verified MF and UF technologies based on data from the Economic Analysis (EA) for the LT2ESWTR (U.S. EPA, 2005a) and the market penetration scenarios described in the previous section.

Exhibit 3.1-3 includes upper- and lower-bound estimates because the EA presents a range of estimates for the health benefits to be realized from the LT2ESWTR, based on data from different sources about the number of systems and population served.[35] Appendix D presents the assumptions used in this analysis in greater detail.

EXHIBIT 3.1–3

ESTIMATED NUMBER OF CRYPTOSPORIDIOSIS CASES AND ASSOCIATED DEATHS PER YEAR PREVENTED BY ETV-VERIFIED MF AND UF TECHNOLOGIES

Market Penetration	Total Cases Prevented per Year (1)	Deaths Prevented per Year (2)
Lower Bound		
10%	1,100	0.1
25%	2,700	0.3
Upper Bound		
10%	5,300	0.9
25%	13,000	2

(1) Values rounded to two significant figures

(2) Values rounded to one significant figure

In addition to the prevention of cryptosporidiosis quantified above, the ETV-verified MF and UF technologies can prevent other negative human health outcomes associated with exposure to *Cryptosporidium*. These include reduction in risk to sensitive subpopulations and health risk during outbreaks. The technologies also can prevent negative human health outcomes associated with exposure to co-occurring/emerging pathogens, such as *Giardia*, *E. coli*, and viruses (U.S. EPA, 2005a).

The estimates in Exhibit 3.1-3 assume only small systems will apply the ETV-verified technologies. This assumption is conservative because, as shown by the example discussed below under "Technology Acceptance and Use Outcomes," the technologies can be scaled up for use by larger systems. If large systems are considered, the estimated benefits would increase to approximately 23,000 to 96,000 cases and 5 to 21 deaths prevented per year at 10% market penetration, with associated economic benefits.

Financial and Economic Outcomes

In addition to personal and societal impacts, disease prevention also has an economic benefit. For the LT2ESWTR, EPA quantified the economic value of the cryptosporidiosis cases avoided as a range based on differing assumptions

---

[35] These estimates (both upper- and lower-bound) are conservative (low) because they are based on the conservative estimates of the market for ETV technologies. In addition, many of the ETV technologies consistently provide *Cryptosporidium* removal in excess of that required by the LT2ESWTR and, thus, could provide even greater benefits.

about the value of preventing illness and the discount rate. The ETV Program estimated the economic benefits associated with the human health outcomes shown in Exhibit 3.1-3 based on the upper- and lower-bound economic estimates provided in EPA's EA for the LT2ESWTR (U.S. EPA, 2005a).

Exhibit 3.1-4 presents these estimates.[36] Appendix D presents the assumptions used in this analysis in greater detail. Additional economic benefits could result from the prevention of other human health outcomes discussed above and from including predicted impacts for large system applications.

EXHIBIT 3.1–4

ESTIMATED POTENTIAL PILOT TESTING SAVINGS FOR ETV-VERIFIED MF AND UF TECHNOLOGIES

	Million dollars per year	
Market Penetration	**Lower Bound**	**Upper Bound**
10%	0.80	7.4
25%	2.0	19

Values rounded to two significant figures

Regulatory Outcomes

States establish drinking water regulations to ensure that drinking water is safe and meets applicable drinking water standards. These rules can govern drinking water system design, construction, operation, and upkeep, including testing requirements for alternative/innovative treatment systems. In some cases, they also mention or recommend sources of performance information. For example, section R309-535-13 of Utah's Safe Drinking Water Act states that new drinking water treatment processes and equipment must be tested before plans can be approved for their use. It also states that the ETV Program facilitates deployment by verifying the performance of new technologies and refers engineers and manufacturers to ETV's partner, NSF International, for more information about testing package treatment processes (Utah, 2005). The state's Web site indicates that an ETV-verified drinking water technology can be accepted in Utah without further pilot plant testing (see quote below left). The State of Massachusetts has proposed changes to its regulations whereby, to obtain approval of a new drinking water technology in Massachusetts, a manufacturer must demonstrate that it has received a favorable review from third parties such as ETV or be piloted for multiple seasons (Massachusetts, 2006). The State of Washington requires that alternate technologies for surface water treatment undergo a stand-alone approval process and indicates that ETV testing protocols can be used to demonstrate adequate performance under this process (Washington, 2001). Citations like these indicate that ETV testing and data are valued by states and can provide information that can be used to approve technology use at the state level.

> "A number of treatment processes have undergone rigorous testing under the ETV Program. If a particular treatment process is a 'verified technology,' it may be accepted in Utah without further pilot plant testing."—Utah Department of Environmental Quality, Division of Drinking Water Web Site (Utah, 2006)

State acceptance of verification data can result in cost savings for drinking water systems that use the data to reduce the amount of pilot testing required by some state regulatory agencies. The results of a 2003 Association of State Drinking Water Administrators (ASDWA) survey show that a majority of states responding use ETV verification data to reduce the frequency and/or length of site-specific pilot tests. The survey found that 25 of the 38 states that responded use ETV data to reduce pilot testing for surface water systems and 20 states use ETV data to reduce pilot testing for ground water systems (ASDWA, 2003).

Although the survey report does not specifically mention the applications described in this case study, to receive removal credit (and therefore comply with the rule) for a given technology, the LT2ESWTR requires that prior testing be conducted in a manner that demonstrates a removal efficiency for *Cryptosporidium* commensurate with the treatment credit awarded to the process. EPA's guidance

---

[36] These estimates are conservative (low) because: (1) they are based on the conservative estimates of the number of cases prevented, and (2) they are in year 2003 dollars.

manual on using membrane filtration for the LT2ESWTR (U.S. EPA, 2005b) cites the NSF ETV test plan (NSF, 2005a) as an example of a protocol that can be used to conduct this testing economically (see quote at right).

Thus, it is reasonable to assume that ETV verification can reduce pilot study costs for drinking water treatment systems. To estimate national pilot study cost savings, the ETV Program assumed a pilot study cost of $20,000 (Adams, 2005). There can be significant variation in pilot study costs, depending on site-specific factors, state agency requirements, and technology type. The ETV Program developed upper- and lower-bound scenarios with a range of assumptions about the degree of pilot testing cost reduction. Appendix D presents the assumptions used in these scenarios in greater detail.

Exhibit 3.1-5 presents the estimated pilot testing cost savings depending on market penetration scenario.[37] In addition to cost savings, reducing the length of site-specific pilot tests provides an opportunity for water systems to comply with the LT2ESWTR requirements more quickly. Shorter pilot tests could result in systems achieving health benefits sooner than would otherwise be possible.

Exhibit 3.1–5

Estimated Pilot Testing Savings for the ETV-Verified MF and UF Technologies

Market Penetration	Million dollars Lower Bound	 Upper Bound
10%	0.29	3.3
25%	0.71	8.3

Values rounded to two significant figures

> "The evaluation of small-scale (as opposed to full-scale) modules during a challenge test is permitted under the LT2ESWTR to allow for cases in which it may not be feasible or practical to test a full-scale module … the use of a small-scale module may be the only economically viable alternative …. For the purposes of consistency, it is recommended that manufacturers or independent testing agencies that opt to subject a product line to challenge testing using small-scale modules utilize a protocol that has been accepted by a wide range of stakeholders. Such a protocol has been developed for use under the National Sanitation Foundation (NSF) Environmental Technology Verification (ETV) program."—U.S. EPA, 2005b

California has a process under the California Surface Water Treatment Rule for evaluating alternative filtration technologies, including MF and UF. California also has identified several of the ETV-verified technologies and/or vendors as having completed demonstrations, primarily in relation to turbidity. These alternatives are not intended to be applicable to any future regulations (i.e., finalization of the LT2ESWTR) until California officially updates its acceptance process (California Department of Health Services, 2001a). The results from the ETV demonstrations could assist in this state program.

Finally, EPA included the ETV verification reports for MF and UF technologies in the rulemaking docket for the LT2ESWTR (EPA-HQ-OW-2002-0039, which can be found at *http://www.regulations.gov*). Thus, the ETV results are part of the scientific and technology analysis that EPA performed in its decision-making process for the final rule.

Technology Acceptance and Use Outcomes

Vendor information indicates that municipalities are choosing to install the ETV-verified technologies. Following completion of ETV testing at its facility, the Pittsburgh Sewer and Water Authority (PSWA) chose one of the ETV-verified technologies for full-scale installation. The full-scale system treats 20 million gallons per day, demonstrating that the ETV technologies can be successfully scaled up for use at large systems. According to a representative of the PSWA, the technology was chosen, in part, because of the results of the ETV testing (see quote on next page). An evaluation by PSWA and its consultant showed the technology saved $5 million compared to conventional treatment technologies (Pall Corporation, undated). Because it represents a large system, this application also could result in significant health and associated economic benefits.

---

[37] These estimates are conservative (low) because they are based on the conservative estimates of the market for ETV technologies.

> "Results of our pilot testing showed that the Pall system was not only theoretically effective, but was able to exceed federally mandated standards under actual field conditions with water flowing through our distribution network. The system's small footprint and low wastewater rate, coupled with first-rate design effort, allowed Pall to submit the most competitive prices. The citizens of Pittsburgh are really excited that we will be able to preserve the beauty of our park while providing drinking water filtered to the highest levels available."—Mike Hullihan, Director of Engineering, Pittsburgh Water and Sewer Authority (Pall Corporation, 2006)

Scientific Advancement Outcomes

NSF and ETV have recently developed an updated protocol for testing technologies, including MF and UF, for removal of microbiological contaminants (NSF, 2005a). This protocol incorporates new alternative testing procedures to address the LT2ESWTR (Adams, 2006; U.S. EPA, 2004a). EPA's guidance manual on using membrane filtration for the LT2ESWTR (U.S. EPA, 2005b) specifically cites this protocol, as discussed above under "Regulatory Compliance Outcomes."

ACRONYMS USED IN THIS CASE STUDY:

ASDWA	Association of State Drinking Water Administrators	MCLG	maximum contaminant level goal
DWS Center	ETV's Drinking Water Systems Center	MF	microfiltration
EA	Economic Analysis	PSWA	Pittsburgh Sewer and Water Authority
LT2ESWTR	Long Term 2 Enhanced Surface Water	UF	ultrafiltration

3.2

Nanofiltration for Removal of Disinfection Byproduct (DBP) Precursors

The ETV Program's Drinking Water Systems (DWS) Center, operated by NSF International under a cooperative agreement with EPA, verified the performance of a nanofiltration system manufactured by PCI Membrane Systems Inc. (PCI). The technology is a transportable, package system designed for small drinking water systems. It is designed to remove microbial contaminants and reduce organic matter that can act as a precursor in the formation of disinfection byproducts (DBPs). Research links DBPs, which include total trihalomethane (TTHM) and the sum of five haloacetic acids (HAA5), with cancer. Studies also show a possible association between DBPs and other, non-cancer human health effects. Under the Stage 1 Disinfectants and Disinfection Byproducts Rule (DBPR), EPA has set standards for TTHM and HAA5 in drinking water of 80 and 60 micrograms per liter (µg/L), respectively. EPA also has enacted the Stage 2 DBPR to further reduce disinfection byproducts in drinking water systems with the highest risk levels. As a result of the Stage 1 and 2 DBPRs, certain drinking water systems must use treatment technologies similar to the ETV-verified PCI system to control formation of DBPs by removing the organic precursors.

Based on the analysis in this case study and 25% market penetration, the ETV Program estimates that:

- The ETV-verified PCI nanofiltration technology would assist 1,200 small drinking water systems (out of 4,800 systems) comply with EPA's DBP standards.
- At these systems, the technology could prevent up to 20 cases of bladder cancer per year.[38] The technology also could prevent other negative human health effects, including developmental and reproductive effects.
- The technology could result in economic benefits of up to $110 million per year[39] due to the prevention of the above cases of bladder cancer.

Verification has also increased awareness of the ETV-verified nanofiltration technology and its benefits among state regulatory agencies and potential users. The following benefits have been or can be realized from the availability and use of the ETV data:

- Twenty-five states reportedly use ETV verification data to reduce the frequency and/or length of site-specific pilot tests for drinking water treatment and the vendor has

---

[38] In 71 FR 388, EPA acknowledges that causality has not yet been established between chlorinated water and bladder cancer and that the actual number of cases attributable to DBPs could be zero. Therefore, the actual number of cases avoided could be as low as zero.

[39] In year 2003 dollars. Because causality has not been established, the actual economic value of bladder cancer cases avoided could be as low as zero.

reported this result in several installations of this technology. Drinking water regulations and guidance in several states identify the ETV Program as a source of performance verification data and testing protocols.

- Assuming 25% market penetration, 1,200 systems would use ETV data to reduce pilot testing requirements, saving up to $18 million in pilot testing costs.
- The reduction in pilot testing length also could lead to systems achieving the above health benefits sooner than would otherwise be possible.
- ETV verification has led to sales of the technology by the vendor, potentially resulting in reductions in exposure to DBPs with human health and associated economic benefits.

3.2.1 Environmental, Health, and Regulatory Background

In the United States, more than 48,000 public water systems serving nearly 260 million people chemically disinfect their water (U.S. EPA, 2005c). Chemical disinfectants, however, can react with anthropogenic and naturally occurring compounds in the water to form DBPs. Since the discovery of DBPs in 1974, research has shown that some DBPs, including TTHM and HAA5, could be associated with increased risks of bladder and other cancers (71 FR 388; NSF, 2004). While causality has not been established, EPA believes that the weight of evidence supports the link between cancer and exposure to DBPs (71 FR 388).

In addition, recent studies show a possible association between exposure to DBPs and an increased risk of adverse reproductive and developmental health effects. These health effects include early-term miscarriage, stillbirth, low birth weight, and other birth defects. While the data in these studies are not sufficient to support a conclusion that exposure to DBPs causes these health effects, EPA believes the evidence supports potential health concerns associated with DBP exposure (U.S. EPA, 2005c; 71 FR 388).

To help address the potential health effects of DBPs, EPA has developed rules to control DBP formation. These rules, the Stage 1 and Stage 2 DBP rules, are part of a set of regulations that address risks from microbial pathogens and disinfectants/disinfection byproducts. The Stage 1 DBP Rule was promulgated to reduce long-term exposure to DBPs and cancer health risk. The Stage 1 DBP Rule set maximum contaminant levels for TTHMs and HAA5 at 80 and 60 µg/L, respectively, and required precursor removal measured as total organic carbon. The Stage 2 DBPR builds on the 1979 Total Trihalomethane Rule and the 1998 Stage 1 DBPR to decrease exposure to DBPs. The requirements of the Stage 2 DBPR apply to water systems that add a disinfectant other than ultraviolet light (UV) or deliver water that has been treated with a disinfectant other than UV. The Stage 2 DBPR maintains the standards at 80 µg/L TTHM and 60 µg/L HAA5, but requires reporting measured as locational running annual averages instead of the Stage 1 running annual average monitoring. The use of locational running annual averages targets short-term exposure to DBPs to address potential reproductive and developmental effects (71 FR 388).

Small drinking water systems, which EPA defines as those that serve fewer than 10,000 people each, were required to comply with the Stage 1 DBPR by January 1, 2004 (U.S. EPA, 2001b; 63 FR 69390). Under the Stage 2 DBPR, small systems must conduct initial evaluations by July 2010 and begin full compliance monitoring by October 2013 (U.S. EPA, 2005d). Additionally, consecutive systems that get their water from upstream systems must perform evaluations at the same time as the parent systems. EPA estimates that these systems will begin installing treatment to comply with the Stage 2 DBPR in 2010 (U.S. EPA, 2005c).

EPA estimated that nearly 13,000 drinking water systems would have to install treatment to comply with the Stage 1 DBPR. Of these systems, more than 90% (or nearly 12,000) were small systems (63 FR 69390). In addition, EPA estimates that more than 2,200 drinking water systems will have to install treatment processes to comply with the Stage 2 DBPR. Of these systems, nearly 80% (or approximately 1,700) are small systems (U.S. EPA, 2005c). The ETV-verified PCI nanofiltration technology is designed for use by these small systems (NSF, 2000i, 2004) and EPA includes nanofiltration among the best available technologies (BATs) for compliance with the Stage 1 and Stage 2 DBPRs (63 FR 69390; 71 FR 388).

3.2.2 Technology Description

The ETV Program has verified the performance of a nanofiltration technology used in package drinking water treatment systems: the PCI Membrane Systems Fyne Process Model ROP 1434 with AFC-30 nanofiltration membranes. Nanofiltration employs a molecular membrane barrier to remove microbial contaminants and other small particles, including DBP precursors such as organic matter. The system tested was equipped with a membrane module containing 72 tubular polyamide nanofiltration membranes connected in series. The PCI system was originally developed to treat waters with high concentrations of organic materials. The technology is designed to both remove microbial contaminants and reduce organic content that acts as a precursor in the formation of DBPs. The system's small footprint, modular construction, and performance characteristics make it suited to applications from the smallest to up to 50,000 gallons per day (NSF, 2000i; NSF, 2004; Howorth, 2006). One innovative characteristic of the technology is the automated cleaning process it employs (see quote at right).

The ETV Program conducted verification testing for 57 consecutive days at the Barrow Utilities Electric Cooperative Incorporated in Barrow, Alaska. Barrow is an Inupiat Eskimo village that draws raw water year round from Isatkoak Reservoir, a surface water source that has moderate alkalinity, moderate turbidity, and an elevated organic content. The testing verified that the nanofiltration membrane effectively removed organic compounds and particulates from the source water. The system reduced raw water total organic content by over 95%. As a result, the treatment system was able to reduce the source water TTHM and HAA5 concentration by 94% and 98%, respectively, and produced treated water that contained an average of 31 ppb TTHM and 6.2 ppb HAA5. The test skid also removed 47% to 99% of iron, manganese, calcium, and sulfate from solution. The testing also confirmed modest reductions in source water alkalinity (10%) and total dissolved solids concentration (34.5%) (NSF, 2000i).

> "A unique and innovative feature of the PCI nanofiltration system is the use of the Fyne Process, an automated foam ball cleaning process to remove accumulated organic and inorganic foulants from the membrane surface. A valve arrangement allows for a flow direction change through the membrane tubes. As the foam ball passes down the membrane tubes, accumulated foulants are removed. 'Filter-catchers' (small, perforated plates installed in the module inlet and outlet lines) retain the foam-balls in the system. Cleaning frequency is adjustable and the entire process is fully automated."—NSF, 2004

The ETV Program also verified chemical cleaning performance. A single high pH chemical cleaning cycle at the end of the two-month continuous verification test recovered at least 100% of the transmembrane pressure and specific flux measured at the start of the study. Finally, the ETV tests examined operation and maintenance needs, including labor and power requirements (NSF, 2000i). The verification report (NSF, 2000i) can be found at *http://www.epa.gov/etv/verifications/vcenter2-7.html.*

The PCI Nanofiltration Technology

3.2.3 Outcomes

The most likely market for the ETV-verified PCI nanofiltration technology includes small drinking water systems serving less than 10,000 people that must install or modify treatment systems to comply with the Stage 1 and Stage 2 DBPRs.[40] The ETV Program used data from the Stage 1 DBPR (63 FR 69390) and the Economic Analysis (EA) for the Stage 2 DBPR (U.S. EPA, 2005c) to estimate the market. The result of this analysis, which is described in more detail in Appendix E, is a potential market of approximately 4,800 systems. It is a conservative (low) estimate of the market because it only includes small systems that were projected to select membranes as of 1998, as discussed in Appendix E.

Reports from the technology vendor, discussed below under "Technology Acceptance and Use Outcomes," provide some evidence of market penetration. Because the ETV Program does not have access to a comprehensive set of sales data for the PCI nanofiltration technology, the ETV Program used two market penetration scenarios, 10% and 25% of the potential market, to estimate health, economic, and regulatory compliance outcomes. Exhibit 3.2-1 lists the number of systems that would apply the technology based on these market penetration scenarios.

> "...Some small systems may find nanofiltration cheaper than [granular activated carbon] … if their specific geographic locations cause a relatively high cost for routine [granular activated carbon] shipment."
> —71 FR 388 (page 413)

EXHIBIT 3.2–1

PROJECTED NUMBER OF SYSTEMS THAT WOULD APPLY THE PCI NANOFILTRATION TECHNOLOGY

Market Penetration	Number of Systems	Population Served (number of people)
10%	480	330,000
25%	1,200	830,000

Values rounded to two significant figures

Environmental and Health Outcomes

EPA has determined that reducing DBPs in drinking water could provide significant health benefits, including the prevention of bladder cancer (71 FR 388). The ETV Program estimated the number of bladder cancer cases (see Exhibit 3.2-2) that could potentially be avoided by using the ETV-verified PCI nanofiltration technology based on data in the Stage 1 DBPR (63 FR 69390), the EA for the Stage 2 DBPR (U.S. EPA, 2005c) and the market penetration scenarios described in the previous section.[42] Appendix E presents the assumptions used in this analysis in greater detail.

In addition to the prevention of bladder cancer quantified above, the PCI nanofiltration technology could reduce other negative human health outcomes potentially associated with exposure to DBPs. These include adverse reproductive and developmental health effects and other health effects (U.S. EPA, 2005c; 71 FR 388).

EXHIBIT 3.2–2

ESTIMATED NUMBER OF BLADDER CANCER CASES PER YEAR POTENTIALLY PREVENTED BY THE PCI NANOFILTRATION TECHNOLOGY

Market Penetration	Number of Cases Prevented[41]
10%	8.0
25%	20

Values rounded to two significant figures

---

[40] Although EPA forecasts that few systems would use nanofiltration for compliance with the Stage 2 DBPR (Chen, 2005; U.S. EPA, 2005c), EPA did list nanofiltration as a BAT for the Stage 2 rule (71 FR 388). EPA also found that some small systems could find nanofiltration cheaper than another BAT alternative, granular activated carbon (see quote above). Therefore, nanofiltration is a reasonable technology alternative for compliance with the Stage 2 rule.

[41] In 71 FR 388, EPA acknowledges that causality has not yet been established between chlorinated water and bladder cancer and that the actual number of cases attributable to DBPs could be zero. Therefore, the actual number of cases avoided could be as low as zero.

[42] These estimates are conservative (low) because they are based on the conservative estimates of the market for ETV technologies. However, because causality has not been established, the actual lower-bound estimate could be as low as zero.

Financial and Economic Outcomes

In addition to personal and societal impacts, cancer prevention also has an economic benefit. For the Stage 2 DBPR, EPA quantified the economic value of the bladder cancer cases that could be avoided as a range based on differing assumptions about the value of preventing non-fatal cancer cases and the discount rate. Based on these assumptions, the ETV Program estimated the economic benefits associated with the potential human health outcomes shown in Exhibit 3.2-2.[44] Exhibit 3.2-3 presents the economic estimates.[45] Appendix E presents the assumptions used in this analysis in greater detail. Additional economic benefits could result from the prevention of the other human health outcomes discussed above. The vendor also indicates that, because the verified technology is largely chemical free, that is, it uses no coagulants, that it can be cost competitive compared to other technologies (Howorth, 2006).

Exhibit 3.2–3

Estimated Potential Economic Benefits of Bladder Cancer Prevention by the PCI Nanofiltration Technology[43]

	Million Dollars per year	
Market Penetration	Lower Bound	Upper Bound
10%	18	44
25%	44	110

Values rounded to two significant figures

Regulatory Compliance Outcomes

States establish drinking water regulations to ensure that drinking water is safe and meets applicable drinking water standards. These rules can govern drinking water system design, construction, operation, and upkeep, including testing requirements for alternative/innovative treatment systems. In some cases, they also mention or recommend sources of performance information. For example, section R309-535-13 of Utah's Safe Drinking Water Act states that new drinking water treatment processes and equipment must be tested before plans can be approved for their use. It also states that the ETV Program facilitates deployment by verifying the performance of new technologies and refers engineers and manufacturers to ETV's partner, NSF International, for more information about testing package treatment processes (Utah, 2005). The state's Web site indicates that an ETV-verified drinking water technology can be accepted in Utah without further pilot plant testing (see quote below). The State of Massachusetts has proposed changes to its regulations whereby, to obtain approval of a new drinking water technology in Massachusetts, a manufacturer must demonstrate that it has received a favorable review from third parties such as ETV or be piloted for multiple seasons (Massachusetts, 2006). The State of Washington requires that alternate technologies for surface water treatment undergo a stand-alone approval process and indicates that ETV testing protocols can be used to demonstrate adequate performance under this process (Washington, 2001). Citations like these indicate that ETV testing and data are valued by states and can provide information that can be used to approve technology use at the state level.

State acceptance of verification data can result in cost savings for drinking water systems that use the verification data to reduce the amount of pilot testing required by some state regulatory agencies. This outcome is supported by reports from the vendor that, in the example applications discussed below under "Technology Acceptance

> "A number of treatment processes have undergone rigorous testing under the ETV Program. If a particular treatment process is a 'verified technology,' it may be accepted in Utah without further pilot plant testing."
> —Utah Department of Environmental Quality, Division of Drinking Water Web Site (Utah, 2006)

---

[43] Again, because causality has not yet been established, the actual lower-bound estimate could be as low as zero.

[44] For the Stage 1 DBPR, EPA used different assumptions about the economic value of avoiding bladder cancer. The ETV Program used the Stage 2 economic valuation assumptions because they are based on more recent economic data.

[45] These estimates are conservative because they are in year 2003 dollars. For comparison, using the Stage 1 assumptions, the economic benefits would be $14 million per year at 10% market penetration and $35 million per year at 25% market penetration in 1998 dollars. In either case, however, because causality has not yet been established, the actual lower-bound estimate could be as low as zero.

and Use Outcomes," the cost of pilot testing was avoided as a result of the data available from the ETV verification test (NSF, 2004, 2005b). In addition, the results of a 2003 Association of State Drinking Water Administrators (ASDWA) survey indicate that most states responding use ETV verification data to reduce the frequency and/or length of site-specific pilot tests. The survey found that 25 of the 38 states that responded to the survey use ETV data to reduce pilot testing for surface water systems and 20 states use ETV data to reduce pilot testing for ground water systems (ASDWA, 2003). Although the survey report does not mention the applications described in this case study, it is reasonable to assume that ETV verification can reduce pilot study costs for DBP removal.

To estimate national pilot study cost savings, the ETV Program assumed a pilot study cost of $20,000 (Adams, 2005). There can be significant variation in pilot study costs, depending on site-specific factors, state agency requirements, and technology type, the ETV Program developed upper- and lower-bound scenarios with a range of assumptions about the degree of pilot testing cost reduction. Appendix E presents the assumptions used in these scenarios in greater detail.

Exhibit 3.2-4 presents the estimated pilot testing cost savings depending on market penetration scenario.[46] In addition to cost savings, reducing the length of site-specific pilot tests provides an opportunity for water systems to comply with the Stage 2 DBPR requirements more quickly. Shorter pilot tests could result in systems achieving potential health benefits sooner than would otherwise be possible.

Exhibit 3.2–4

Estimated Pilot Testing Savings for the PCI Nanofiltration Technology

Market Penetration	Million dollars Lower Bound	 Upper Bound
10%	1.0	7.2
25%	2.4	18

Values rounded to two significant figures

Technology Acceptance and Use Outcomes

Vendor information shows that small drinking water systems are choosing to install the ETV-verified nanofiltration technology. PCI has reported that it has installed at least five new treatment systems based on the ETV verification testing. These installations have generated more than $1 million in sales for the vendor. Thus, given the cost of participating in the testing, ETV verification has been a good return on the vendor's investment (NSF, 2005b). The vendor also reports that it has installed systems using the Fyne Process cleaning system in 60 rural communities in Europe and North America (Howorth, 2006). Examples of organizations that have chosen to install the technology include the following:

- An industrial customer in Alaska chose a six-gallon-per-minute system to treat its potable water supply (NSF, 2004).
- The Lower Kushkokwim School District, which serves small communities in Alaska and covers an area the size of Ohio, installed one-gallon-per-minute systems in three of its schools (NSF, 2004; Water & Wastes Digest, 2005).
- The Conne River Micmac First Nation community in the Canadian Province of Newfoundland, with a population of approximately 700 people, selected a 1.3 million-liter-per-day (approximately 240 gallons per minute) system because of savings on chemical supplies and sewage disposal costs and the high quality of the water produced (InfraStructures, 2004).

Each of these applications could result in health and economic benefits.

The National Rural Water Association chose one of the schools served by the technology as having the best-tasting water in the nation in its Great American Water Taste Test, a competition involving water systems from 48 state rural water associations (Water & Wastes Digest, 2005). This outcome suggests that the technology can improve the aesthetic quality of the water it treats.

---

[46] These estimates are conservative (low) because they are based on the conservative estimates of the market for ETV technologies.

ACRONYMS USED IN THIS CASE STUDY:

ASDWA	Association of State Drinking Water Administrators	HAA5	the sum of five haloacetic acids
BAT	best available technology	PCI	PCI Membrane Systems Inc.
DBPR	Disinfectants and Disinfection Byproducts Rule	TTHM	total trihalomethane
DBP	disinfection byproduct	UV	ultraviolet light
DWS Center	ETV's Drinking Water Systems Center	µg/L	micrograms per liter
EA	Economic Analysis		

3.3

Immunoassay Test Kits for Atrazine in Water

The ETV Program's Advanced Monitoring Systems (AMS) Center, operated by Battelle under a cooperative agreement with EPA, has verified the performance of four immunoassay test kits for atrazine. These test kits provide results within hours for atrazine in various drinking water and environmental water matrices, allowing the user to quickly identify and take corrective actions to reduce atrazine levels or mitigate exposure if detected at levels of concern. Atrazine is an herbicide that is widely used in agriculture for corn, sorghum, and other crops. Because of its frequent usage and concern about its health and environmental effects, EPA established a drinking water standard for atrazine in 1991 of three parts per billion (ppb). EPA is currently re-evaluating the drinking water standard to determine if a revision is needed. As part of the Interim Reregistration Eligibility Decision (IRED) for atrazine in 2003, EPA updated the human health risk assessment for atrazine. The IRED also required additional atrazine monitoring for certain vulnerable public drinking water systems and watersheds.

Based on the analysis in this case study and 25% market penetration, the ETV Program estimates that:

- The test kits would be used at 240,000 private water wells, 960 community surface water systems, and 2,500 watersheds (out of 940,000 private water wells, 3,900 community water systems, and 10,000 watersheds) to provide timely information on atrazine levels in water. This estimate includes systems and watersheds that require additional monitoring under the IRED.
- The information provided by the test kits can be used to identify whether mitigation is needed to reduce atrazine levels. Ultimately, this information can assist in the reduction of atrazine exposure, with associated environmental and human health benefits.
- The test kits would reduce monitoring costs and save time, since the immunoassay analyses used by the verified technologies cost approximately five times less than gas chromatography/mass spectrometry (GC/MS) laboratory analyses and have significantly shorter sample turnaround times (hours versus days).[47] National sampling cost savings would be $5,000,000 per year,[48] assuming the test kits partially replace GC/MS in model sampling programs at 960 community surface water systems and 2,500 watersheds.

In addition, the ETV verification results have been used by state and federal agencies, including the State of Nebraska and the National Oceanic and Atmospheric Administration (NOAA), and other organizations as a basis for purchasing ETV-verified atrazine test kits. EPA also is using the data from the verification studies in deciding

---

[47] This cost savings is most apparent when atrazine is the only contaminant of concern for laboratory analysis.
[48] In late 1990s dollars.

whether to withdraw or modify one of the approved analysis methods used for monitoring compliance with drinking water regulations.

3.3.1 Environmental, Health, and Regulatory Background

Atrazine is a common herbicide or weed killer used in the United States. Approximately 76.5 million pounds of atrazine are used annually in formulations of various products (U.S. EPA, 2003e). These products are widely applied to a variety of crops, primarily corn and sorghum, and are also used in nonagricultural (e.g., residential) applications. Following application, atrazine is absorbed by plants or disperses in the environment through: (1) surface water runoff; (2) ground water seepage; (3) primary spray drift settling on adjacent terrestrial and aquatic habitat; or (4) air dispersion and precipitation. Concentrations of atrazine observed in surface water are seasonal. That is, they increase in the growing season. Atrazine is mobile and persistent in the environment and can be found in surface water and ground water (U.S. EPA, 2003e).

As part of its IRED for atrazine, EPA evaluated atrazine's ecological and environmental effects. Atrazine is slightly to highly toxic to fish and slightly to highly toxic to invertebrates, depending on species. Atrazine is slightly toxic to mammals and birds, and toxic to non-target plants. Coupling these toxic effects to exposure scenarios in its IRED, EPA found that atrazine in the environment could reach levels that are likely to have an impact on sensitive aquatic species, particularly during seasonal variations in atrazine concentrations in ponds, lakes or reservoirs, streams, and estuaries (U.S. EPA, 2003e).

In toxicological studies with animals, atrazine has been shown to disrupt the hypothalamic-pituitary-gonadal axis, part of the central nervous system, causing cascading changes to hormone levels, developmental delays, and reproductive consequences. These effects are considered relevant to humans and are biomarkers of a neuroendocrine mechanism of toxicity that is shared by several other structurally-related chlorinated triazines including atrazine, propazine, and three chlorinated degradates – G-28279 (des-isopropyl atrazine), and G-30033 (des-ethyl atrazine), and G-28273 (diaminochlorotriazine) (U.S. EPA, 2003e).

To help address the potential long-term human health effects of atrazine in drinking water, EPA established a maximum contaminant level (MCL) of 3 ppb under the Safe Drinking Water Act in 1991. Community water systems are required to ensure that atrazine is below this level. Systems that have historically observed atrazine concentrations above 1 ppb are required to monitor quarterly for atrazine under the Safe Drinking Water Act (U.S. EPA, 2005i). Under the six-year review of regulated contaminants required by the Safe Drinking Water Act, EPA has begun revisiting the MCL for atrazine to determine if a revision is appropriate. This re-evaluation will consider the updated human health risk assessment from the reregistration process for atrazine discussed below.

In 2003, EPA's Office of Pesticide Programs completed an IRED for atrazine following a detailed review of the potential human health and ecological risks from the triazine pesticides, including atrazine, simazine, propazine, and three chlorinated degradates. The Agency has since completed a cumulative risk assessment for the chlorinated triazine class of pesticides and concluded that, with the mitigation measures in the individual atrazine and simazine decisions, cumulative risks are below EPA's Food Quality Protection Act (FQPA) regulatory level of concern. EPA's earlier IRED and Revised IRED for atrazine are considered final, and the tolerance reassessment and reregistration eligibility process for atrazine is complete. As part of the Agency's determination that atrazine is eligible for reregistration, EPA and atrazine registrants developed a Memorandum of Agreement, under which the registrants and formulators of atrazine are required to implement additional steps to protect human health and the environment (U.S. EPA, 2003g). These steps include:

- *A drinking water monitoring program:* This program is designed to detect levels of atrazine and its chlorinated degradates that could result in health concerns from short-term exposure (i.e., shorter than the exposure periods considered in setting the MCL). The program requires registrants to conduct more frequent sampling than that required under the Safe Drinking Water Act in community water systems served by surface water sources that have historically elevated atrazine levels. EPA is requiring a minimum of biweekly sampling and analysis, with weekly sampling during the use season (e.g., when atrazine is applied to crops), for a duration of at least five years. These systems and all other community water systems also are continuing to perform monitoring under the requirements of the Safe Drinking Water Act. EPA has additionally established a trigger level for all community water systems served by surface water that, if exceeded, would require the registrants to monitor systems more frequently than stipulated in the IRED. Safe Drinking Water Act monitoring data will be the primary source for determining if this trigger is met. An estimated 130 community water systems will require intensive monitoring under this program. EPA also requires monitoring for rural drinking water wells.

- *An ecological monitoring program:* This program focuses on watersheds known to be vulnerable to the impacts of atrazine use. EPA requires registrants to perform initial monitoring of flowing water bodies (i.e., streams) in a statistical sample of 40 watersheds associated with corn and sorghum production. Requirements include identifying multiple monitoring sites in the streams and collecting samples every four days during the growing season for at least two years. Following this monitoring, EPA will identify whether further monitoring is needed for the 1,172 most vulnerable watersheds. Registrants also are conducting a program to monitor atrazine levels in watersheds associated with sugarcane producing areas, and programs are being considered for estuaries and static water bodies (U.S. EPA, 2003e, 2003f).

State regulators also have an interest in monitoring for atrazine. For example, in 2004, the State of Minnesota conducted sampling at 71 public and private wells to assess atrazine levels (Minnesota Department of Agriculture, 2005).

One of the verified immunoassay test kits

Other states, such as Nebraska, regularly conduct atrazine monitoring in watersheds.

3.3.2 Technology Description

To help address concerns about the environmental impacts of atrazine, the ETV Program has verified four atrazine test kits that measure atrazine levels in water samples. The verified test kits are portable, use immunoassay methods, and are designed to provide near real-time information (e.g., within hours) about atrazine concentrations in environmental and drinking water samples. Conventional laboratory methods use GC/MS to measure atrazine in water. GC/MS can be more costly and time consuming than the test kits, as discussed in Section 3.3.3. Thus, the test kits can offer advantages over GC/MS in terms of time and cost, although they might not completely substitute for laboratory analysis when determining compliance with regulatory requirements.[49]

---

[49] For example, EPA's approved methods for measuring atrazine for drinking water compliance monitoring currently include an immunoassay method. EPA, however, is considering modifying or withdrawing this method, as discussed in Section 3.3.3.

All of the verified test kits are based on colorimetric immunoassay methods, which use specific antibodies to detect and measure atrazine. In some cases, structurally similar compounds also can be detected to varying degrees and be quantified as atrazine as a result of cross-reactivity. Three of the verified test kits provide quantitative results, while the fourth is a qualitative method (i.e., the technology identifies if the sample exceeds the MCL, but does not provide a quantitative measurement) (Battelle, 2004b, 2004c, 2004d, 2004e). Exhibit 3.3-1 identifies the ETV-verified technologies and indicates the type of result each provides.

EXHIBIT 3.3–1

ETV-VERIFIED IMMUNOASSAY TEST KITS FOR ATRAZINE IN WATER

Technology	Type of Result
Abraxis LLC Atrazine ELISA Kit	Quantitative
Beacon Analytical Systems, Inc. Atrazine Tube Kit	Quantitative
Silver Lake Research Corporation Watersafe® Pesticide Kit	Qualitative
Strategic Diagnostics, Inc. RaPID Assay® Kit	Quantitative

Sources: Battelle 2004b, 2004c, 2004d, 2004e.

The verification tests were conducted in September 2003 on surface water samples collected in South Carolina, ground water samples from an aquifer on the Missouri River, and chlorinated drinking water samples from a Battelle laboratory in Duxbury, Massachusetts. A staff member from the Texas Commission on Environmental Quality (Texas CEQ) analyzed the samples using the immunoassay test kits at the Battelle laboratory. EPA's Office of Prevention, Pesticides, and Toxic Substances analyzed the split samples by GC/MS according to modified EPA Method 525.2 at the EPA Environmental Chemistry Laboratory. The AMS Center also collaborated with NOAA and the University of Missouri-Rolla, who collected the environmental samples (Battelle, 2004b, 2004c, 2004d, 2004e).

The ETV Program evaluated the test kits for the following parameters: accuracy, linearity, matrix interference, rate of false positives/negatives, precision, method detection limit, cross-reactivity, and sample throughput. Various matrices were analyzed, including performance test samples using ASTM water and the environmental samples discussed above. Results from the GC/MS reference analyses performed by OPPTS were used, in part, to define the occurrence of false positives and false negatives for the test kits. Control samples, analyzed in accordance with vendor instructions using a sample supplied by the vendor, were used to verify that the test kits were calibrated properly and reading within defined control limits. Exhibit 3.3-2 summarizes some of the performance data for the verified technologies. Because the ETV Program does not compare technologies, the performance results shown in Exhibit 3.3-2 do not identify the vendor associated with each result and are not in the same order as the list of technologies in Exhibit 3.3-1. Also, additional information on the quality assurance and quality control procedures employed during testing can be found in the verification reports (Battelle, 2004b, 2004c, 2004d, 2004e), which are posted at *http://www.epa.gov/etv/verifications/vcenter1-28.html.*

Accuracy, precision, and linearity were determined for the three test kits that provide quantitative results. The ETV Program verified that the average relative accuracy for the monitors, calculated as percent recovery, ranged from 82% to 171% depending on the matrix analyzed. A result of 100% indicates perfect accuracy compared to the tested atrazine concentration. The concentrations of atrazine as measured by several of the test kits were found to be biased high. The precision, as relative standard deviation, ranged from 0.9% to 51.1%. A result of 0% indicates perfect precision. The ETV Program used linear regression to correlate the test kits over the range of atrazine concentrations tested (0.1 to 5 ppb). The slope values ranged from 0.81 to 1.23; the intercept values ranged from -0.025 to 0.26 ppb; and the correlation coefficient (r) values ranged from 0.9575 to 0.9950.[50] The frequency

---

[50] Slope and intercept are measures of the relationship between test kit response and the standard or reference method value. The degree to which the slope deviates from a value of 1 and the intercept deviates from zero are indicators of the test kit's accuracy or comparability to the reference method. The correlation coefficient r is a measure of how well observed data fit a linear relationship. Values of r range from 0 to 1, with values closest to 1 indicating a better fit. Thus, an r value near 1 indicates a high linearity over the range of concentrations tested and high comparability to the standard test method.

Exhibit 3.3–2

Performance of ETV-Verified Immunoassay Test Kits for Atrazine in Water[51]

Technology	Accuracy (percent recovery) (2)	Precision (relative standard deviation)	Rate of false positives	Rate of false negatives	Linearity (slope, intercept, r) (3)	Sample throughput (4)
A	PT: 96 to 151% Env: 102 to 156%	PT: 0.9 to 51.1% Env: 2.6 to 16.7%	4 of 38 (11%)	none	Slope: 0.93 Intercept: 0.26 r: 0.9950	50–60 samples in 1.5 hours (27–40 per hour)
B	PT: 102 to 127% Env: 100 to 140%	PT: 6.9 to 24.1% Env: 3.5 to 15.2%	4 of 38 (11%)	none	Slope: 1.23 Intercept: –0.025 r: 0.9937	50 samples in 1 hour
C	PT: 82 to 133% Env: 83 to 171%	PT: 5.0 to 25.4% Env: 3.9 to 22.8%	6 of 38 (16%)	none	Slope: 0.81 Intercept: 0.24 r: 0.9575	30 samples in 1 hour
D (1)	PT: 18 of 21 Env: 31 of 36	PT: 7 of 7 Env: 9 of 12	8 of 56 (14%)	none	Not evaluated	0 samples in ½ hour (20 per hour)

(1) The technology used by Vendor D is a qualitative method (i.e., the technology identifies if the sample exceeds the MCL, but does not provide a quantitative measurement). In this case, "accuracy" refers to the number of accurate results out of the total number of tests, and "precision" is the number of consistent sets of replicate sample results out of total number of sets.

(2) PT = Performance test samples; Env = Environmental samples (overall range for all environmental samples)

(3) Linearity was assessed using PT samples

(4) Sample throughput includes calibration standards, QC samples, and test samples

Sources: Battelle, 2004b, 2004c, 2004d, 2004e.

of false positive and false negative readings was measured for all four of the test kits. For the three quantitative technologies, between 4 and 6 of 38 samples evaluated were false positive readings. That is, the test kit identified that atrazine was present, but the actual atrazine concentration was less than the lowest calibration standard of 0.1 ppb. For the fourth technology, 8 of 56 samples evaluated were false positive readings compared to a 3 ppb threshold level. No false negative readings were identified for any of the four technologies (Battelle, 2004b, 2004c, 2004d, 2004e).

The costs of the technologies were reported by the vendors. For the kits providing quantitative measurements, costs ranged from $230 for a set of 30 tubes to $510 for a set of 100 tubes. For the kit providing qualitative measurements, costs were $60 for a set of 10 packets, with each packet containing a test vial, pipette, and single test strip. The quantitative kits require additional equipment such as pipettes and a photometer.

3.3.3 Outcomes

The market for the ETV-verified atrazine test kits includes users that monitor community water systems, private water wells, and watersheds. The ETV Program developed the following estimates of the market for each category:

- *Community Water Systems:* Based on data from the IRED (U.S. EPA, 2003e) and U.S. EPA (2005m), the ETV program estimates that approximately 3,900 community surface water systems are located in atrazine use areas.[52] Because systems using surface water are those most likely to be affected by atrazine (U.S. EPA, 2003e), the ETV Program limited its estimate of the potential market in this category to surface water systems.
- *Private Water Wells:* Based on data from several sources (U.S. Department of Agriculture, 2004; InfoPlease, 2000; U.S. Census Bureau, 1990), the ETV Program estimates that

---

[51] Because the ETV Program does not compare technologies, the performance results shown in Exhibit 3.3-2 do not identify the vendor associated with each result and are not in the same order as the list of technologies in Exhibit 3.3-1.

[52] U.S. EPA (2005m) reported there are 11,574 community surface water systems in the United States. The IRED (U.S. EPA, 2003e) conducted exposure assessments for 33% of these systems and reported that this 33% represents 99% of atrazine use. Thus, the total number of community surface water systems in atrazine use areas would be 11,574 x 0.33 / 0.99 = approximately 3,900.

approximately 940,000 private wells are present in atrazine use areas.[53] This number represents the potential market of private wells that could apply the ETV-verified test kits.

- *Watersheds:* As part of the IRED, EPA identified approximately 10,000 watersheds where atrazine is used for corn and sorghum production (U.S. EPA, 2003f). This number represents the potential market of watersheds that could apply the ETV-verified test kits.

Reports from state regulators and vendors, discussed below under "Technology Acceptance and Use Outcomes," provide some evidence of market penetration. Because the ETV Program does not have access to a comprehensive set of sales data for the ETV-verified test kits, ETV used two market penetration scenarios, 10% and 25% of the potential market, to estimate the number of locations that would adopt the technologies, as shown in Exhibit 3.3-3.

Pollutant Reduction, Environmental, and Human Health Outcomes

As discussed in Section 3.3.1, atrazine is likely to have an adverse impact on sensitive aquatic species, has adverse effects on animals, and has potential long-term human health effects. Use of ETV-verified test kits for watersheds, well water, or small drinking water systems can lead to the timely identification of atrazine levels. If atrazine is detected at levels of concern, users can take corrective actions to reduce atrazine levels or mitigate exposure. Such actions could include reducing application rates in affected areas or encouraging improvements in agricultural practices. Thus, use of the verified technologies can result in reduction of atrazine in water, with health and environmental benefits.

Financial and Economic Outcomes

The verified technologies can be used for screening a large number of samples, resulting in savings of time and money over conventional techniques. As part of its ground water monitoring program for herbicides and pesticides including atrazine, Texas CEQ uses immunoassay test kits with laboratory confirmation, such as by GC/MS. Costs for samples analyzed during the late 1990s using the immunoassay methods (average of $37 per sample for 162 samples) were substantially less than costs for laboratory methods (average of $211 per sample for 72 samples). Advantages of the test kits cited by Texas CEQ staff include lower cost, faster turnaround, increased portability, and lower detection limits over laboratory methods (Musick et al., 2000). This cost savings is most apparent when atrazine is the only contaminant of concern for laboratory analysis.

To estimate cost savings from the use of the ETV-verified test kits, the ETV Program assumed they could be used at each of the community water systems and watersheds shown in Exhibit 3.3-3 in a program of frequent sampling designed for early detection of elevated atrazine concentrations. ETV assumed this model sampling program would undertake biweekly sampling during a six-month growing season, for a total of 12 samples per year. Verified test

EXHIBIT 3.3–3

PROJECTED NUMBER OF LOCATIONS THAT WOULD APPLY ETV-VERIFIED IMMUNOASSAY TEST KITS FOR ATRAZINE IN WATER

Market Penetration	Community Surface Water Systems	Private Wells	Watersheds
10%	390	94,000	1,000
25%	960	240,000	2,500

Values rounded to two significant figures

---

[53] To estimate the private well market, the ETV Program used data from the 1990 Census to identify the number of drinking water wells in each state, 2004 data from U.S. Department of Agriculture to identify the acreage of corn and sorghum in each state, and data from InfoPlease (2000) to identify the land area of each state. As a simplifying assumption, only corn and sorghum (the principal uses of atrazine) were evaluated and the ETV Program assumed 100% of these crops were treated with atrazine. The ETV Program assumed the wells were evenly dispersed in the state, such that the percent of acreage used for these two crops (i.e., as a percentage of total land area) was equal to the percent of wells potentially affected by atrazine. The numbers of such wells in each state were summed to obtain the nationwide estimate. This estimate is conservative because private wells tend to be clustered in agricultural use areas rather than dispersed evenly throughout the state as assumed in the calculation.

kits would replace GC/MS for all samples except those showing an elevated concentration, which would require GC/MS confirmation. Assuming 25% of the samples required GC/MS confirmation and using the average costs reported in Musick et al. (2000), a program using the verified test kits would save approximately $1,500 per year at each community water system and watershed.[54] Exhibit 3.3-4 shows the estimated national annual sampling cost savings. These estimates exclude private wells, because these are less likely to be tested using conventional laboratory analysis.[55]

The verified technologies also provide a time-effective method of sample analysis. The ETV Program evaluated the verified technologies in terms of sample throughput for a given batch as identified in Exhibit 3.3-2. All the test kits can process multiple samples in approximately one hour, as opposed to one to two samples per hour using GC/MS. Throughput time is decreased over GC/MS techniques because, unlike GC/MS, multiple samples can be analyzed concurrently using immunoassay technologies.

Regulatory Outcomes

EPA currently is considering whether to continue to allow the use of an immunoassay method (the "Syngenta method") to comply with drinking water monitoring requirements. EPA originally approved the Syngenta method in 2002. In 2004, EPA proposed to withdraw the method due to concerns regarding interferences with chlorine and chlorine dioxide, which are sometimes added to drinking water in treatment plants (69 FR 18116). Subsequently, EPA published a Notice of Data Availability seeking further comments on whether to modify or withdraw the method, given additional data. The notice included the four ETV verification reports as part of the information to be considered in this decision (70 FR 7909). The ETV data will contribute to EPA's future decision to modify or withdraw the Syngenta method for use in drinking water compliance measurements.

Exhibit 3.3–4

Estimated Annual Sampling Cost Savings from ETV-Verified Immunoassay Test Kits for Atrazine in Water (1)

Market Penetration	Cost Savings (million dollars)
10%	2.0
25%	5.0

Values in late 1990s dollars, rounded to two significant figures

(1) Assumes tests kits would be used in a model sampling program, as described in the text, at 390 and 960 community surface water systems and 1,000 to 2,500 watersheds, respectively.

Given the pending decision, it is uncertain whether the ETV-verified test kits will be applicable for compliance monitoring purposes under the Safe Drinking Water Act. They could, however, provide a quick and cost-effective screening method for atrazine levels, with subsequent laboratory confirmation. As discussed in Section 3.3.1, EPA has developed a Memorandum of Agreement with the atrazine registrants and formulators that requires the registrants to conduct water monitoring programs to identify elevated levels of atrazine in community surface water systems with historically elevated atrazine levels and watersheds that are known to be vulnerable to the impacts of atrazine use. These monitoring programs apply to 130 community water systems and a statistical sample of 40 watersheds, with possible future extension to up to 1,172 vulnerable watersheds. These monitoring programs are currently using immunoassay test kit methods followed by laboratory confirmation (e.g., GC/MS methods). ETV-verified technologies could assist in this program.

Scientific Advancement Outcomes

ETV also stimulates technology innovation. One of the participating vendors asserts that the ETV Program provides an incentive for companies, including small companies, to improve or develop environmental technologies (see quote next page).

---

[54] A program using GC/MS would cost 12 x $211 = approximately $2,500 per year. A program using the verified test kits would cost 12 x $37 + 0.25 x 12 x $211 = approximately $1,000 per year.

[55] These estimates are conservative because they exclude potential savings for private wells and they are in late 1990s dollars.

"Without a program like ETV to get a company over the 'valley of death,' an innovator company like Silver Lake Research would not even know where to begin to market their technologies in EPA-regulated markets. It is not just a question of having the ability to validate a technology to get them over that state, it is the fact that, without knowing ETV exists, companies like [Silver Lake Research] would not begin to develop new technologies for environmental markets because they would not see the means to get them to the marketplace ....There is a hidden value in having the program in place and having stakeholders and users ask for the technologies to be evaluated. Another advantage is the opportunity to have technologies looked at by EPA during the early stages to enable small companies to improve or further develop new technologies. It is possible that a lot more of these types of technologies would come out of nowhere if vendors knew that there was a stakeholders path to some type of validation."
—Mark Geisberg, Director of Research and Development, Silver Lake Research Corporation (U.S. EPA, 2004a)

Technology Acceptance and Use Outcomes

State, federal, and other organizations are actively using the verified atrazine test kits. For example, NOAA's National Ocean Service's Center for Coastal Environmental Health and Biomolecular Research Center in Charleston, South Carolina, uses the kits for monitoring water quality in coastal ponds. NOAA found ETV's quality-assurance/quality-control program, as well as timely posting of results on the EPA Web site, as extremely important in deciding to use these technologies (U.S. EPA, 2004a). The Nebraska Department of Environmental Quality also began using two of the ETV-verified test kits in summer 2004 for surface water/watershed monitoring. Nebraska used the results obtained from the ETV verifications in deciding to select the test kits (Link, 2005). Texas CEQ uses the ETV-verified test kits for their ground water monitoring program (Musick et al., 2000). Based in part on the ETV results, a study (Graziano et al., 2006) sponsored by the American Water Works Association also chose one of the verified test kits for use in weekly sampling of 47 drinking water facilities over a seven month period (Graziano et al., 2006; Rubio, 2006).

Acronyms used in this case study:

AMS Center	ETV's Advanced Monitoring Systems Center	NOAA	National Oceanic and Atmospheric Administration
GC/MS	gas chromatography/mass spectrometry	ppb	parts per billion
IRED	Interim Reregistration Eligibility Decision	Texas CEQ	Texas Commission on Environmental Quality
MCL	maximum contaminant level		

3.4

Ultraviolet (UV) Disinfection for Secondary Wastewater Effluent and Water Reuse

The ETV Program's Water Quality Protection (WQP) Center, operated by NSF International under a cooperative agreement with EPA, verified the performance of three ultraviolet (UV) disinfection systems for secondary wastewater effluent and water reuse applications. These technologies can be used in place of chemical disinfection to inactivate or destroy infectious organisms in wastewater treatment plant effluent prior to release or reuse. Ultimately, these technologies can help to prevent infectious organisms, such as *E. coli* and enterococci, from contaminating beaches, drinking water supplies, and shellfish beds, potentially reducing outbreaks of disease and beach closings. Wastewater treatment facilities can use these technologies to install or upgrade disinfection systems, allowing them to comply with discharge standards, including those under the Total Maximum Daily Load (TMDL) program and the recently established health-based federal bacteria standards for states and territories bordering Great Lakes or ocean waters. As water demands grow, these technologies could become an increasingly important element of private, state, and/or regional water reuse projects, providing a way to disinfect wastewater to meet state reuse regulations or guidelines. Water reuse is particularly important in areas where water resources are scarce and/or where water demands are high, providing these areas with a dependable, locally controlled water supply that can be used for irrigation, industrial cooling, vehicle washing, and dust control.

Based on the analysis in this case study and 25% market penetration, the ETV Program estimates that:

- The ETV-verified UV disinfection technologies would be installed at 77 wastewater treatment facilities (out of 309 facilities) that, based on the results of the 2000 Clean Watersheds Needs Survey, plan to add UV disinfection, replace existing disinfection technology with UV, or expand their UV disinfection capacity.
- The technologies would assist 23 wastewater treatment facilities (out of 90 facilities) in complying with EPA's new water quality standards for coastal and Great Lakes recreation waters. They also could assist facilities that discharge to any of the 8,690 river segments, lakes, and estuaries listed as impaired by pathogens in complying with TMDL requirements. Installation at these facilities, as well as the facilities above, would have human health and environmental benefits including prevention of disease and reduced restrictions on the use of natural resources.
- The technologies would enable water reuse at 29 facilities in Florida and California (out of 114 facilities), resulting in the

capacity to recycle 140 million gallons per day (MGD) of water. The resulting reuse would have environmental benefits including resource conservation, pollution reduction, and environmental restoration. In addition to avoiding alternative water supply and waste discharge costs, reuse would realize economic benefits associated with avoiding environmental impacts.

- The technologies would replace chemical disinfection at many of the facilities above, avoiding the adverse health effects potentially associated with disinfection chemicals, eliminating the need to manage hazardous chemicals, and potentially reducing operating costs.

In addition, the ETV protocol for validating UV technologies has been acknowledged by the State of California as meeting a minimum requirement for acceptance of a technology under the state's regulations for UV disinfection, because the protocol touches on the major points of the National Water Research Institute/American Water Works Association Research Foundation UV Disinfection Guidelines (California Department of Health Services, 2001b). This provides an advantage for ETV-verified vendors in gaining acceptance from the state regulatory agency and in marketing their technology in California. It also represents the first step in national acceptance of a standardized protocol, with benefits for vendors and regulatory agencies alike.

3.4.1 Environmental, Health, and Regulatory Background

Wastewater effluents can contain an array of pathogenic organisms that can cause a variety of diseases in humans, as shown in Exhibit 3.4-1. Pathogen-containing discharges also can limit the public's ability to use valuable natural resources, such as beaches, lakes, and rivers. For example, in 2005, more than 1,100 U.S. beaches, 28% of those monitored, were posted with warnings or closed for at least one day because the water was contaminated with pathogenic organisms (U.S. EPA, 2006c).

Exhibit 3.4–1

INFECTIOUS ORGANISMS POTENTIALLY PRESENT IN WASTEWATER

Organism	Disease Caused
Bacteria	
Escherichia coli (enterotoxigenic)	Gastroenteritis
Leptospira (spp.)	Leptospirosis
Salmonella typhi	Typhoid fever
Salmonella (=2,100 serotypes)	Salmonellosis
Shigella (4 spp.)	Shigellosis (bacillary dysentery)
Vibrio cholerae	Cholera
Protozoa	
Balantidium coli	Balantidiasis
Cryptosporidium parvum	Cryptosporidiosis
Entamoeba histolytica	Amebiasis (amoebic dysentery)
Giardia lamblia	Giardiasis
Helminths	
Ascaris lumbricoides	Ascariasis
T. solium	Taeniasis
Trichuris trichiura	Trichuriasis
Viruses	
Enteroviruses (72 types, e.g., polio, echo, and coxsackie viruses)	Gastroenteritis, heart anomalies, meningitis
Hepatitis A virus	Infectious hepatitis
Norwalk agent	Gastroenteritis
Rotavirus	Gastroenteritis

Source: U.S. EPA, 1999a (adapted from Crites and Tchobanoglous, 1998).

To protect the public from the health effects of pathogenic organisms in water, EPA sets water quality criteria under the Clean Water Act. States are required to adopt standards at least as stringent as these criteria and can adopt more stringent standards. Recently, EPA established health-based federal bacteria standards for a number of states and territories bordering the Great Lakes or ocean waters. These more stringent standards apply in areas that have not

---

56 The new standards set limits for *E. coli* and enterococci because, although these organisms generally do not cause illness themselves, they are indicator organisms that help identify where disease-causing microbes could be present. Indicator organisms are used as the water quality criteria because most disease-causing microbes exist in very small amounts and are difficult and expensive to find in water samples (U.S. EPA, 2004d).

yet adopted standards in accordance with the Beaches Environmental Assessment and Coastal Health Act of 2000 (U.S. EPA, 2004c). These criteria limit the geometric mean for enterococci in marine coastal recreation waters to 35 colonies per 100 milliliters (35/100 mL) and add four different single sample maximums, which vary based on how the water body is used. For fresh coastal recreation waters, the criteria limit the geometric mean for *E. coli* to 126/100 mL and for enterococci to 33/100 mL, also with different single sample maximums based on intensity of use (69 FR 67218).[56]

Also, under section 303(d) of the Clean Water Act, states are required to identify impaired waters that do not meet water quality standards even after point sources of pollution have installed the minimum required levels of pollution control technology. There are 8,690 river segments, lakes, or estuaries listed as impaired by pathogens, accounting for almost 15% of the total number of impaired waters and representing the second most frequent general cause of impairment (after metals) (U.S. EPA, 2006d). States must set priorities for these impaired waters and develop TMDLs that specify the maximum amount of a pollutant that a waterbody can receive. Under the TMDLs, states allocate pollutant loadings among point and non-point pollutant sources (U.S. EPA, 2006e). To ensure the nation's waters meet criteria like those established under the TMDL program or the federal bacteria criteria, wastewater treatment plants and other facilities that discharge to our nation's water bodies could be required, through their National Pollutant Discharge Elimination System permits, to modify or install treatment systems capable of disinfecting their effluent.

The removal or destruction of pathogenic organisms is also an essential element of wastewater reuse projects, which are being promoted by a number of states to help meet growing water demands and conserve existing water resources (see box at right). Reuse efforts are particularly important in areas where water resources are scarce and where water demands are high, as well as areas that are subject to drought. According to the National Drought Mitigation Center, 41 states experienced water-related drought impacts, such as lower water levels, reduced flow, and increased ground water depletion, in calendar year 2005 (National Drought Mitigation Center, 2006). Recycled water can provide a dependable, locally-controlled water supply that can be used for irrigation, industrial cooling, vehicle washing, and dust control, thus reducing private, state, and regional dependency on natural water supplies. Water reuse can also:

- Decrease the diversion of water from sensitive ecosystems
- Decrease the use of scarce water supplies
- Decrease wastewater discharges

STATE PROGRAMS PROMOTING WATER REUSE

- As of 2001, approximately 280 wastewater treatment facilities in California were recycling approximately 525,000 acre-feet of water per year. California has a goal to increase recycling to 1 million acre-feet per year by 2010 (California State Water Resources Control Board, 2003).
- As of 2004, Florida had a total of 468 domestic wastewater treatment facilities with permitted capacities greater than 0.1 MGD that supplied a total of 630 MGD of reclaimed water to 440 water reuse projects. Most of these facilities (77%) were located in water resource caution areas, which the state defines as areas that have critical water supply problems or are projected to have critical water supply problems within the next 20 years. Florida requires water reuse in these areas, unless such reuse is not economically, environmentally, or technically feasible as determined by a reuse feasibility study (Florida Department of Environmental Protection, 2005).
- Facilities in Texas recycle 230 MGD and those in Arizona recycle 200 MGD (U.S. EPA and U.S. AID, 2004).
- California, Florida, Texas, and Arizona account for the majority of water reuse in the U.S., but other states also have growing programs, including Nevada, Colorado, Georgia, North Carolina, Virginia, and Washington (U.S. EPA and U.S. AID, 2004).

- Reduce and prevent pollution
- Create, restore, or enhance wetlands and wildlife habitats (U.S. EPA, 2001a).

To help ensure that the public is protected, most states have established regulations or guidelines that require or recommend treatment when wastewater is reused (U.S. EPA, 2001a; U.S. EPA and U.S. AID, 2004). At the federal level, EPA and the U.S. Agency for International Development have jointly developed a technical document with guidelines for water reuse. These guidelines recommend a "high degree" of treatment wherever the public exposure to reused water is expected. UV disinfection is among the disinfection processes discussed in the guidelines (U.S. EPA and U.S. AID, 2004). EPA's Region 9 recommends disinfection for all types of water reuse, and reuse is not recommended without disinfection (U.S. EPA, 2001a). Similarly, most states require disinfection for reuse applications, even those where public access is restricted (U.S. EPA and U.S. AID, 2004).

3.4.2 Technology Description

UV disinfection technologies generate electromagnetic radiation that can penetrate the cell walls of microbial organisms, damaging their genetic material and rendering them unable to reproduce. UV disinfection has certain advantages and disadvantages over traditional chemical disinfection technologies (e.g., chlorination), as shown in Exhibit 3.4-2 (U.S. EPA, 1999a).

Typically, these UV technologies utilize either "low-pressure" or "medium-pressure" mercury lamps to generate radiation. Because of their higher intensity, medium-pressure lamps disinfect faster and have greater penetration capability than low-pressure lamps. Medium-pressure lamps, however, operate at higher temperatures with higher energy consumption (U.S. EPA, 1999a; NSF, 2002b). Most UV reactors are contact reactors, with the lamps submerged in the water to be treated and enclosed in quartz sleeves to minimize the cooling effect of the water. There also are less common, non-contact reactors in which the lamps are suspended outside a transparent conduit that carries the water to be treated (U.S. EPA, 1999a).

The ETV Program has evaluated three UV disinfection systems, one for secondary wastewater effluent and two for water reuse applications. All three technologies utilize contact reactors with lamps that are enclosed in quartz sleeves. Two of the technologies use low-pressure lamps, while the third employs medium-pressure lamps. Exhibit 3.4-3 identifies the ETV-verified technologies and provides a description of each.

All the verification tests were conducted at the Parsippany-Troy Hills Wastewater Treatment Plant in Parsippany, New Jersey. Before verification testing began, the lamps were aged for 100 hours to allow the lamp intensity to stabilize. The testing used the MS2 bacteriophage as the target organism because it has a high tolerance for UV light, typically requires a larger delivered dose for inactivation than most bacterial and viral organisms, and has a consistent dose-

EXHIBIT 3.4–2

ADVANTAGES AND DISADVANTAGES OF UV DISINFECTION VERSUS CHEMICAL DISINFECTION

Advantages	Disadvantages
❖ Effective at inactivating most viruses, spores, and cysts	❖ Dosage must be sufficient to deactivate certain microorganisms
❖ Eliminates the need to manage toxic, hazardous, or corrosive chemicals	❖ Organisms sometimes are able to reverse the destructive effects
❖ Might not generate potentially harmful residuals (e.g., trihalomethanes)	❖ Preventive maintenance is necessary
❖ Can be less intensive to operate	❖ Must be designed to account for turbidity and suspended solids in wastewater that can reduce the transmittance of the UV radiation
❖ Uses shorter contact times	❖ Does not provide a disinfectant residual, which may be a disadvantage in cases where a residual is desirable.
❖ Requires less space for equipment.	

Source: Adapted from U.S. EPA (1999a).

EXHIBIT 3.4–3

ETV-VERIFIED UV DISINFECTION TECHNOLOGIES FOR SECONDARY WASTEWATER EFFLUENT AND WATER REUSE

Technology	Description
Aquionics, Inc. bersonInLine® 4250 UV System	Uses high-output, medium-pressure, mercury lamps in quartz sleeves that are oriented horizontally and perpendicular to the direction of flow
Ondeo Degremont, Inc. Aquaray® 40 HO VLS Disinfection System	Uses high-output, low-pressure, mercury discharge lamps in quartz sleeves oriented vertically and perpendicular to the direction of flow
SUNTEC environmental, Inc. LPX200 UV Disinfection System (1)	Uses high-output, low-pressure UV lamps in quartz sleeves oriented horizontally and parallel to the direction of water flow

(1) No longer in business

Sources: NSF, 2003c, 2003d, 2003e.

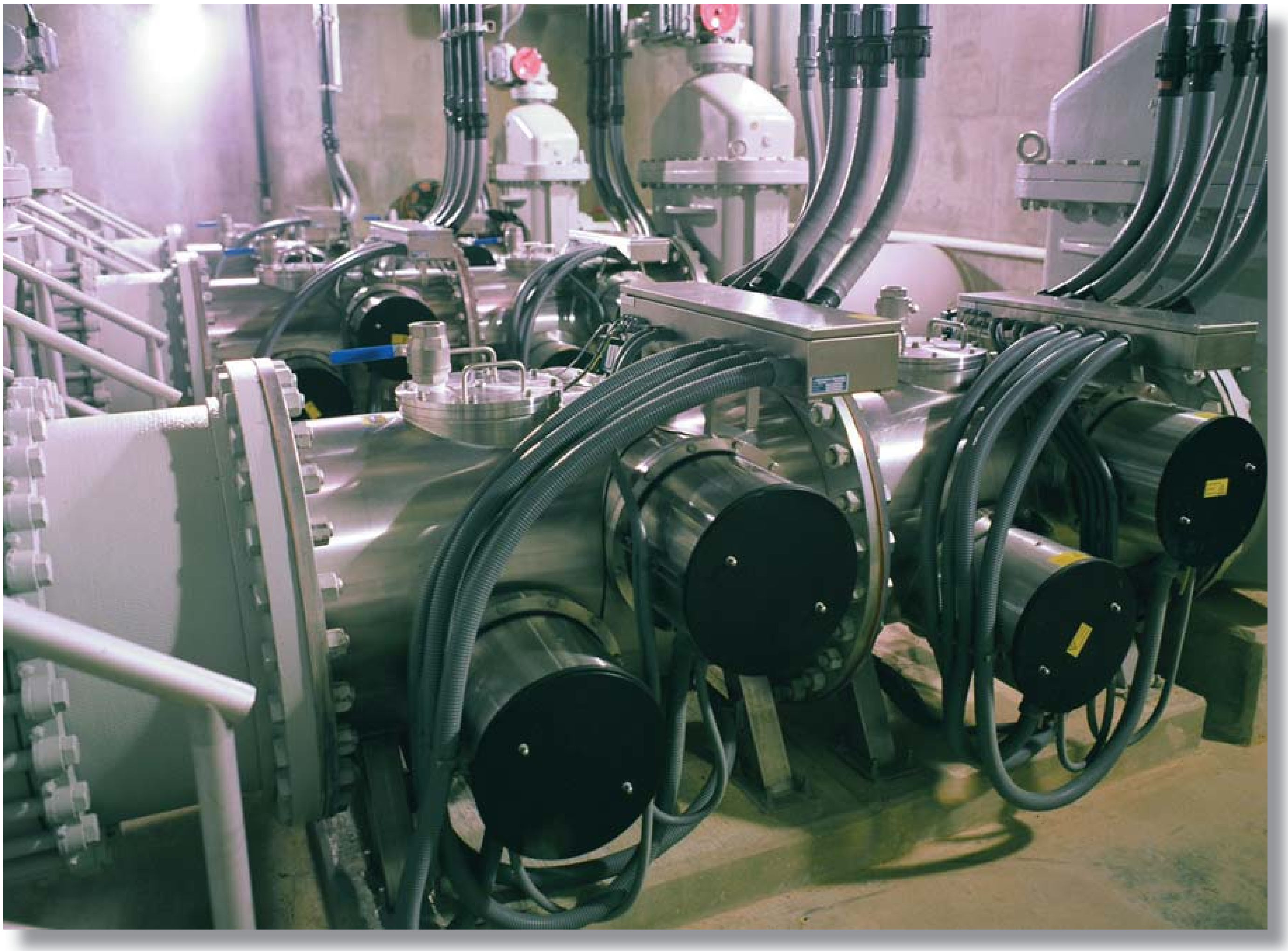
response over repeated applications. This allows development of dose-response and delivered dose relationships that encompass dose levels required for most disinfection applications. The tests were conducted on water with UV transmittances of 55 and 65 percent (intended to represent granular or fabric filtered effluent and membrane filtered effluent, respectively). Testing at the different transmittances allows system design that accounts for different wastewater qualities, thus addressing one of the disadvantages listed in Exhibit 3.4-2. All of the verifications measured power consumption and headloss results, developed dose-response calibration curves, developed dose delivery-flow curves, and obtained reactor design data for use in scaling system designs for larger applications than those tested (NSF, 2002b, 2003c, 2003d, 2003e). The details of ETV's test protocol (NSF, 2002b) differed, however, depending on the desired application (secondary effluent treatment or water reuse). These details are outlined in the protocol, which can be found at *http://www.epa.gov/etv/verifications/protocols-index.html.*

The technical objective of the tests was to verify the effective delivered dose for each UV system's reactor under varying conditions (flow and water transmittance). Each of the verifications met this objective, developing dose delivery curves based on the MS2 bacteriophage survival rates seen during testing. These curves can be used to design a UV reactor for an application, based on site-specific criteria for inactivation of a target microorganism. The verification reports for each technology provide more detailed results, including power consumption and headloss results (NSF, 2002b, 2003c, 2003d, 2003e). These reports can be found at *http://www.epa.gov/etv/verifications/vcenter9-5.html.*

3.4.3 Outcomes

The market for the ETV-verified UV disinfection technologies includes wastewater treatment facilities that require disinfection, either to meet discharge requirements or to enable treated water reuse. In estimating outcomes for the ETV-verified UV disinfection technologies, the ETV Program developed three market estimates: an estimate of the market for UV disinfection in general ("general market estimate"), an estimate of the market for UV disinfection specifically for water reuse applications ("water reuse market estimate"), and an estimate of the market for UV disinfection specifically to meet wastewater discharge requirements ("discharge-related market estimate").

The ETV Program used data from EPA's 2000 Clean Watersheds Needs Survey (U.S. EPA, 2003h, 2003i) to estimate the general market. In response to the survey, 309 wastewater treatment facilities reported plans to install new UV disinfection technology, replace existing disinfection processes with UV, or expand or improve their UV disinfection capacity. As discussed in Appendix F, facilities that reported plans to add, replace, improve, or expand UV disinfection could be doing so to meet discharge requirements, enable water reuse, or both. Accordingly, the ETV Program used this value to define the general market for application of



One of the verified UV technologies at a facility in Georgia

the verified UV disinfection technologies.[57] The ETV Program used other data sources to estimate purpose-specific markets for the verified UV disinfection technologies. These purpose-specific market estimates quantify the number of facilities that could apply the technologies to enable water reuse (discussed below under "Resource Conservation and Economic Outcomes") or to meet discharge requirements (discussed below under "Regulatory Compliance Outcomes").

Because the ETV Program does not have access to a comprehensive set of sales data for the ETV-verified UV technologies, ETV used two market penetration scenarios, 10% and 25% of the market, to estimate the number of facilities that would install the technologies. Exhibit 3.4-4 shows these estimates.

EXHIBIT 3.4–4

PROJECTED NUMBER OF FACILITIES THAT WOULD APPLY ETV-VERIFIED UV TECHNOLOGIES FOR SECONDARY EFFLUENT DISCHARGE AND WATER REUSE

Market Penetration	Number of Facilities
10%	31
25%	77

Resource Conservation and Economic Outcomes

As discussed in Section 2.5.1, EPA and states generally require or recommend the use of disinfection when wastewater is reused. Thus, the feasibility of water reuse depends upon effective disinfection methods like the ETV-verified technologies. In addition to the environmental

---

[57] As discussed in Appendix F, this estimate is conservative (low) because it only includes facilities that reported planning to add or expand UV disinfection as of the year 2000 as part of projects eligible for funding under the Clean Water State Revolving Fund. All told, approximately 4,800 facilities reported that they plan to install, replace, improve, or expand disinfection, but only 309 specifically mentioned UV.

benefits noted above under "Human Health and Environmental Outcomes" and in Section 2.5.1, water reuse reduces the need to use scarce water supplies. Recycled water replaces water that would otherwise have been taken from these supplies.

To estimate the market for water reuse, the ETV Program used data from the Florida Department of Environmental Protection (2005) and for the State of California (U.S. Bureau of Reclamation, 2002). Appendix F describes this analysis in more detail. Based on the analysis, the market for the verified technologies in reuse applications would be 114 facilities (68 in Florida and 46 in California).[58] As discussed in Appendix F, this reuse market is likely in addition to the general market defined above and the compliance market defined below, although there could be some overlap.

ETV applied two market penetration scenarios, 10% and 25% of the reuse market, to estimate the number of facilities that would install the technologies for water reuse. As discussed in Appendix F, ETV also applied average recycling capacities derived from Florida Department of Environmental Protection (2005) and U.S. Bureau of Reclamation (2002) to estimate the quantity of water that could be recycled by these facilities.[59] Exhibit 3.4-5 shows these estimates for the two market penetration scenarios.

In addition to conserving resources, water reuse has an economic impact. The economic benefits of reuse include avoided alternative water supply costs, avoided waste discharge costs, and the economic value of the avoided environmental impacts. The U.S. Bureau of Reclamation (2002) considered all these benefits when estimating the total net benefit associated with the 34 water reuse projects identified for implementation by 2010. After accounting for the costs of the projects, the US Bureau of Reclamation estimated that a net benefit of $2.56 billion dollars would be realized.

EXHIBIT 3.4–5

PROJECTED NUMBER OF FACILITIES THAT WOULD APPLY THE ETV-VERIFIED UV TECHNOLOGIES FOR WATER REUSE AND THEIR RECYCLING CAPACITY

Market Penetration	Number of Facilities	Recycling Capacity (MGD) (1)
10%	12	60
25%	29	140

(1) Values rounded to two significant figures

Regulatory Compliance Outcomes

When applied to treat wastewater effluent, UV disinfection can assist facilities in complying with federal and state discharge requirements and water quality standards. Although such requirements could include current or potential future standards for water quality and wastewater discharges, this analysis of regulatory compliance outcomes focuses on EPA's 2005 health-based federal bacteria standards for states and territories bordering Great Lakes or ocean waters, and on waters listed as impaired under section 303(d) of the Clean Water Act, both discussed in Section 3.4.1.

EPA estimated that approximately 90 facilities will have to implement additional or new treatment to comply with the new water quality standards for coastal and Great Lakes recreation waters (69 FR 67218). In estimating the cost of the new standards, EPA assumed that affected facilities will upgrade or adjust existing chlorination treatment processes to comply with effluent limitations resulting from the new standards (U.S. EPA, 2004d; 69 FR 67218). These facilities, however, also could install the ETV-verified UV disinfection technologies, particularly if they do not have existing chlorination processes, their chlorination facilities are reaching the end of their useful life, or they wish to benefit from the relative advantages of UV technology over chemical processes, such as operating cost savings and reduced space requirements (see Exhibit 3.4-2). Accordingly, ETV used the EPA estimate of 90 facilities as the market for meeting discharge requirements. As discussed in Appendix F, this compliance market is likely in addition to the general market and the reuse-specific market described above, although there could be some overlap.

ETV applied two market penetration scenarios, 10% and 25% of the discharge-related

---

[58] As discussed in Appendix F, this estimate is conservative because it only includes facilities in Florida and California and the estimate for each state is individually conservative.

[59] These estimates are conservative because they are based on the conservative estimates of the market for ETV technologies.

market, to estimate the number of facilities that would apply the technologies to meet new discharge requirements. Exhibit 3.4-6 shows these estimates for the two market penetration scenarios.

Exhibit 3.4–6

Projected Number of Facilities that Would Apply ETV-Verified UV Technologies to Comply with New Water Quality Standards

Market Penetration	Number of Facilities
10%	9
25%	23

In addition to the facilities shown in Exhibit 3.4-6, as TMDLs are developed for waters impaired by pathogens, additional facilities could use the verified technologies to comply with their discharge requirements under the TMDL program. As discussed in Section 3.4.1, there are 8,690 river segments, lakes, or estuaries listed as impaired by pathogens. Facilities discharging to these impaired waters could benefit from application of the verified technologies.

Human Health and Environmental Outcomes

Use of the ETV-verified UV technologies will reduce the occurrence of releases of infectious organisms in secondary wastewater effluent. Such treatment ultimately will reduce exposure of downstream users to these organisms, reducing the incidence of diseases and protecting the public's ability to use natural resources such as beaches and rivers. In addition to treating wastewater effluent to meet discharge requirements, the ETV-verified technologies also can be used in water reuse projects, resulting in environmental benefits like those described in Section 2.5.1. Also, when UV disinfection replaces chemical chlorination, it eliminates potential for formation of harmful residuals like trihalomethanes, which have been linked to bladder and other cancers (71 FR 388). EPA also believes the evidence supports concern for potential adverse reproductive and developmental health effects that might be associated with these residuals (U.S. EPA, 2005c; 71 FR 388). Finally, replacing chemical disinfection with UV technologies eliminates the need for onsite management of toxic, hazardous, or corrosive chemicals. Installation of the ETV-verified UV technologies at the facilities shown in Exhibits 3.4-4, 3.4-5, and 3.4-6, therefore, would have human health and environmental benefits.

Financial Outcomes

Although UV technologies can have higher capital costs than chemical disinfection, they generally require a smaller footprint than chemical disinfection technologies (see Exhibit 3.4-2). Thus, adding UV instead of chemical disinfection can avoid additional land costs associated with expanding a treatment facility. Also, UV technologies can be less labor-intensive to operate, resulting in reduced labor costs when they replace chemical disinfection. Finally, UV technologies avoid the use of chemicals, although they are more energy-intensive. The cost savings associated with this advantage depend on the relative cost of chemicals versus the cost of energy.

Scientific Advancement and Technology Acceptance and Use Outcomes

The ETV protocol for validating UV technologies has been acknowledged by the State of California as meeting a minimum requirement for acceptance of a technology under the state's regulations for UV disinfection, because the protocol touches on the major points of the National Water Research Institute/American Water Works Association Research Foundation UV Disinfection Guidelines (California Department of Health Services, 2001b).[60] This provides an advantage for ETV-verified vendors in gaining acceptance from the state regulatory agency and in marketing their technology in California (U.S. EPA, 2004a). It also represents the first step in national acceptance of a standardized protocol, with benefits for vendors and regulatory agencies (see quote on next page).

Vendor information indicates that wastewater treatment facilities are choosing to install the ETV-verified UV disinfection technologies. Examples of facilities that have chosen to install one vendor's technology (Aquionics) include the following:

---

[60] The state still requires full-scale commissioning tests to verify performance of the final system design, in addition to ETV verification.

- Flat Creek Water Reclamation Facility in Gainesville, Georgia, which initially installed three Aquionics InLine systems treating approximately 10 MGD of wastewater in 2001, added three new Aquionics InLine systems in 2004. The additional units allowed the facility to expand its treatment capacity to 12 MGD and meet new, more stringent permit requirements (fecal coliform limits of 23/100 mL versus 200/100 mL) (Aquionics, 2004a).
- The City of Fairfield, Ohio, installed two Aquionics InLine systems in April 2003 to handle a wastewater flow capacity of 15 MGD. The treatment system allowed the facility to meet the fecal coliform limits established in its permit (Aquionics, 2004b).
- The Laguna County Sanitation District in California began operating four Aquionics InLine units in April of 2003. The purpose of installing the technology was to upgrade the quality of the treated water, allowing it to be reused in a greater number of applications (including for spray irrigation on edible food crops) under the state's water reuse requirements. The District chose UV over chemical disinfection because of operating costs and chemical hazards (see quote at right). In October 2005, the District received approval from the California Department of Health Services for the Aquionics system as meeting the state's water reuse criteria (Aquionics, 2003).

> "The ETV Program is a success story as their protocol has been accepted by California—as California goes, generally the rest of the nation tends to follow. What should occur is that a number of states will adopt the California protocol …. If there is no uniformity, each technology can only be demonstrated and accepted in certain states. It could be extremely costly for vendors if different protocols had to be developed in 15 different states. One of the key advantages of ETV is having a national program—one that can be accepted by state regulators throughout the country, and that offers an opportunity for manufacturers to subject their equipment once for testing and then have other states accept it. The states can be confident that the testing was conducted using a protocol and established quality assurance procedures, and that the technology underwent a uniform evaluation by an independent third party."—Karl Scheible, HydroQual (U.S. EPA, 2004a)

> "We knew that we didn't want a chlorine-based system because of the high operating cost and potential hazards in storing and handling the needed chemicals … We really liked the comparatively low operating and maintenance costs in addition to the fact that UV is safe and leaves no chemicals or other by-products in the treated water."—Martin Wilder, Laguna County Civil Engineer Manager (Aquionics, 2003)

Acronyms used in this case study:

MGD	million gallons per day	UV	ultraviolet
mL	milliliters	WQP	ETV's Water Quality Protection Center
TMDL	Total Maximum Daily Load		

4.

References

63 FR 69390. *National Primary Drinking Water Regulations: Disinfectants and Disinfection Byproducts; Final Rule. Federal Register* 63, no. 241 (16 December 1998).

63 FR 69478. *National Primary Drinking Water Regulations: Interim Enhanced Surface Water Treatment; Final Rule. Federal Register* 63, no. 241 (16 December 1998).

67 FR 1812. *National Primary Drinking Water Regulations: Long Term 1 Enhanced Surface Water Treatment Rule; Final Rule. Federal Register* 67, no. 9 (14 January 2002).

69 FR 18166. *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 (Proposed Rule). Federal Register* 69, no. 66 (6 April 2004).

69 FR 67218. *Water Quality Standards for Coastal and Great Lakes Recreation Waters; Final Rule. Federal Register* 69, no. 220 (16 November 2004).

70 FR 7909. *Guidelines Establishing Test Procedures for the Analysis of Pollutants Under the Clean Water Act; National Primary Drinking Water Regulations; Notice of Data Availability. Federal Register* 70, no. 31 (16 February 2005).

70 FR 25162. *Rule to Reduce Interstate Transport of Fine Particulate Matter and Ozone (Clean Air Interstate Rule); Revisions to Acid Rain Program; Revisions to the* NO_x *SIP Call; Final Rule. Federal Register* 70, no. 91 (12 May 2005).

70 FR 28606. *Standards of Performance for New and Existing Stationary Sources: Electric Utility Steam Generating Units; Final Rule. Federal Register* 70, no. 95 (18 May 2005).

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 388. *National Primary Drinking Water Regulations: Stage 2 Disinfectants and Disinfection Byproducts Rule; Final Rule. Federal Register* 71, no. 2 (4 January 2006).

71 FR 654. *National Primary Drinking Water Regulations: Long Term 2 Enhanced Surface Water Treatment Rule; Final Rule. Federal Register* 71, no. 3 (5 January 2006).

71 FR 2620. *National Ambient Air Quality Standards for Particulate Matter; Proposed Rule. Federal Register* 71, no. 10 (17 January 2006).

Adams, J. 2005. E-mail communication to Evelyn Hartzell, U.S. EPA, regarding ETV Drinking Water Systems Center Steering Committee Teleconference, 31 March.

Aquionics. 2003. *UV Upgrades Water Treatment Quality in Laguna County.* 6 March. *http://www.aquionics.com/news.php?id=4*

Aquionics. 2004a. *Aquionics UV Equipment Grows with Flat Creek WRF.* 9 November. *http://www.aquionics.com/news.php?id=11*

Aquionics. 2004b. *UV Treatment Keeps Bacteria Out of Wastewater Receiving Stream.* 22 March. *http://www.aquionics.com/news.php?id=7*

Association of State Drinking Water Administrators (ASDWA). 2003. *Results of 2003 Annual Survey of State Drinking Water Administrators about the ETV Drinking Water Systems Center.*

Bartley, B. 2005. E-mail communication. 29 July.

Battelle. 2001a. *Environmental Technology Verification Report: Nippon Instruments Corporation, Model MS-1/DM-5 Mercury Continuous Emission Monitor.* Prepared by Battelle under a cooperative agreement with U.S. Environmental Protection Agency. August.

Battelle. 2001b. *Environmental Technology Verification Report: Lumex Ltd., Mercury Continuous Emission Monitor.* Prepared by Battelle under a cooperative agreement with U.S. Environmental Protection Agency. August.

Battelle. 2001c. *Environmental Technology Verification Report: Nippon Instruments Corporation, Model AM-2 Elemental Mercury Continuous Emission Monitor.* Prepared by Battelle under a cooperative agreement with U.S. Environmental Protection Agency. August.

Battelle. 2001d. *Environmental Technology Verification Report: PS Analytical, Ltd., Sir Galahad II Mercury Continuous Emission Monitor.* Prepared by Battelle under a cooperative agreement with EPA U.S. Environmental Protection Agency. August.

Battelle. 2003a. *Environmental Technology Verification Report: Envimetrics, Argus-Hg 1000 Mercury Continuous Emission Monitor.* Prepared by Battelle under a cooperative agreement with U.S. Environmental Protection Agency. September.

Battelle. 2003b. *Environmental Technology Verification Report: Nippon Instruments Corporation, DM-6/DM-6P Mercury Continuous Emission Monitor.* Prepared by Battelle under a cooperative agreement with U.S. Environmental Protection Agency. September.

Battelle. 2003c. *Environmental Technology Verification Report: Nippon Instruments Corporation, MS-1/DM-5 Mercury Continuous Emission Monitor.* Prepared by Battelle under a cooperative agreement with U.S. Environmental Protection Agency. August.

Battelle. 2003d. *Environmental Technology Verification Report: OPSIS AB., HG-200 Mercury Continuous Emission Monitor.* Prepared by Battelle under a cooperative agreement with EPA U.S. Environmental Protection Agency. September.

Battelle. 2003e. *Environmental Technology Verification Report: PS Analytical, Ltd., Sir Galahad II Mercury Continuous Emission Monitor.* Prepared by Battelle under a cooperative agreement with EPA U.S. Environmental Protection Agency. September.

Battelle. 2004a. *Case Study—Continuous Emission Monitors For Mercury ETV Advanced Monitoring Systems Center.* Draft. 10 February.

Battelle. 2004b. *Environmental Technology Verification Report, ABRAXIS LLC, ATRAZINE ELISA KIT®.* Prepared by Battelle under a cooperative agreement with the Environmental Protection Agency. March.

Battelle. 2004c. *Environmental Technology Verification Report, BEACON ANALYTICAL SYSTEMS, INC., ATRAZINE TUBE KIT®.* Prepared by Battelle under a cooperative agreement with the Environmental Protection Agency. March.

Battelle. 2004d. *Environmental Technology Verification Report, SILVER LAKE RESEARCH CORP., WATERSAFE® PESTICIDE TEST.* Prepared by Battelle under a cooperative agreement with the Environmental Protection Agency. March.

Battelle. 2004e. *Environmental Technology Verification Report, STRATEGIC DIAGNOSTICS INC., RAPID ASSAY® KIT.* Prepared by Battelle under a cooperative agreement with the Environmental Protection Agency. March.

Boedecker, E., J. Cymbalsky, and S. Wade. 2000. “Modeling Distributed Electricity Generation in the NEMS Buildings Models.” *Issues in Midterm Analysis and Forecasting 2000.* Energy Information Administration, U.S. Department of Energy.

Bosch, John. 2006. E-mail communication. 3 May.

Breakthrough Technologies Institute. 2006. *State Activities That Promote Fuel Cells And Hydrogen Infrastructure Development.* April.

Cadmus and Pirnie. 2003. *Technologies and Costs for Control of Microbial Contaminants and Disinfection Byproducts.* Prepared for U.S. Environmental Protection Agency—Office of Ground Water and Drinking Water. June.

California Department of Health Services. 2001a. *California Surface Water Treatment Alternative Filtration Technology Demonstration Report.* Draft. June.

California Department of Health Services. 2001b. Letter from Richard H. Sakaji to Thomas Stevens, NSF. 21 December 2001.

California State Water Resources Control Board. 2003. *2002 Statewide Recycled Water Survey.* June.

Chen, J. 2005. E-mail communication. 15 August.

Government Performance and Results Act (GPRA). 1993. Section 4. *http://www.whitehouse.gov/omb/mgmt-gpra/gplaw2m.html*

Energy and Environmental Analysis, Inc. (EEA). 2003. *Advanced Microturbine System: Market Assessment.* Submitted to Oak Ridge National Laboratory. Final Report. May.

Engle, David. 2005. "Back to Market in a Riper Niche … Plug Power's PEM Fuel Cell Comeback." *Distributed Energy.* July/August. *http://www.distributedenergy.com/de_0507_back.html*

ETS and RTI. 2000a. *Environmental Technology Verification Report, Baghouse Filtration Products: Air Purator Corporation, Huyglas® 1405M Filter Sample.* Prepared by ETS, Incorporated and the Research Triangle Institute in cooperation with EPA's National Risk Management Research Laboratory under a cooperative agreement with U.S. Environmental Protection Agency. September.

ETS and RTI. 2000b. *Environmental Technology Verification Report, Baghouse Filtration Products: Albany International Corporation, Primatex™ Plus I Filter Sample.* Prepared by ETS, Incorporated and the Research Triangle Institute in cooperation with EPA's National Risk Management Research Laboratory under a cooperative agreement with U.S. Environmental Protection Agency. September.

ETS and RTI. 2000c. *Environmental Technology Verification Report, Baghouse Filtration Products: BASF Corporation, AX/BA-14/9-SAXP® 1405M Filter Sample.* Prepared by ETS, Incorporated and the Research Triangle Institute in cooperation with EPA's National Risk Management Research Laboratory under a cooperative agreement with U.S. Environmental Protection Agency. September.

ETS and RTI. 2000d. *Environmental Technology Verification Report, Baghouse Filtration Products: BHA Group, Inc. QG061® Filter Sample.* Prepared by ETS, Incorporated and the Research Triangle Institute in cooperation with EPA's National Risk Management Research Laboratory under a cooperative agreement with U.S. Environmental Protection Agency. September.

ETS and RTI. 2000e. *Environmental Technology Verification Report, Baghouse Filtration Products: Inspec Fibres 5512BRF® Filter Sample.* Prepared by ETS, Incorporated and the Research Triangle Institute in cooperation with EPA's National Risk Management Research Laboratory under a cooperative agreement with U.S. Environmental Protection Agency. September.

ETS and RTI. 2000f. *Environmental Technology Verification Report, Baghouse Filtration Products: Menardi-Criswell 50-504® Filter Sample.* Prepared by ETS, Incorporated and the Research Triangle Institute in cooperation with EPA's National Risk Management Research Laboratory under a cooperative agreement with U.S. Environmental Protection Agency. September.

ETS and RTI. 2000g. *Environmental Technology Verification Report, Baghouse Filtration Products: Standard Filter Corporation PE16ZU® Filter Sample.* Prepared by ETS, Incorporated and the Research Triangle Institute in cooperation with EPA's National Risk Management Research Laboratory under a cooperative agreement with U.S. Environmental Protection Agency. September.

ETS and RTI. 2000h. *Environmental Technology Verification Report, Baghouse Filtration Products: Tetratec PTFE Technologies Tetratex® 8005 Filter Sample.* Prepared by ETS, Incorporated and the Research Triangle Institute in cooperation with EPA's National Risk Management Research Laboratory under a cooperative agreement with U.S. Environmental Protection Agency. September.

ETS and RTI. 2000i. *Environmental Technology Verification Report, Baghouse Filtration Products: W.L. Gore & Associates, Inc. L4347® Filter Sample.* Prepared by ETS, Incorporated and the Research Triangle Institute in cooperation with EPA's National Risk Management Research Laboratory under a cooperative agreement with U.S. Environmental Protection Agency. September.

ETS and RTI. 2001a. *Environmental Technology Verification Report, Baghouse Filtration Products: BHA Group, Inc. QP131® Filter Sample.* Prepared by ETS, Incorporated and the Research Triangle Institute in cooperation with EPA's National Risk Management Research Laboratory under a cooperative agreement with U.S. Environmental Protection Agency. September.

ETS and RTI. 2001b. *Environmental Technology Verification Report, Baghouse Filtration Products: Polymer Group, Inc. DURAPEX™ PET Filter Sample.* Prepared by ETS, Incorporated and the Research Triangle Institute in cooperation with EPA's National Risk Management Research Laboratory under a cooperative agreement with U.S. Environmental Protection Agency. September.

ETS and RTI. 2001c. *Environmental Technology Verification Report, Baghouse Filtration Products: Tetratec PTFE Technologies Tetratex® 6212 Filter Sample.* Prepared by ETS, Incorporated and the Research Triangle Institute in cooperation with EPA's National Risk Management Research Laboratory under a cooperative agreement with U.S. Environmental Protection Agency. September.

ETS and RTI. 2001d. *Environmental Technology Verification Report, Baghouse Filtration Products: W.L. Gore & Associates, Inc. L4427® Filter Sample.* Prepared by ETS, Incorporated and the Research Triangle Institute in cooperation with EPA's National Risk Management Research Laboratory under a cooperative agreement with U.S. Environmental Protection Agency. September.

ETS and RTI. 2001e. *Generic Verification Protocol for Baghouse Filtration Products.* Prepared by ETS, Incorporated and the Research Triangle Institute in cooperation with EPA's National Risk Management Research Laboratory under a cooperative agreement with U.S. Environmental Protection Agency. October.

ETS and RTI. 2002. *Environmental Technology Verification Report, Baghouse Filtration Products: BWF America, Inc. Grade 700 MPS Polyester® Filter Sample.* Prepared by ETS, Incorporated and the Research Triangle Institute in cooperation with EPA's National Risk Management Research Laboratory under a cooperative agreement with U.S. Environmental Protection Agency. June.

ETS and RTI. 2005. *Environmental Technology Verification Report, Baghouse Filtration Products: BWF America, Inc. Grade 700 MPS Polyester® Felt Filter Sample.* Prepared by ETS, Incorporated and the Research Triangle Institute in cooperation with EPA's National Risk Management Research Laboratory under a cooperative agreement with U.S. Environmental Protection Agency. September.

ETS and RTI. 2006. *Environmental Technology Verification Report, Baghouse Filtration Products: W. L. Gore & Associates, Inc. L3650 Filter Sample.* Prepared by ETS, Incorporated and the Research Triangle Institute in cooperation with EPA's National Risk Management Research Laboratory under a cooperative agreement with U.S. Environmental Protection Agency. July.

ETV Vendor. 2005. E-mail communication. October.

ETV Vendor. 2006. E-mail communication. 8 February.

Field, Keith. 2005. E-mail communication. 11 October.

Florida Department of Environmental Protection. 2005. *2004 Reuse Inventory.* June.

Florida Department of Environmental Protection. 2006. *Notice of Permit: Natural Resources of Central Florida dba American Cement Company, Sumterville Cement Plant.* DEP File No. 1190042-001-ACP, SD-FL-361. 13 February.

Fuel Cells 2000. 2006. *Worldwide Stationary Fuel Cell Installation Database.* Accessed June. *http://www.fuelcells.org/db/*

Graziano, N., M. McGuire, A. Roberson, C. Adams, H. Jiang , and N. Blute. 2006. "2004 National Atrazine Occurrence Monitoring Program Using the Abraxis ELISA Method." *Environ. Sci. Technol.* 40: 1163–1171.

Howorth, Chris. 2006. E-mail communication. 18 May.

InfoPlease. 2000. *Land and Water Area of States. http://www.infoplease.com/ipa/A0108355.html*

InfraStructures. 2004. "Largest-Ever Membrane Filtration Process Installed in Newfoundland Community Water Treatment Plant." *InfraStructures* 9, no. 8 (September).

Institute of Clean Air Companies (ICAC). 2005. *ICAC Clean Air Technologies And Strategies Conference & Workshops.* Baltimore, Maryland. 7–10 March.

Intergovernmental Panel on Climate Change (IPCC). 2001a. *Third Assessment Report: Climate Change 2001: Working Group I: The Scientific Basis.* New York: Cambridge University Press.

IPCC. 2001b. *Third Assessment Report: Climate Change 2001: Working Group II: Impacts, Adaptation, and Vulnerability.* New York: Cambridge University Press.

Link, Marty. 2005. Personal Communication. 7 April.

Massachusetts. 2002. *Evaluation of The Technological And Economic Feasibility Of Controlling And Eliminating Mercury Emissions From The Combustion Of Solid Fossil Fuel: Pursuant To 310 CMR 7.29—Emissions Standards For Power Plants.* Massachusetts Department of Environmental Protection, Bureau of Waste Prevention, Division of Planning and Evaluation. December.

Massachusetts. 2004. *Appendix A: Final regulatory revisions to 310 CMR 7.29.* May. *http://www.mass.gov/dep/toxics/stypes/hgres.htm*

Massachusetts. 2006. *310 CMR 22.00 DRINKING WATER REGULATION: 2006 Proposed Revisions.* 10 February.

McKenna, John. 2006. Personal communication to Andrew Trenholm, RTI. 21 April.

Minnesota Department of Agriculture. 2005. *Atrazine in Minnesota Groundwater: A Summary Report.* February.

Musick, S., A. Cherepon, and J. Peters. 2000. *Immunoassay Analysis for the Determination of Pesticides in Groundwater Samples: The Texas Experience.* Conference Proceedings of the National Water Quality Monitoring Council.

Mycock, J., J. Turner, and J. Farmer. 2002. *Baghouse Filtration Products Verification Testing: How it Benefits the Boiler Baghouse Operator.* Fluid Bed XIV Conference, Council of Industrial Boiler Operators. Nemacolin Woods, PA. 6–8 May.

National Drought Mitigation Center. 2006. *Drought Impact Reporter.* Accessed 13 April. *http://droughtreporter.unl.edu/*

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.

NSF. 2000a. *Environmental Technology Verification Report: Physical Removal of Cryptosporidium oocysts and Giardia cysts in Drinking Water: Pall Corporation, WPM-1 Microfiltration Pilot System, Pittsburgh, PA.* Prepared by NSF Under a Cooperative Agreement with U.S. Environmental Protection Agency. NSF 00/09/EPADW395. February.

NSF. 2000b. *Environmental Technology Verification Report: Physical Removal of Cryptosporidium oocysts and Giardia cysts in Drinking Water: Aquasource North America, Ultrafiltration system Model A35, Pittsburgh, PA.* Prepared by NSF International Under a Cooperative Agreement with U.S. Environmental Protection Agency. NSF 00/07/EPADW395. May.

NSF. 2000c. *Environmental Technology Verification Report: Physical Removal of Cryptosporidium oocysts and Giardia cysts in Drinking Water: Leopold Membrane Systems, Ultrabar Ultrafiltration System with 60 Inch Mark III Membrane Element, Pittsburgh, PA.* Prepared by NSF Under a Cooperative Agreement with U.S. Environmental Protection Agency. NSF 00/01/EPADW395. July.

NSF. 2000d. *Environmental Technology Verification Report: Physical Removal of Cryptosporidium oocysts and Giardia cysts in Drinking Water: ZENON, ZeeWeed® ZW-500 Ultrafiltration Membrane System, Pittsburgh, PA.* Prepared by NSF International Under a Cooperative Agreement with U.S. Environmental Protection Agency. NSF 00/06/EPADW395. August.

NSF. 2000e. *Environmental Technology Verification Report: Physical Removal of Particulate Contaminants in Drinking Water: Aquasource North America, Ultrafiltration System Model A35, Escondido, California.* Prepared by NSF International Under a Cooperative Agreement with U.S. Environmental Protection Agency. NSF 00/03/EPADW395. September.

NSF. 2000f. *Environmental Technology Verification Report: Physical Removal of Microbiological and Particulate Contaminants in Drinking Water: Hydranautics, HYDRACap™ Ultrafiltration Membrane System, Escondido, California.* Prepared by NSF International Under a Cooperative Agreement with U.S. Environmental Protection Agency. NSF 00/04/EPADW395. September.

NSF. 2000g. *Environmental Technology Verification Report: Physical Removal of Microbiological and Particulate Contaminants in Drinking Water: Ionics UF-1-7T Ultrafiltration Membrane System, Escondido, California.* Prepared by NSF Under a Cooperative Agreement with U.S. Environmental Protection Agency. NSF 00/13/EPADW395. September.

NSF. 2000h. *Environmental Technology Verification Report: Physical Removal of Microbiological, Particulate and Organic Contaminants in Drinking Water: ZENON, Enhanced Coagulation ZeeWeed® ZW-500 Ultrafiltration Membrane System, Escondido, California.* Prepared by NSF International Under a Cooperative Agreement with U.S. Environmental Protection Agency. NSF 00/02/EPADW395. August.

NSF, 2000i. *Environmental Technology Verification Report: Removal of Precursors to Disinfection By-Products in Drinking Water: PCI Membrane Systems, Fyne Process® Model ROP 1434 With AFC-30 Nanofiltration Membranes.* Prepared by NSF International Under a Cooperative Agreement with U.S. Environmental Protection Agency. NSF 00-19-EPADW-395. September.

NSF. 2001. *Environmental Technology Verification Report: Physical Removal of Microbiological and Particulate Contaminants in Drinking Water: ZENON, ZeeWeed® ZW-500 Ultrafiltration Membrane System, Sandy, OR.* Prepared by NSF Under a Cooperative Agreement with U.S. Environmental Protection Agency. NSF 01/05/EPADW395. June.

NSF. 2002a. *Environmental Technology Verification Report: Physical Removal of Cryptosporidium oocysts, E. coli, and Bacillus spores in Drinking Water: Pall Corporation, Microza™ Microfiltration 3-inch Unit, Model 4UFD40004-45, Manchester, New Hampshire.* Prepared by NSF Under a Cooperative Agreement with U.S. Environmental Protection Agency. NSF 02/18/EPADW395. March.

NSF. 2002b. *Environmental Technology Verification Protocol, Water Quality Protection Center: Verification Protocol for Secondary Effluent and Water Reuse Disinfection Applications.* Prepared by NSF Under a Cooperative Agreement with U.S. Environmental Protection Agency. October.

NSF. 2003a. *Environmental Technology Verification Report: Physical Removal of Particulate Contaminants in Drinking Water: Polymem, Polymem UF120 S2 Ultrafiltration Membrane Module, Luxemburg, Wisconsin.* Prepared by NSF Under a Cooperative Agreement with U.S. Environmental Protection Agency. NSF 03/05/EPADWCTR. May.

NSF. 2003b. *Environmental Technology Verification Report: Physical Removal of Microbiological Particulate Contaminants in Drinking Water: US Filter, 3M10C Microfiltration Membrane System, Chula Vista, California.* Prepared by NSF International Under a Cooperative Agreement with U.S. Environmental Protection Agency. NSF 03/07/EPADWCTR. June.

NSF. 2003c. *Environmental Technology Verification Report: UV Disinfection For Reuse Applications, Aquionics, Inc. bersonInLine® 4250 UV System.* Prepared by NSF Under a Cooperative Agreement with U.S. Environmental Protection Agency. 03/11/WQPC-SWP. September.

NSF. 2003d. *Environmental Technology Verification Report: UV Disinfection For Reuse Applications, Ondeo Degremont, Inc. Aquaray® 40 HO VLS Disinfection System.* Prepared by NSF Under a Cooperative Agreement with U.S. Environmental Protection Agency. 03/10/WQPC-SWP. September.

NSF. 2003e. *Environmental Technology Verification Report: UV Disinfection of Secondary Effluent, SUNTEC environmental, Inc. LPX200 UV Disinfection System.* Prepared by NSF Under a Cooperative Agreement with U.S. Environmental Protection Agency. 03/09/WQPC-SWP. September.

NSF. 2004. *Case Study: Drinking Water Systems—Disinfection By-Product Treatment for Small Communities.* Draft. 12 February.

NSF. 2005a. *Environmental Technology Verification Protocol: Drinking Water Systems Center: Protocol for Equipment Verification Testing For Physical Removal Of Microbiological And Particulate Contaminants.* Prepared by NSF International Under a Cooperative Agreement with U.S. Environmental Protection Agency. 05/9205/EPADWCTR. February.

NSF. 2005b. *Steering Committee Teleconference Meeting Summary: ETV Drinking Water Systems Center.* 16 February.

Pall Corporation. 2006. *Pall Water Treatment System Installation Saves Park and Protects Water for Residents of Pittsburgh, PA.* Web site accessed 23 March. *http://www.pall.com/water_8150.asp*

Pham, Minh. 2006. E-mail communication. 3 May.

Poon, W. 2002. *U.S. EPA ETV Program: A Success Story.* ETV Stakeholders Meeting, EPA Campus, Research Triangle Park, NC. 13 March.

Rubio, Fernando. 2006. E-mail communication. 28 May.

Scoble, Clint. 2006. E-mail communication. 2 June.

South Coast Air Quality Management District (SCAQMD). 2005. *Rule 1156: Further Reductions of Particulate Emissions from Cement Manufacturing Facilities.* 4 November.

Southern Research Institute. 1998. *Electric Power Generation Using A Phosphoric Acid Fuel Cell On A Municipal Solid Waste Landfill Gas Stream: Technology Verification Report.* Prepared by Greenhouse Gas Technology Center, Southern Research Institute, Under a Cooperative Agreement with U.S. Environmental Protection Agency. August.

Southern Research Institute. 2001a. *Environmental Technology Verification Report: Mariah Energy Corporation Heat PlusPower™ System.* Prepared by Greenhouse Gas Technology Center, Southern Research Institute, Under a Cooperative Agreement with U.S. Environmental Protection Agency. SRI/USEPA-GHG-VR-13. September.

Southern Research Institute. 2001b. *Environmental Technology Verification Report: Honeywell Power Systems, Inc. Parallon® 75 kW Turbogenerator.* Prepared by Greenhouse Gas Technology Center, Southern Research Institute, Under a Cooperative Agreement with U.S. Environmental Protection Agency. SRI/USEPA-GHG-VR-10. September.

Southern Research Institute. 2001c. *Environmental Technology Verification Report: Honeywell Power Systems, Inc. Parallon® 75 kW Turbogenerator With CO Emissions Control.* Prepared by Greenhouse Gas Technology Center, Southern Research Institute, Under a Cooperative Agreement with U.S. Environmental Protection Agency. SRI/USEPA-GHG-VR-15. September.

Southern Research Institute. 2003a. *Environmental Technology Verification Report: Ingersoll-Rand Energy Systems IR PowerWorks™ 70 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-21. April.

Southern Research Institute. 2003b. *Environmental Technology Verification Report: Combined Heat and Power at a Commercial Supermarket—Capstone 60 kW Microturbine CHP System.* Prepared by Greenhouse Gas Technology Center, Southern Research Institute, Under a Cooperative Agreement with U.S. Environmental Protection Agency. SRI/USEPA-GHG-VR-27. September.

Southern Research Institute. 2003c. *Environmental Technology Verification Report: Residential Electric Power Generation Using the Plug Power SU1 Fuel Cell System.* Prepared by Greenhouse Gas Technology Center, Southern Research Institute, Under a Cooperative Agreement with U.S. Environmental Protection Agency. SRI/USEPA-GHG-VR-25. September.

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 U.S. Environmental Protection Agency. SRI/USEPA-GHG-VR-26. September.

Stockwell, Peter. 2006. E-mail communication. 7 July.

Trenholm, Drew and John McKenna. 2006. E-mail communication. 10 August.

U.S. Bureau of Reclamation. 2002. *Southern California Water Reclamation and Reuse Study.* Cooperative effort funded and managed by U.S. Bureau of Reclamation in partnership with Southern California Department of Water Resources, Central Basin and West Basin Water Districts, City of Los Angeles, City of San Diego, Metropolitan Water District of Southern California, San Diego County Water Authority, Santa Ana Watershed Project Authority, and South Orange County Reclamation Authority. July.

U.S. Census Bureau. *1990. 1990 Summary Tape File 3 (STF 3)—Sample data. DP-5: Housing Characteristics. http://factfinder.census.gov/servlet/DatasetMainPageServlet*

U.S. Department of Agriculture. 2004. *Acreage*. National Agriculture Statistics Service. June.

U.S. Department of Energy (DOE). 2006a. *Fuel Cells: Basics. Office of Energy Efficiency and Renewable Energy*. Last Updated 26 April. *http://www.eere.energy.gov/hydrogenandfuelcells/fuelcells/basics.html*

U.S. DOE. 2006b. *Fuel Cell Facts.* Office of Energy Efficiency and Renewable Energy. Accessed 10 May. *http://www.hydrogen.energy.gov*

U.S. EPA and U.S. Agency for International Development (U.S. AID). 2004. *Guidelines for Water Reuse.* EPA/625/R-04/108. September.

U.S. EPA. 1993. *Report to Congress on Cement Kiln Dust.* December.

U.S. EPA. 1997a. *Climate Change and Public Health.* Office of Policy, Planning, and Evaluation. EPA 236-F-97-005. October.

U.S. EPA. 1997b. *Regulatory Impact Analyses for the Particulate Matter and Ozone National Ambient Air Quality Standards and Proposed Regional Haze Rule.* Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. 17 July.

U.S. EPA. 1998. *NOX: 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. 1999a. *Wastewater Technology Fact Sheet: Ultraviolet Disinfection.* EPA 832-F-99-064. September.

U.S. EPA. 1999b. *Report to Congress: Wastes from the Combustion of Fossil Fuels.* EPA 530-R-99-010. March.

U.S. EPA. 2000a. *Global Warming—Impacts.* Last updated 7 January. *http://yosemite.epa.gov/OAR/globalwarming.nsf/content/impacts.html*

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

U.S. EPA. 2001a. *Water Recycling And Reuse: The Environmental Benefits.* Region 9, U.S. Environmental Protection Agency. EPA 909-F-98-001.

U.S. EPA. 2001b. *Stage 1 Disinfectants and Disinfection Byproducts Rule: A Quick Reference Guide.* EPA 816-F-01-010. May.

U.S. EPA. 2002a. "Report to Congress; The Environmental Technology Verification Program; Case Study: Greenhouse Gas Reduction—Microturbine With Heat Recovery." Draft. 11 July.

U.S. EPA. 2002b. *Technology Characterization: Fuel Cells.* April.

U.S. EPA. 2003a. *National Primary Drinking Water Standards.* EPA 816-F-03-016. June.

U.S. EPA. 2003b. *Status of Hg Measurement Methodologies for Coal-Fired Combustion Sources: Manual Methods and Continuous Emission Monitors.* December. Included in Clean Air Mercury Rule Docket Number OAR-2002-0056-0022.

U.S. EPA. 2003c. *Status of Commercially Available Hg CEMS.* Prepared by ARCADIS for U.S. Environmental Protection Agency. 3 December. Included in Clean Air Mercury Rule Docket Number OAR-2002-0056-0022.

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

U.S. EPA. 2003e. *Interim Reregistration Eligibility Decision for Atrazine (Case No. 0062).* January.

U.S. EPA. 2003f. *Revised Atrazine Interim Reregistration Eligibility Decision (IRED).* October.

U.S. EPA. 2003g. *Memorandum of Agreement Between the U. S. Environmental Protection Agency and Agan Chemical Manufacturing, Dow AgroSciences, Drexel Chemical, Oxon Italia S.P.A., and Syngenta Crop Protection Concerning the Registration of Pesticide Products Containing Atrazine.* January.

U.S. EPA. 2003h. *Clean Watersheds Needs Survey (CWNS) 2000 Unit Process Database. http://cfpub.epa.gov/cwns/process.cfm*

U.S. EPA. 2003i. *Clean Watersheds Needs Survey 2000: Report to Congress.* EPA-832-R-03-001. August.

U.S. EPA. 2003j. *Latest Findings on National Air Quality: 2002 Status and Trends.* Office of Air Quality Planning and Standards, Emissions, Monitoring, and Analysis Division, Research Triangle Park, North Carolina. EPA 454/ K-03-001. August.

U.S. EPA. 2003k. *Air Pollution Control Technology Fact Sheet: Fabric Filter—Reverse-Air/Reverse-Jet Cleaned Type with & without Sonic Horn Enhancement.* EPA-452/F-03-026.

U.S. EPA. 2003l. *Air Pollution Control Technology Fact Sheet: Fabric Filter—Mechanical Shaker-Cleaned Type with & without Sonic Horn Enhancement.* EPA-452/F-03-024.

U.S. EPA. 2004a. *Environmental Technology Verification (ETV) Program Stakeholder's Briefing: Meeting Summary.* 11–12 May.

U.S. EPA. 2004b. *Air Quality Criteria for Particulate Matter (October 2004).* Volume I of II. EPA/600/P-99/002aF. October.

U.S. EPA. 2004c. *Nationwide Bacteria Standards Protect Swimmers at Beaches.* Fact Sheet. November. *http://www.epa.gov/waterscience/beaches/bacteria-rule-final-fs.htm*

U.S. EPA. 2004d. *Economic Analysis for Final Water Quality Standards for Coastal Waters.* Prepared for Office of Science and Technology, U.S. Environmental Protection Agency by Science Applications International Corporation. Docket Number OW-2004-0010-0263. November.

U.S. EPA. 2004e. *Inventory of U.S. Greenhouse Gas Emissions And Sinks: 1990–2002.* EPA 430-R-04-003. April 15, 2004.

U.S. EPA. 2004f. "Output-based Regulations: A Handbook for Air Regulators." Office of Atmospheric Programs, Climate Protection Partnerships Division. Draft Final Report. August.

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

U.S. EPA. 2005a. *Economic Analysis for the Final Long Term 2 Enhanced Surface Water Treatment Rule.* EPA 815-R-06-001. December.

U.S. EPA. 2005b. *Membrane Filtration Guidance Manual.* EPA 815-R-06-009. November.

U.S. EPA. 2005c. *Economic Analysis for the Final Stage 2 Disinfectants and Disinfection Byproducts Rule.* EPA 815-R-05-010. December.

U.S. EPA. 2005d. *Fact Sheet: Stage 2 Disinfectants and Disinfection Byproducts Rule.* EPA 815-F-05-003. December.

U.S. EPA. 2005e. *FACT SHEET: EPA's Clean Air Mercury Rule.* 15 March.

U.S. EPA. 2005f. *Regulatory Impact Analysis of the Clean Air Mercury Rule.* EPA-452/R-05-003. March.

U.S. EPA. 2005g. *National Emission Inventory Air Pollutant Emissions Trends—PM 2.5—1990 to 2002.* Updated 4 August.

U.S. EPA. 2005h. *PM 2.5 Nonattainment Areas: Point Sources Exceeding Emission Thresholds by Pollutant.* EPA Docket No. EPA-HQ-OAR-2003-0062-0046. September.

U.S. EPA. 2005i. *Consumer Factsheet on Atrazine.* Office of Ground Water and Drinking Water. February 2005. *http://www.epa.gov/safewater/contaminants/dw_contamfs/atrazine.html*

U.S. EPA. 2005j. *Public Drinking Water Systems: Facts and Figures.* Office of Ground Water and Drinking Water. February. *http://www.epa.gov/safewater/pws/factoids.html*

U.S. EPA. 2005k. *Environmental Protection Agency Combined Heat and Power Partnership.* Last updated 2 May. *http://www.epa.gov/chp/index.htm*

U.S. EPA. 2005l. *EPA—CHP—State Resources—Output-based Regulations.* Last updated 2 May. *http://www.epa.gov/chp/state_resources/output_based_reg.htm*

U.S. EPA. 2005m. *Factoids: Drinking Water and Ground Water Statistics for 2004.* EPA 816-K-05-001. May.

U.S. EPA. 2005n. *EPA Voluntary Diesel Retrofit Program—Glossary of Terms. http://www.epa.gov/otaq/retrofit/glossary.htm*

U.S. EPA. 2006a. Long Term 2 Enhanced Surface Water Treatment Rule (LT2); Basic Information. Last Updated 28 February. *http://www.epa.gov/safewater/disinfection/lt2/basicinformation.html*

U.S. EPA. 2006b. *Fact Sheet: National Air Quality Standards for Fine Particle Pollution: Changes to Designated "Nonattainment" or "Unclassifiable" Areas and Standards for Fine Particle Pollution Become Effective.* Last Updated 2 March. *http://www.epa.gov/oar/oaqps/particles/designations/documents/Apr05/factsheet.htm*

U.S. EPA. 2006c. *EPA's BEACH Report: 2005 Swimming Season.* EPA 823-F-06-010. June. *http://www.epa.gov/ost/beaches/seasons/2005/*

U.S. EPA. 2006d. *National Section 303(d) List Fact Sheet.* Accessed 3 May. *http://oaspub.epa.gov/waters/national_rept.control*

U.S. EPA. 2006e. *Overview of Current Total Maximum Daily Load—TMDL—Program and Regulations.* Last Updated 14 March. *http://www.epa.gov/owow/tmdl/overviewfs.html*

U.S. EPA. 2006f. *Environmental Technology Verification (ETV) Program Case Studies: Demonstrating Program Outcomes.* EPA/600/R-06/001. January.

U.S. EPA. 2006g. *CHP Project Resources—Wastewater.* Last Updated 10 May. *http://www.epa.gov/chp/project_resources/wastewater.htm*

U.S. EPA. 2006h. *Health and Environmental Impacts of SO2.* Last Updated 2 March. *http://www.epa.gov/air/urbanair/so2/hlth1.html*

U.S. EPA. Undated. *Cost Estimates for Mercury Emissions Monitoring.* U.S. Environmental Protection Agency, Clean Air Mercury Rule Docket Number OAR-2002-0056-6161.

Utah. 2005. *Utah Safe Drinking Water Act.* R309-535-13. June.

Utah. 2006. *Utah Division of Drinking Water Construction Approval Process.* Utah Department of Environmental Quality. Last Updated 19 April. *http://www.drinkingwater.utah.gov/plan_review_intro.htm*

UTC Power. 2006a. *Environmental, Educational, and Power Security Benefits.* Accessed 10 May. *http://www.utcpower.com/fs/com/bin/fs_com_Page/0,9235,0400,00.html*

UTC Power. 2006b. *During the Big Blackout, One NYC Police Station Kept Its Cool.* Accessed 10 May. *http://www.utcpower.com/fs/com/bin/fs_com_Page/0,9235,0400,00.html*

Washington. 2001. *Water System Design Manual.* Washington State Department of Health, Environmental Health Programs, Division of Drinking Water. DOH #331–123. August.

Water & Wastes Digest. 2005. “ITT Aquious-PCI Membranes Help Alaska School District Win NWRA’s Great American Water Taste Test.” *Water & Wastes Digest.* 17 November. *http://www.wwdmag.com/WWD/index.cfm?fuseaction=sni&nid=10506*

Appendices

Appendix A. Methods for Baghouse Filtration Products Outcomes

Number of Facilities

ETS, RTI's subcontractor during the verifications, estimates that there are more than 100,000 baghouses in the United States, of which 10,000 are medium to large (McKenna, 2006). Any of these existing baghouses could install the ETV-verified products. In addition to these existing baghouses, there could be other facilities without existing controls that might be candidates for installing baghouses using the ETV-verified products. Because a precise estimate of the number of facilities nationwide that could apply the products was not available, ETV limited its estimate of the market for the ETV-verified baghouse filtration products to large stationary sources located in areas of the country that exceed the NAAQS for $PM_{2.5}$ (i.e., non-attainment areas). Because these facilities are large and located in non-attainment areas, they are the most likely candidates for pollution control as states implement the NAAQS through their SIPs.

U.S. EPA (2005h) estimated that there were 358 facilities that each emit more than 100 tons per year of $PM_{2.5}$ located in non-attainment areas. The same document estimated there were 443 facilities emitting more than 70 tons per year and 553 facilities emitting more than 50 tons per year. ETV chose the facilities emitting more than 100 tons per year as its market estimate because this group represents the largest facilities, which are the most likely candidates for control. In addition, these facilities account for 94% of $PM_{2.5}$ emissions from point sources in non-attainment areas. Facilities that emit between 50 and 100 tons per year account for only 2% of total $PM_{2.5}$ emissions in non-attainment areas (U.S. EPA, 2005h), so adding these facilities to the market would have a limited impact on pollutant reduction estimates.

The resulting market estimate is conservative (low) because it considers only large facilities in non-attainment areas. It does not include smaller facilities, facilities in areas that meet the NAAQS, or new facilities that could apply the ETV-verified technologies. It also does not include facilities that could require additional control if EPA's proposed revisions to the NAAQS (71 FR 2620) are finalized.

Pollutant Reductions

U.S. EPA (2005h) estimated that the 358 facilities included in ETV's market estimate emitted 381,400 tons of $PM_{2.5}$ in 2001. To estimate the portion of these emissions attributable to baghouses, ETV used data from U.S. EPA (2005g, 1999b, and 1993). First, based on data from U.S. EPA (2003d, 2003k, and 2003l), ETV identified the following industry categories as amenable to baghouse technology for $PM_{2.5}$ control:

- Combustion of coal and wood in electric utility, industrial, and commercial/institutional facilities
- Ferrous and non-ferrous metals processing
- Asphalt manufacturing

- Grain milling
- Mineral products.

ETV extracted data from U.S. EPA (2005g) on 2002 $PM_{2.5}$ emissions from these selected industry categories. These industry categories account for 13% of national $PM_{2.5}$ direct emissions, and an estimated 41% of national $PM_{2.5}$ direct emissions from point sources.

Second, ETV applied assumptions about the portion of total $PM_{2.5}$ emissions in each industry category attributable specifically to baghouses. ETV derived these assumptions from data in U.S. EPA (1999b and 1993) on the frequency of baghouse use in three of the most significant industry categories. Exhibit A-1 shows these assumptions. Applying these assumptions to the emissions data from U.S. EPA (2005g), ETV estimated that baghouses account for $PM_{2.5}$ emissions of 170,000 tons per year, or approximately 8% of an estimated 2,100,000 million tons per year nationwide from point sources.[61] ETV applied this percentage to the 381,400 tons emitted by large facilities in non-attainment areas.

ETV assumed large facilities in non-attainment areas have existing baghouses with a removal efficiency of 95% and that applying ETV-verified filtration products would increase their efficiency to 99.9%. There is substantial uncertainty involved in applying these assumptions, because data are not available to estimate overall baghouse removal efficiency using the ETV-verified filtration products or the efficiency of existing baghouses at the selected facilities. Pollutant reductions from the application of baghouse technologies vary based on a number of factors, including gas velocity, particle concentration, particle characteristics, and cleaning mechanism. Design efficiencies for new baghouse devices are between 99% and 99.9%, whereas older models have actual operating efficiencies between 95% and 99.9% (U.S. EPA, 2003d, 2003k, 2003l). Also, although removal efficiency was not a parameter in the verification tests, data in the verification reports show that the ETV-verified technologies removed greater than 99.99% of $PM_{2.5}$ under the test conditions. The ETV results accurately reflect $PM_{2.5}$ penetration of the media, but overall baghouse efficiencies are a function of both media penetration and leaks through components of the baghouse other than the bags.

EXHIBIT A-1

ASSUMPTIONS ON PORTION OF EMISSIONS ATTRIBUTABLE TO BAGHOUSES

Industry Category	Percent Using Baghouses	Source/Notes
Electric utility coal combustion	11.5	Percent using fabric filters + ½ of percent using combined technologies in Figure 3-3 of U.S. EPA, 1999b
Industrial, commercial, and institutional coal combustion	18.0	Percent using fabric filters + ½ of percent using combined technologies in Figure 4-5 of U.S. EPA, 1999b
Industrial wood/bark waste combustion and miscellaneous non-residential fuel combustion	18.0	Facilities presumed similar in size and emissions characteristics to industrial coal combustion facilities
Cement manufacturing	43.8	Exhibit 3-4 of U.S. EPA, 1993
Other mineral products	43.8	Cement manufacturing is part of the mineral products category and other facilities in the category are presumed similar in industrial processes used and emissions characteristics.
Asphalt manufacturing	43.8	Facilities presumed similar in industrial processes used and emissions characteristics to cement manufacturing
Ferrous and non-ferrous metals processing	11.5	Used percentage for electric utilities to be conservative
Grain mills (1)	11.5	Used percentage for electric utilities to be conservative

Values rounded to three significant figures
(1) Includes wheat mills and other grain mills, but not feed mills because source does not indicate how many feed mills mill grain.

---

[61] ETV derived nationwide point source emissions from U.S. EPA (2005g) by categorizing emissions in the stationary fuel combustion and industrial process categories as primarily from point sources and emissions in the transportation and miscellaneous categories as primarily from non-point sources.

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

$$PR = (CE – PE \times (1 – 0.999)) \times \%MP$$

Where:

- PR is $PM_{2.5}$ reduction in tons per year.
- CE is current $PM_{2.5}$ emissions from baghouses at large facilities in non-attainment areas, or 381,400 x 8%.
- PE is potential $PM_{2.5}$ emissions from baghouses at large facilities in non-attainment areas assuming no existing controls are present, or CE / (1 – 0.95), where 0.95 is the assumed removal efficiency of existing baghouses.
- 0.999 is the assumed removal efficiency of baghouses using ETV-verified baghouse filtration products.
- %MP is the percent market penetration for the ETV-verified baghouse filtration products.

The resulting estimates likely are conservative (low) because some of the facilities might not have existing controls in place. They also do not account for additional reductions that could occur if EPA's proposed revisions to the NAAQS (71 FR 2620) are finalized.

To estimate pollutant reductions if the ETV-verified baghouse filtration products were applied nationwide, ETV used the same method, substituting the 170,000 tons per year estimated above for baghouse emissions nationwide in place of current emissions (CE).

Human Health Outcomes

To estimate nationwide human health outcomes, ETV used data from the RIA for the 1997 NAAQS (U.S. EPA, 1997b) and applied the following equation:

$$Outcome_{ETV} = (Outcome_{RIA} / PR_{RIA}) \times PR_{ETV}$$

Where:

- $Outcome_{ETV}$ is the quantified measure for a given human health endpoint (e.g., avoided cases of premature mortality) attributable to $PM_{2.5}$ reductions from the ETV-verified baghouse filtration products.
- $Outcome_{RIA}$ is the quantified measure for the same $PM_{2.5}$-related human health endpoint from Table 12.4 of the RIA for the 1997 NAAQS (U.S. EPA, 1997b) and varied between the upper- and lower-bound scenarios.
- PR_{RIA} is the total nationwide $PM_{2.5}$ reduction estimated in Table 6-5 of the RIA for the 1997 NAAQS (U.S. EPA, 1997b).
- PR_{ETV} is the $PM_{2.5}$ reduction estimated from application of the ETV-verified baghouse filtration products in each market penetration scenario.

This method assumes there would be a linear relationship between human health outcomes and emissions reductions. This method is most likely a simplification of the actual relationship. First, it assumes that the relationship between emissions reductions and the ambient concentration of $PM_{2.5}$ in a given area is linear. Second, it assumes that the relationship between ambient PM concentrations and human health effects is linear. In fact, these relationships are complex and subject to external factors (e.g., state NAAQS implementation strategies, PM emissions from other sources, other environmental factors, and the population in a given area). Data are not available to determine how close the overall relationship among these factors is to linear. Finally, the method assumes that the nationwide distribution of $PM_{2.5}$ reductions from the ETV technologies would be similar to that from the 1997 NAAQS. This assumption could be reasonable for very high market penetration scenarios. It is likely less accurate for lower market penetration scenarios, where penetration might occur first in certain areas of the country. In spite of these limitations, the resulting estimates could be conservative (low) because they are based on the conservative estimates of pollutant reductions.

Economic Outcomes

To estimate the economic value of human health and environmental benefits, the ETV Program used values for total annual benefits from the RIA for the 1997 NAAQS (U.S. EPA, 1997b) and a method parallel to that discussed above for human health outcomes. That is, ETV applied the following equation:

$$\text{Benefits}_{ETV} = (\text{Benefits}_{RIA} / \text{PR}_{RIA}) \times \text{PR}_{ETV}$$

Where:

- Benefits_{ETV} is the total monetary benefit per year realized from the human health and environmental outcomes associated with $PM_{2.5}$ reductions from the ETV-verified baghouse filtration products.
- Benefits_{RIA} is the total monetary benefit per year reported in Tables 12.5 (for human health benefits) and 12.13 (for environmental benefits, including consumer cleaning cost savings and visibility improvements) of the RIA for the 1997 NAAQS (U.S. EPA, 1997b). These values varied between the upper- and lower-bound scenarios.
- PR_{RIA} is the total nationwide $PM_{2.5}$ reduction estimated in Table 6-5 of the RIA for the 1997 NAAQS (U.S. EPA, 1997b).
- PR_{ETV} is the $PM_{2.5}$ reduction estimated from application of the ETV-verified baghouse filtration products in each market penetration scenario.

In addition to monetary benefits associated with human health outcomes, ETV included monetary benefits associated with environmental outcomes (consumer cleaning cost savings and visibility improvements) in this calculation. This method is subject to the same limitations discussed above for human health outcomes. In spite of these limitations, the resulting estimates could be conservative for the same reasons discussed above, and because they are in 1990 dollars, as reported in the RIA. Therefore, they provide a conservative (low) estimate of economic outcomes in current year dollars.

Appendix B. Methods for Fuel Cell Outcomes

Number and Capacity of ETV-Verified Fuel Cells

The ETV Program used data from Fuel Cells 2000's Worldwide Stationary Fuel Cell Installation Database (Fuel Cells 2000, 2006) to estimate the number and capacity of ETV-verified fuel cells that have been installed in the United States since the verifications were completed. Specifically, to estimate current installations, ETV searched the database for all U.S. projects involving PAFC fuel cells installed by UTC Power and PEM fuel cells installed by PlugPower and examined the details of each project found. In determining whether to count a given project, ETV included PureCell™ and PureComfort™ systems from UTC Power and GenSys systems from PlugPower. Although these technology names are not the same as those in the verification reports (PC25 and SU1), information from the vendor Web sites indicates that these are likely new brand names for the same technology.[62] ETV also included projects where the technology name was not specified, if the fuel cells were of the same capacity as those verified. ETV excluded from its count the following types of projects:

- Projects installed before the verifications were completed (1998 for UTC Power and 2003 for PlugPower)
- Projects that provide backup or emergency power only
- Projects that have been decommissioned or are no longer operating
- Short-term demonstration projects.

Using these guidelines, ETV estimated 134 verified fuel cells, with a total of approximately 15 MW of capacity, have been installed in the United States since verifications were completed and are currently operating. This estimate is conservative (low) in terms of number and capacity because it excludes projects that provide backup or emergency power only. These projects, however, likely operate only intermittently and would not contribute significantly to annual pollutant reductions. The estimate also is conservative because it excludes short-term demonstration projects. Some of these demonstration fuel cells might have remained in place and continued operating after the demonstration was complete, continuing to contribute to pollutant reductions.

To project future installations, the ETV Program examined projects that were installed in 2005. In making the projection, however, ETV did not include future installations of the PlugPower technology. Information from the vendor Web site and media sources (see, for example, Engle, 2005) suggest the company is now targeting the backup power market using hydrogen fuel directly, without a fuel reformer. Although verification results might contribute to future sales of the technology in backup power applications, the resulting installations would not contribute significantly to pollutant reductions.

---

[62] The technology vendors were provided an opportunity to review this case study and did not comment on this assumption.

Excluding 2005 PlugPower sales, 18 fuel cells, with a total capacity of 3.8 MW, were installed in 2005. The ETV Program used this estimate of fuel cells installed in 2005 to project future installations over the next five years as follows:

$$18 \text{ fuel cells} \times 5 \text{ years} = 90 \text{ fuel cells}$$

$$3.8 \text{ MW} \times 5 \text{ years} = 19 \text{ MW}$$

Adding these values to 134 fuel cells currently installed, with 15 MW capacity, results in a future projection of 224 fuel cells with 34 MW capacity. This projection is conservative (low) because it excludes future PlugPower sales and assumes no growth in sales from 2005 levels.

Emissions Reductions

In developing the current estimate and future projection, the ETV Program maintained separate estimates in three categories, for use in estimating emissions reductions:

1) Small, residential-scale fuel cells operating on conventional fuels
2) Larger, commercial/institutional-scale fuel cells operating on conventional fuels
3) Larger, commercial/institutional-scale fuel cells operating on anaerobic digester gas

Emissions reductions from fuel cell applications vary on a site-by-site basis. Because of this variation, producing a precise nationwide estimate is difficult. To produce a rough estimate, the ETV Program assumed that applications that fell within the same fuel cell category produced identical emissions reductions. For categories 1 and 3, the ETV Program used the reduction estimates developed by Southern Research Institute in the verification reports to estimate the emission reductions from installations within those categories. For category 2, ETV modified the reduction estimate for one of the test sites to subtract the credit for eliminating emissions from the digester gas flare. Exhibit B-1 summarizes the category-specific reduction estimates. The verification reports (Southern Research Institute, 1998, 2003c, 2004b) describe the test sites and the baseline assumptions (e.g., displaced conventional power source) used to generate the reduction estimates in more detail. The reduction estimates account for CO_2 emissions from the fuel reformer or gas processing units associated with the fuel cells.

To calculate national emissions reductions for each category, the ETV Program used the following equation:

$$R_{TOTAL} = (C_{TOTAL} / C) \times R / 2000$$

Where:

- R_{TOTAL} is total CO_2 or NO_X reduction for a given category in tons per year.
- C_{TOTAL} is the total capacity in MW of ETV-verified fuel cells installed and varies for each category and for current and future installations.
- C is the individual fuel cell capacity in MW for the given category.
- R is the model site CO_2 or NO_X reduction in pounds per year and varies for each category.

ETV then summed the results for each category to estimate total national emissions reductions.

Exhibit B-1

Assumed Emissions Reductions per Fuel Cell

Category and Facility Type	Fuel Cell Capacity (kW)	CO_2 Reduction (pounds per year)	NO_X Reduction (pounds per year)	Source
1) Small, residential-scale fuel cells operating on conventional fuels	5	723	44.3	Southern Research Institute, 2003c, Table 2-8
2) Larger, commercial/institutional-scale fuel cells operating on conventional fuels	200	74,000	3,080	Southern Research Institute, 2004b, Table 2-6, subtracting credit for eliminating flare emissions
3) Larger, commercial/institutional-scale fuel cells operating on anaerobic digester gas	200	2,850,000	3,640	Southern Research Institute, 2004b, Table 2-6

Values rounded to three significant figures

Appendix C. Methods for Microturbine/ Combined Heat and Power (CHP) Outcomes

Microturbine/CHP Markets

As discussed in Section 2.4.3, one vendor has reported sales of 13 MW of ETV-verified microturbines for CHP applications in the United States since the verifications were completed (ETV Vendor, 2006). The ETV Program used this value as the current minimum market penetration. This is a conservative (low) estimate because it includes sales by only one vendor. The vendor also reported sales of approximately 8.4 MW for CHP applications in the United States during 2005 (ETV Vendor, 2006). The ETV Program used 2005 sales to calculate future penetration over the next five years as follows:

8.4 MW x 5 years = 42 MW

Adding this value to the current minimum penetration of 13 MW results in a total installed capacity of 55 MW. This estimate also is conservative (low) because it is based on the conservative estimate of current penetration and assumes no growth in sales. The vendor forecasts sales will double this year and double again the following year (ETV Vendor, 2005). It also includes U.S. sales only. The vendor reported that U.S. sales represented approximately half of its global sales (ETV Vendor, 2005). Also, various economic estimates of the microturbine/CHP market project an increasing market for these technologies, as discussed below.

EEA (2003) reports that current microturbine sales in CHP applications average 50 units per year. Assuming an average capacity per unit in the range reported for the ETV-verified technologies (30 to 75 kW), current sales as reported by EEA (2003) translate to 1.5 to 3.75 MW of capacity per year. The same source, however, estimates an increasing market for these technologies: 1,530 MW in CHP applications, both new and retrofit, over the next 20 years. This translates to sales of 76.5 MW per year. This latter estimate assumes advances in technology that result in greater efficiency and cost-effectiveness than achieved by current technology. Another estimate of the microturbine market can be derived from data in Boedecker et al. (2000). This source estimates microturbines will generate 1 billion kWh in 2010 and 3 billion kWh in 2020. The capacity required to generate this much electricity would be a minimum of 57 MW in 2010 and 171 MW in 2020.[63] This capacity increase would require microturbine sales of 114 MW over ten years, or 11.4 MW per year. Exhibit C-1 compares the estimates used in this analysis with the projections from these economic analyses. The estimates used in this analysis are at the lower end, but within, the range from the economic analyses.

Emissions Reductions

Emissions reductions from microturbine applications vary on a site-by-site basis. Because of this variation, producing a precise nationwide estimate is difficult. To produce a rough estimate,

---

[63] These capacity estimates assume 100% utilization of installed capacity, and are, therefore, low.

Exhibit C-1

FIVE-YEAR MICROTURBINE/CHP MARKET ESTIMATES

Source	Sales per year (MW)	Total over five years (MW)	Comments/Limitations
EEA, 2003	1.5 to 3.75	7.5 to 18.8	Based on current sales averaged over the last 20 years. Includes CHP applications only.
Estimate used in ETV's analysis	8.4	42	Based on sales by a single vendor (ETV Vendor, 2006). Assumes no growth in sales. Includes CHP applications only.
Boedecker et al., 2000	11.4	57	Based on 100% capacity utilization. Assumes limited technology advancement.
EEA, 2003	76.5	383	Assumes technology advancement. Includes CHP applications only.

the ETV Program calculated the total emissions reductions assuming all applications are identical and represented by model sites. The ETV Program examined several possible model sites, all developed by Southern Research Institute in the verification reports for the technologies. Exhibit C-2 summarizes the model sites examined. The verification reports (Southern Research Institute, 2001a, 2003a, 2003b) describe the model sites and the baseline assumptions (e.g., displaced conventional power source) used to generate the reduction estimates in more detail. For the estimates in this analysis, the ETV Program used only the first two sites in Exhibit C-2 for the following reasons:

- The estimates for these sites are based on actual test site operations (as opposed hypothetical sites).
- The estimates include both CO_2 and NO_X reductions.
- The estimates were developed using more recent assumptions about displaced emissions rates.

The ETV Program generated upper- and lower-bound estimates for CO_2 and NO_X by choosing the model sites that result in the highest and lowest CO_2 and NO_X reductions, respectively. The national estimates use the following equation:

$$TR = (TC / MC) \times MR / 2000$$

Where:

- TR is total CO_2 or NO_X reduction in tons per year.
- TC is the total capacity in MW of ETV-verified microturbines installed and varies depending on the market penetration scenario.
- MC is the model site capacity in MW and varies depending on the model site chosen.
- MR is model site CO_2 or NO_X reduction in pounds per year and varies depending on the model site chosen.

EXHIBIT C-2

MODEL SITES EXAMINED IN ESTIMATING EMISSIONS REDUCTIONS

Location and Facility Type	Site Capacity (kW)	Site CO_2 Reduction (pounds per year)	Site NO_X Reduction (pounds per year)	Source
New York, Community Center (e)(1)	70	212,000	1,330	Southern Research Institute, 2003a
New York, Supermarket (e)(2)	60	328,000	1,060	Southern Research Institute, 2003b
Chicago, Large Office (h)	60	527,000	Not estimated	Southern Research Institute, 2001a
Chicago, Medium Hotel (h)	60	558,000	Not estimated	Southern Research Institute, 2001a
Chicago, Large Hotel (h)	90	884,000	Not estimated	Southern Research Institute, 2001a
Chicago, Hospital (h)	420	3,920,000	Not estimated	Southern Research Institute, 2001a
Atlanta, Large Office (h)	60	1,050,000	Not estimated	Southern Research Institute, 2001a
Atlanta, Medium Hotel (h)	60	1,160,000	Not estimated	Southern Research Institute, 2001a
Atlanta, Large Hotel (h)	90	1,700,000	Not estimated	Southern Research Institute, 2001a
Atlanta, Hospital (h)	420	9,770,000	Not estimated	Southern Research Institute, 2001a

Values rounded to three significant figures

(h) Hypothetical site

(e) ETV test site

(1) Used to generate lower-bound CO_2 estimates and upper-bound NO_X estimates

(2) Used to generate upper-bound CO_2 estimates and lower-bound NO_X estimates

Appendix D. Methods for Microfiltration (MF) and Ultrafiltration (UF) Outcomes

Number of Systems and Population Served

For the LT2ESWTR, EPA examined several different *Cryptosporidium* occurrence data sets: the Information Collection Rule (ICR) data set, the Information Collection Rule Supplemental Survey of Medium Systems (ICRSSM) data set, and the Information Collection Rule Supplemental Survey of Large Systems (ICRSSL) data set. Differences among these data sets resulted in different estimates of the number of public water systems (PWSs) required to install treatment. The ETV Program used this range of estimates to select upper- and lower-bound estimates of the number of small PWSs that could install the verified technologies. Specifically, the ETV Program used data from Table VI-D.3 of 71 FR 654. For the upper-bound estimate, the ETV Program used the number of small systems corresponding to the ICR data set. For the lower-bound estimate, the ETV Program used the number of small systems corresponding to the ICRSSL data set.[64] The resulting upper- and lower-bound estimates are 2,200 and 1,400 small systems, respectively. To produce the estimates in Exhibit 3.1-2, the ETV Program multiplied the total number of systems by each market penetration percentage. These upper- and lower-bound estimates of the number of systems also correspond to upper- and lower-bound estimates of human health outcomes and economic benefits.

The ETV Program also estimated the total population served by these systems. This estimate used an average population served per system by small systems derived from Exhibit 5.9 of U.S. EPA (2005a). To produce the population estimates in Exhibit 3.1-2, the ETV Program multiplied the number of systems in each market penetration scenario by this average population per system.

Human Health Outcomes

The ETV Program estimated the cryptosporidiosis cases prevented by ETV-verified MF and UF technologies by assuming a straight-line relationship between market penetration for the technologies and the total estimated cryptosporidiosis cases prevented at small PWSs by the LT2ESWTR as a whole. That is, the ETV Program applied the following equation:

---

[64] The ICR data set describes a source water occurrence pattern with a greater frequency of high oocyst concentrations than either the ICRSSM or ICRSSL system data sets (U.S. EPA, 2005a). Therefore, the ICR data set results in a larger estimate of the number of systems installing treatment, with greater human health and economic benefits. Accordingly, the ETV Program chose the data associated with the ICR data set for use in its upper-bound estimates. Of the three data sets, the ICRSSL data set results in the lowest estimates of the number of systems installing treatment and human health and economic benefits. Therefore, the ETV Program chose the data associated with the ICRSSL data set for use in its lower-bound estimates.

$$\text{Cases}_{ETV} = \text{Cases}_{EA} \times \%MP$$

Where:

- Cases_{ETV} is the number of cryptosporidiosis cases per year prevented by ETV-verified MF and UF technologies.
- Cases_{EA} is the number of cryptosporidiosis cases per year prevented at small systems by the LT2ESWTR.
- %MP is the percent market penetration for the ETV-verified MF and UF technologies.

Cases_{EA} varied for the upper- and lower-bound scenarios based on the range of estimates shown in U.S. EPA (2005a) and presented in Exhibit D-1. Specifically, the upper-bound value corresponds to the ICR data set and the lower-bound value corresponds to the ICRSSL data set. The ETV Program's method assumes the characteristics (e.g., *Cryptosporidium* occurrence, average population served) of systems applying the ETV technologies are distributed in the same manner as those of all affected small PWSs. This assumption might be reasonable for very high market penetration scenarios. It is likely less accurate for lower market penetration scenarios, where penetration might occur first in certain areas of the country. In spite of this limitation, the resulting estimates represent the resulting estimates represent reasonable, conservative (low) estimates of human health outcomes attributable to the ETV-verified MF and UF technologies.

Economic Outcomes

To estimate the economic value of cryptosporidiosis cases and associated deaths prevented, the ETV Program used values for total annual benefits from EPA's EA for the LT2ESWTR (U.S. EPA, 2005a). That is, the ETV Program applied the following equation:

$$\text{Benefits}_{ETV} = \text{Benefits}_{EA} \times \%MP$$

Where:

- Benefits_{ETV} is the total monetary benefit per year realized by preventing cryptosporidiosis and associated death by employing ETV-verified MF and UF technologies.
- Benefits_{EA} is the total monetary benefit per year realized by the implementation of the LT2ESWTR at small systems.
- %MP is the percent market penetration for the ETV-verified MF and UF technologies.

Benefits_{EA} varied for the upper- and lower-bound scenarios, based on the range of estimates presented in U.S. EPA (2005a) and presented in Exhibit D-1. This range of estimates resulted from the different data sets examined for the rule and differing assumptions about the value of avoiding cryptosporidiosis cases and the discount rate. For the upper-bound estimate, the ETV Program used the total annual benefits annualized at 3%, based on enhanced cost of illness, from the ICR data set. For the lower bound, the ETV Program used the total annual benefits annualized at 7%, based on traditional cost of illness, from the ICRSSL data set.

To develop the pilot cost savings estimates, the ETV Program assumed a total pilot study cost of $20,000 per individual system. This assumption is based on a vendor estimate of $100,000 total in pilot testing costs for five installations of an ETV-verified membrane drinking water treatment technology (other than one of the ETV-verified MF and UF technologies) (Adams, 2005). There can be significant variation in individual pilot study costs, depending on site-specific factors, state agency requirements, and technology type. The assumption, however, is within the lower part of the range ($1,000 to $60,000) assumed for pilot testing costs for the LT2ESWTR (Cadmus and Pirnie, 2003). It also is at the low end of the range of costs for ETV testing ($20,000 to $30,000) (Bartley, 2005).

To address some of the uncertainty associated with individual pilot study costs, the ETV Program developed two scenarios. The lower bound assumes ETV verification eliminates the need for pilot studies for 10% of systems installing ETV-verified technologies (or reduces pilot study costs by 10%). The upper bound assumes ETV verification eliminates the need for pilot studies for 75% of systems installing ETV-verified technologies (or reduces pilot study costs by 75%). Using these assumptions, the ETV Program estimated pilot cost savings using the following equation:

$$\text{Savings}_{ETV} = \text{Potential Market} \times \%MP$$
$$\times \$20{,}000 \times \text{Reduction}$$

Where:

- Savings_{ETV} is the total pilot study cost savings from employing ETV-verified MF and UF technologies.
- Potential Market is the number of facilities in the market, which varied for the upper- and lower-bound scenarios, as discussed above.
- %MP is the percent market penetration for the ETV-verified MF and UF technologies.
- Reduction is the percent reduction in pilot study costs or percent of facilities for which ETV data eliminates the need for a pilot study (10% in the lower bound and 75% in the upper bound).

Exhibit D-1

Assumptions Used to Develop Health and Economic Outcome Estimates

Variable		Upper-Bound Assumption	Lower-Bound Assumption	Source and Derivation
Outcome_{EA}	Total cases prevented at small systems (1)	53,000	11,000	U.S. EPA (2005a), Exhibits 5.16 and 5.17
	Fatal cases prevented at small systems	9	1	
	Total cases prevented including large systems (1)	960,000	230,000	
	Fatal cases prevented including large systems	210	52	
Benefits_{EA} ($ millions)	Small systems (1)	$74	$8.10	U.S. EPA (2005a), Exhibits C.4a and C.5f
	Including large systems (1)	$1,900	$270	

(1) Values rounded to two significant figures

Appendix E. Methods for Nanofiltration Outcomes

Number of Systems and Population Served

In estimating the market for the ETV-verified PCI nanofiltration technology, the ETV Program included small systems projected to install technology as a result of either the Stage 1 or Stage 2 DBPR. Although systems were required to comply with the Stage 1 DBPR by January 2004, the ETV verification was completed in September 2000. Therefore, some Stage 1 systems could have chosen the PCI nanofiltration technology on the basis of the verification results and it is appropriate to include these systems in the market estimate. To estimate the market of Stage 1 systems, the ETV Program used data from Tables IV-2 and IV-3 of 63 FR 69390. These data result in a potential market from Stage 1 of approximately 3,100 small systems. The ETV Program included only small systems that were projected to select membranes as the compliance technology for Stage 1. The ETV Program limited the market estimate to systems projected to select membranes because some of the other compliance technologies (e.g., enhanced coagulation) represent modification of existing treatment technologies and, therefore, would be expected to be less costly than a new membrane process. Also, because systems installing membranes to comply with Stage 1 would be unlikely to require additional technology to comply with Stage 2, using membrane systems only ensures no double counting of systems between the Stage 1 and Stage 2 market estimates. The resulting Stage 1 estimate is conservative (low) because some systems projected to install technologies other than membranes in 1998 might have chosen a membrane technology instead.

To estimate the market of Stage 2 systems, the ETV Program used data from the EA (U.S. EPA, 2005c) – specifically from the rows of Exhibit 7.3 that represent systems serving less than 10,000 people. These data result in a potential market from Stage 2 of approximately 1,700 small systems. Although the EA forecast that few systems would use nanofiltration for compliance with the Stage 2 DBPR (Chen, 2005; U.S. EPA, 2005c), EPA did list nanofiltration as a BAT for the Stage 2 rule and found that some small systems could find nanofiltration cheaper than another BAT alternative, granular activated carbon (71 FR 388). The ETV Program then added this market to the Stage 1 market, resulting in a potential market of approximately 4,800 small systems. The resulting market estimate is conservative (low) because, in addition to the Stage 1 market estimate being conservative, the overall estimate does not include systems that might adopt the technology to treat for other contaminants.

To produce the estimates in Exhibit 3.2-1, the ETV Program multiplied this total by each market penetration percentage. The resulting estimates are reasonable in comparison to vendor estimates of the market. The vendor estimated that 200 to 250 systems in Alaska alone could adopt the technology and reported other markets in Washington, Oregon, Maine, Vermont, and New Hampshire (NSF, 2004).

The ETV Program also estimated the total population served by these systems. This estimate used an average population served per system, by system size category and type (ground water versus surface water), derived from Tables IV-1, IV-2, IV-3, and IV-7 of 63 FR 69390 for Stage 1 systems and Exhibits 3.2 and 3.3 of U.S. EPA (2005c) for Stage 2. To produce the population estimates in Exhibit 3.1-2, the ETV Program multiplied the number of systems in each category in each market penetration scenario by the appropriate average population per system.

Human Health Outcomes

Because the verified technology would likely result in compliance with both the Stage 1 and Stage 2 DBPRs, it is appropriate to consider human health outcomes from both rules at each system applying the technology. For Stage 1, the ETV Program estimated the number of cancer cases avoided by applying the ETV-verified technology by assuming a straight-line relationship between the number of bladder cancer cases prevented by the rule and the total population served by systems installing or modifying treatment. That is, the ETV Program applied the following equation:

$$\text{Outcome}_{\text{ETV,S1}} = (\text{Outcome}_{\text{S1}} / \text{TP}_{\text{S1}}) \times \text{TP}_{\text{ETV}}$$

Where:

- $\text{Outcome}_{\text{ETV,S1}}$ is the estimated number of bladder cancer cases per year associated with Stage 1 prevented by the PCI nanofiltration technology.
- $\text{Outcome}_{\text{S1}}$ is 2,232 bladder cancer cases per year, the total prevented by the Stage 1 DBPR (from 63 FR 69390).
- TP_{S1} is approximately 110 million people, the total population served by all systems installing treatment as a result of the Stage 1 DBPR (derived from Tables IV-1, IV-2, IV-3, and IV-7 of 63 FR 69390).
- TP_{ETV} is the total population served by systems applying the ETV-verified technologies in each market penetration scenario.

For Stage 2, the ETV Program estimated the bladder cancer cases prevented by the PCI nanofiltration technology by assuming a straight-line relationship between market penetration for the technology and the total estimated bladder cancer cases prevented at small ground and surface water systems by the Stage 2 DBPR. That is, the ETV Program applied the following equation:

$$\text{Outcome}_{\text{ETV,S2}} = \text{Outcome}_{\text{S2}} \times \%\text{MP}$$

Where:

- $\text{Outcome}_{\text{ETV,S2}}$ is the estimated number of bladder cancer cases per year associated with Stage 2 prevented by the PCI nanofiltration technology.
- $\text{Outcome}_{\text{S2}}$ is 12.5 bladder cancer cases per year, the total prevented at small systems by the Stage 2 DBPR (from Exhibit ES.5 of U.S. EPA, 2005c).
- %MP is the percent market penetration for the PCI nanofiltration technology.

The ETV Program then added together $\text{Outcome}_{\text{ETV,S1}}$ and $\text{Outcome}_{\text{ETV,S2}}$. This addition is reasonable, because the avoided bladder cancer cases reported for the Stage 2 rule are incremental (i.e., in addition to those prevented by Stage 1). This method incorporates several key assumptions. First, it assumes that a causal relationship exists between exposure to chlorinated water and bladder cancer. EPA and the international bodies that classify risk recognize that such causality has not yet been established. This assumption means that the actual number of bladder cancer cases prevented could be as low as zero both for the PCI technology and the Stage 1 and Stage 2 DBPRs. Second, the method assumes that the risk of bladder cancer from drinking water increases linearly with increasing average concentrations of TTHM and HAA5 in drinking water and that the number of cases occurring each year in the population served by disinfecting water supplies is directly proportional to the average DBP levels in those systems. This assumption is identical to that used in the Stage 1 and Stage 2 rules. Finally, the method assumes that the nationwide distribution of DBP reductions from the PCI technology would be similar to that from the DBPRs as a whole. This assumption might be reasonable for very high market penetration scenarios. It is likely less accurate for lower market penetration scenarios, where penetration might occur first in certain areas of the country. In spite of these limitations, the resulting estimates represent reasonable, conservative (low) estimates of human health outcomes attributable to the PCI technology.

Economic Outcomes

To estimate the economic value of bladder cancer cases prevented, the ETV Program used unit values per case derived from Exhibit ES.5 of the EA for Stage 2 (U.S. EPA, 2005). This source presents a range of total economic values for four different scenarios based on differing assumptions about the value of a non-fatal bladder cancer case and the discount rate. Exhibit E-1 shows the unit values derived from the totals for these four different scenarios. For the upper-bound estimate, the ETV Program multiplied the highest unit value per case by the estimate of bladder cancer cases prevented per year. For the lower-bound estimate, the ETV Program multiplied the lowest unit value per case by the estimate of bladder cancer cases prevented per year.

An alternate method for estimating economic value would be to use unit values per case from the Stage 1 rule ($587,500 per non-fatal case, $5.6 million per fatal case, and a 23% mortality rate). These unit values would produce lower estimates than the lower-bound estimates using the Stage 2 unit values ($14 million and $35 million in 1998 dollars at 10% and 25% market penetration, respectively). The ETV Program chose, however, to use the Stage 2 unit values (which are in 2003 dollars), because they are based on more recent economic data.

To develop the pilot cost savings estimates, the ETV Program assumed a total pilot study cost of $20,000 per individual system. This assumption is based on a vendor estimate of $100,000 total in pilot testing costs for five installations of the PCI technology (Adams, 2005). There can be significant variation in individual pilot study costs, depending on site-specific factors, state agency requirements, and technology type. The assumption, however, is within the lower part of the range typically assumed for pilot testing costs in EPA regulatory analyses.[65] It also is at the low end of the range of costs for ETV testing ($20,000 to $30,000) (Bartley, 2005).

To address some of the uncertainty associated with individual pilot study costs, the ETV Program developed two scenarios. The lower bound assumes ETV verification eliminates the need for pilot studies for 10% of systems installing ETV-verified technologies (or reduces pilot study costs by 10%). The upper bound assumes ETV verification eliminates the need for pilot studies for 75% of systems installing ETV-verified technologies (or reduces pilot study costs by 75%). Using these assumptions, the ETV Program estimated pilot cost savings using the following equation:

$$\text{Savings}_{\text{ETV}} = \text{Potential Market} \times \%\text{MP} \times \$20{,}000 \times \text{Reduction}$$

Where:

- $\text{Savings}_{\text{ETV}}$ is the total pilot study cost savings from employing the PCI nanofiltration technology.
- Potential Market is the number of facilities in the market, as discussed above.
- %MP is the percent market penetration for the ETV-verified the PCI nanofiltration technology.
- Reduction is the percent reduction in pilot study costs or percent of facilities for which ETV data eliminates the need for a pilot study (10% in the lower bound and 75% in the upper bound).

---

[65] For example, for the Long Term 2 Enhanced Surface Water Treatment Rule, EPA estimated that the cost of pilot testing for membrane drinking water treatment technologies could range from $1,000 to $60,000 per facility. (Cadmus and Pirnie, 2003)

EXHIBIT E-1

UNIT ECONOMIC VALUE PER CASE OF BLADDER CANCER PREVENTED

Discount Rate	Value of a Non-fatal Bladder Cancer Case	Value per Bladder Cancer Case Prevented ($ millions)
3%	Same as value of avoiding a case of curable lymph cancer (lymphoma) (1)	5.5
	Same as value of avoiding a case chronic bronchitis	2.7
7%	Same as value of avoiding a case of curable lymph cancer (lymphoma)	4.4
	Same as value of avoiding a case chronic bronchitis (2)	2.2

Data derived from Exhibit ES.5 of the EA for Stage 2 (U.S. EPA, 2005c)

Values rounded to two significant figures

(1) Used in upper-bound estimate

(2) Used in lower-bound estimate

Appendix F. Methods for Ultraviolet (UV) Disinfection for Secondary Wastewater Effluent and Water Reuse Outcomes

In estimating outcomes for the ETV-verified UV disinfection technologies, the ETV Program developed three market estimates: an estimate of the market for UV disinfection in general ("general market estimate"), an estimate of the market for UV disinfection specifically for water reuse applications ("water reuse market estimate"), and an estimate of the market for UV disinfection specifically to meet wastewater discharge requirements ("discharge-related market estimate"). This appendix describes the derivation of each estimate and discusses the potential for overlap among the three estimates.

General Market Estimate

For the general market estimate, the ETV Program used data from EPA's 2000 Clean Watersheds Needs Survey (U.S. EPA, 2003h, 2003i). The Clean Watersheds Needs Survey identifies programs and projects that are needed to address water quality or public health problems and are eligible for funding under the Clean Water State Revolving Fund, "Eligible wastewater treatment needs include the capital costs of replacement, rehabilitation, expansion, upgrade, or process improvement of treatment plants; construction of new treatment plants; and construction, replacement, or rehabilitation of individual onsite systems and decentralized systems" (U.S. EPA, 2003i).

To develop the market estimate, ETV queried the Clean Watersheds Needs Survey Unit Process Database (U.S. EPA, 2003h) to identify facilities with plans to install new UV disinfection technology, replace existing disinfection processes with UV, or expand or improve their UV disinfection capacity. Specifically, ETV selected records with the unit processes "Ultraviolet Disinfection" or "UV Radiation (Disinfection)" and changes including the words "new," "increase capacity," "replacement," "expansion," "process improvement," or "increased level of treatment." This query identified 309 facilities.

The survey database does not identify whether individual projects are associated with treatment for discharge or for water reuse. Discharge treatment and water reuse projects both address water quality and public health problems. Also, the database includes zero discharge facilities, where any treatment needs would be associated with water recycling, rather than discharge treatment. Therefore, the estimate could include facilities planning treatment either to meet discharge requirements or enable water reuse.

The estimate is conservative (low) because it only includes facilities that reported planning to add or expand UV disinfection as of 2000 as part of projects eligible for funding under the Clean Water State Revolving Fund. It does not include projects that are not eligible for funding under the Clean Water State Revolving Fund. It does not include facilities that might have developed a need for disinfection since 2000. Finally, it does not include facilities that might have changed their decision about which disinfection technology to apply since 2000. Expanding the query to include all types of disinfection identifies approximately 4,800 facilities with plans to install, replace, improve, or expand disinfection.

Water Reuse Market Estimate

To estimate the market specifically for water reuse applications, the ETV Program used data for two states: Florida (Florida Department of Environmental Protection, 2005) and California (U.S. Bureau of Reclamation, 2002). The ETV Program developed the following estimates of the market for water reuse in each state:

- *Florida:* As of 2004, Florida had a total of 100 domestic wastewater treatment facilities with permitted capacities greater than 0.1 million gallons per day (MGD) that did not provide reuse of any kind. Of these facilities, 68 were located in water caution resources areas (Florida Department of Environmental Protection, 2005). As discussed in Section 3.4.1, Florida requires water reuse in these areas, so these 68 facilities might need to implement water reuse in the future. Florida requires disinfection for most reuse applications (U.S. EPA and U.S. AID, 2004). Therefore, these 68 facilities would need to apply technologies like the ETV-verified UV technologies to enable water reuse. Accordingly, the ETV Program assumed these 68 facilities would be the most likely market for the verified technologies for water reuse applications in Florida.
- *California:* As discussed in Section 3.4.1, California has a goal to increase water recycling to 1 million acre-feet per year by 2010. To assist in meeting this goal, the Southern California Water Reclamation and Reuse Study (U.S. Bureau of Reclamation, 2002) identified 34 water reuse projects in southern California for implementation by 2010. These projects include the addition or expansion of treatment capacity at 46 wastewater treatment facilities.[66] California regulations require disinfection for most reuse applications (U.S. EPA and U.S. AID, 2004). Therefore, these 46 facilities might need to add disinfection or expand disinfection to provide the additional capacity, using technologies like the ETV-verified UV technologies. Accordingly, the ETV Program assumed these 46 facilities would be the most likely market for the verified technologies for water reuse applications in California.

Based on these data, the ETV Program estimated the market for the verified technologies in reuse applications would be 114 facilities (68 in Florida and 46 in California).

This estimate is conservative (low) because it only includes facilities in Florida and California. Also, the estimate for each state is individually conservative (low). The Florida estimate only includes facilities in water resource caution areas. The California estimate only includes facilities in southern California that were identified as part of the short-term implementation plan in U.S. Bureau of Reclamation (2002).

These facilities are likely in addition to the 309 facilities identified in the Clean Watersheds Needs Survey, because the 309 facilities in the general market estimate include no facilities in California and only one facility in Florida. There is potential overlap, however, between the water reuse market estimate and the discharge-related market estimate, as discussed below.

ETV also estimated the quantity of water that could be recycled by facilities in the water reuse market estimate. The Florida Department of Environmental Protection (2005) reported that the 468 facilities with current reuse have a total capacity of 1,273 MGD, for an average of approximately 2.7 MGD per facility. ETV assumed that new facilities adding UV would have similar capacity to the existing facilities. The capacity increase from the 46 facilities in California adding or expanding treatment

---

[66] Based on review of Appendix C of U.S. Bureau of Reclamation (2002).

capacity as part of water reuse projects would be approximately 375 MGD, for an average of approximately 8.1 MGD per facility.[67] The ETV Program used these averages to estimate the reuse capacities shown in Exhibit 3.4-5.

Discharge-related Market Estimate

The discharge-related market estimate is limited to facilities that would have to implement additional or new treatment to comply with the EPA's 2005 water quality standards for coastal and Great Lakes recreation waters. In promulgating the new standards, EPA estimated there were approximately 90 such facilities (69 FR 67218). In estimating the cost of the new standards, EPA assumed that affected facilities would upgrade or adjust existing chlorination treatment processes to comply with effluent limitations resulting from the new standards (U.S. EPA, 2004d; 69 FR 67218). These facilities, however, also could apply the ETV-verified UV disinfection technologies, particularly if they do not have existing chlorination processes, their chlorination facilities are reaching the end of their useful life, or they wish to benefit from the relative advantages of UV technology over chemical processes, such as operating cost savings and reduced space requirements. Accordingly, ETV used the EPA estimate of 90 facilities as the market specifically for meeting discharge requirements.

This estimate is a conservative (low) estimate of the total number of facilities that could apply the verified technologies to comply with regulatory discharge requirements. Additional facilities (e.g., those that do not discharge to the Great Lakes or ocean waters) could apply the technologies to comply with other current or potential future state and federal standards for water quality and wastewater discharges other than the new 2005 standards.

These facilities are likely to be in addition to those in the general market estimate, since the new standards were proposed in 2004 and finalized in 2005, after the 2000 needs survey. There could, however, be some overlap, if facilities anticipated the need to comply with the new standards. The Clean Watersheds Needs Survey includes both short-term and long-term needs. Communities reporting needs in the survey generally plan and estimate their needs over a period of 5 to 10 years, and a few states project their needs for up to a 20-year period (U.S. EPA, 2003i). Therefore, needs in anticipation of the 2005 standards could be within the planning horizon used for some facilities. The 309 facilities in the general market estimate include approximately 40 facilities in states subject to the 2005 standards.

Also, there could be some overlap between the water reuse market estimate and the discharge-related market estimate because facilities in Florida and California are subject to the 2005 standards.

---

[67] Based on review of Appendix C of U.S. Bureau of Reclamation (2002).

United States
Environmental Protection
Agency

National Risk Management
Research Laboratory
Cincinnati, OH 45268

EPA/600/R-06/082
September 2006