Environmental Technology Verification (ETV) Program Case Studies

Demonstrating Program Outcomes

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Environmental Technology Verification (ETV) Program Case Studies: Demonstrating Program Outcomes

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Foreword

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

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments, and 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.

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Sally Gutierrez, Director
National Risk Management Research Laboratory

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Acronyms and Abbreviations

AFO	Animal Feeding Operation
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
ASV	anodic stripping voltammetry
BLL	blood lead level
BMPs	Best Management Practices
bscfy	billion standard cubic feet per year
BTEX	benzene, toluene, ethyl benzene, and xylene
BTU/scf	British Thermal Units per standard cubic foot
CARB	California Air Resources Board
CCEP	ETV's Coatings and Coating Equipment Pilot
CDC	Centers for Disease Control and Prevention
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERR	Consolidated Emissions Reporting Rule
CHP	combined heat and power
CO	carbon monoxide
CO_2	carbon dioxide
COPD	chronic obstructive pulmonary disease
DEP	Department of Environmental Protection
DOC	diesel oxidation catalyst muffler
DOE	Department of Energy
DPF	diesel particulate filter
DWS Center	ETV's Drinking Water Systems Center
EA	Economic Analysis
EPA	Environmental Protection Agency
EMPACT Program	EPA's Environmental Monitoring for Public Access and Community Tracking Program
EPCRA	Emergency Planning and Community Right-to-Know Act
ETV	EPA's Environmental Testing and Verification Program
EVRU	Eductor Vapor Recovery Unit
FSAF	fuel sulfur adjustment factor
FTIR	Fourier transform infrared
FTP	Federal Test Procedure
g/bhp-hr	grams per brake horsepower per hour
GHG Center	ETV's Greenhouse Gas Technology Center
GPRA	Government Performance and Results Act

HAPs	hazardous air pollutants
HCs	Hydrocarbons
HUD	Department of Housing and Urban Development
HVLP	high-volume low-pressure
Hz	Hertz
IEEE	Institute of Electrical and Electronics Engineers
IPCC	Intergovernmental Panel on Climate Change
IWRC	Iowa Waste Reduction Center
KW	Kilowatts
KWh	kilowatt-hours
lbs/kWh	pounds per kilowatt-hour
LQSR	Laboratory Quality System Requirements
LSD	low sulfur diesel
MCL	maximum contaminant level
mg/L	milligrams per liter
mg/L as N	milligrams per liter as nitrogen
MMBTU/day	million British Thermal Units per day
MMscfy	million standard cubic feet per year
MW	Megawatts
NAAQSs	National Ambient Air Quality Standards
NAS	National Academies of Science
NCEA	National Center for Environmental Assessment
NERL	EPA's National Exposure Research Laboratory
NHSRC	EPA's National Homeland Security Research Center
NIOSH	National Institute for Occupational Safety and Health
NLLAP	National Lead Laboratory Accreditation Program
NO_X	nitrogen oxides
NRMRL	EPA's National Risk Management Research Laboratory
NYSERDA	New York State Energy Research and Development Authority
OAQPS	EPA's Office of Air Quality Planning and Standards
OGWDW	EPA's Office of Ground Water and Drinking Water
OIA	EPA's Office of International Affairs
OPPT	EPA's Office of Pollution Prevention and Toxics
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
OTAQ	EPA's Office of Transportation and Air Quality
OWOW	EPA's Office of Wetlands, Oceans, and Watersheds
PADEP	Pennsylvania Department of Environmental Protection
PM	particulate matter
ppb	parts per billion
ppm	parts per million
REMSAD	Regulatory Modeling System for Aerosols and Deposition
RIA	Regulatory Impact Analysis
SIP	State Implementation Plan
SO_2	sulfur dioxide
TE	transfer efficiency
THCs	total hydrocarbons
THD	total harmonic distortion

TMDL	Total Maximum Daily Load
UBRP	EPA's Urban Bus Retrofit Program
ULSD	ultra-low sulfur diesel
USDA	U.S. Department of Agriculture
UV-DOAS	ultraviolet differential optical absorption spectroscopy
VDRP	EPA's Voluntary Diesel Retrofit Program
VMT	vehicle miles traveled
VOCs	volatile organic compounds
WQP Center	ETV's Water Quality Protection Center
XRF	X-ray fluorescence
µg/dL	Micrograms per deciliter
$\mu g/ft^2$	Micrograms per square foot

I.
Introduction and Summary

1.1 Purpose

This document is a collection of case studies that highlight the actual and potential outcomes and benefits of the U.S. Environmental Protection Agency's (EPA's) Environmental Technology Verification (ETV) Program. The ETV Program was initiated in 1995 to verify the performance of innovative technologies that have the potential to improve human health and the environment. The program operates, in large part, as a public-private partnership through competitive cooperative agreements between EPA and the 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 to 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, which assess a government program's activities in their simplest form, and "outcome" measures, which assess the results of these activities compared to their intended purpose (GPRA, 1993).

Historically, the ETV Program has measured its performance with respect to outputs (e.g., the number of technologies verified and testing protocols developed). ETV is expanding its approach to include outcomes, such as potential pollution reductions attributable to the use of ETV technologies and subsequent health or environmental impacts. The case studies presented here highlight how the program's outputs (verified technologies and protocols) translate into actual and potential outcomes. 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 assessing environmental outcomes and human health benefits. Therefore, many of the outcomes quantified in these case studies are described as "potential" outcomes, and should be treated as estimates only. 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 (e.g., regulatory impact analyses). In most cases, this methodology is likely a simplification of the actual relationship between these two factors, as well as 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 more likely to be observed under lower market penetration scenarios.

- Vendors of ETV-verified technologies are not currently 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 total potential market for a given technology or technology group and applied scenarios (e.g., 10% and 25% of the potential market) to project the potential 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 2.1).
- 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 available data from publicly available sources (e.g., regulatory impact analyses), reasonable assumptions, and logical extrapolations.
- These case studies are not intended as a basis for making regulatory decisions, developing or commenting on policy, or as a basis for choosing to purchase or sell a technology. They are merely intended to highlight potential 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.
- 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 project officers, and appropriate program office and other EPA personnel have reviewed the case studies throughout the development process (see Acknowledgements, above). 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 potential outcomes, estimated in a reasonable manner. Vendors were also provided with an opportunity to review the pre-final versions of the case studies.
- Five of the eight case studies presented here were initially based upon draft case studies (U.S. EPA, 2002h, 2004j, 2004k, 2004l; Southern Research Institute, 2004b; Battelle, 2004h) and draft outcomes briefs (U.S. EPA, 2004i, 2005n; Battelle, 2004i)

that were developed by ETV Program staff and verification partners. These case studies include text and other information found in the draft documents. Some of the case studies presented here also underwent parallel development with the outcomes briefs, with ongoing information exchange and input from the respective efforts/authors.

- EPA does not endorse the purchase or sale of any of the products and services from companies mentioned in this document. Also, the use of company- and/or product-specific sales information, images, quotations, or other outcomes-related information does not constitute the endorsement of any 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

ETV Centers and Verification Organizations

ETV Center/Pilot/Effort	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 detection 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. Six of the case studies fall into the category of "Air and Energy Technologies" (Chapter 2) and two fall into the category of "Water Technologies" (Chapter 3). A second set of case studies, to be published in the near future, will include additional technologies in both categories. The document also includes a complete list of references (Chapter 4) and a set of appendices that provide a detailed discussion of the methodology 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.

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 Diesel Engine Retrofit Technologies	APCT	Mobile source emissions, children's health	Particulate matter, hydrocarbons, carbon monoxide
2.2 Eductor Vapor Recovery Unit (EVRU)	GHG	Greenhouse gases, organics, industrial emissions	Methane, hazardous air pollutants, volatile organic compounds
2.3 Microturbine/Combined Heat and Power (CHP) Technologies	GHG	Greenhouse gases, waste-to-energy, community development	Carbon dioxide, nitrogen oxides, sulfur dioxide, methane, carbon monoxide, particulate matter, ammonia, total hydrocarbons
2.4 Laser Touch Spray Painting Targeting Device	CCEP	Organics, industrial emissions	Hazardous air pollutants, volatile organic compounds
2.5 Portable Technologies for Measuring Lead in Dust	AMS	Children's health, community development	Lead
2.6 Ambient Ammonia Monitors	AMS	Animal feeding operations	Ammonia
Water Technologies			
3.1 Arsenic Drinking Water Treatment Technologies	DWS	Small drinking water systems	Arsenic
3.2 Residential Nutrient Reduction Technologies	WQP	Watershed protection, community development	Nitrogen compounds

(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

Each case study begins with a summary of actual and potential 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 potential outcomes from verification and from applying the technology, as well as actual outcomes. These outcomes include:

- Pollutant (or emissions) reduction outcomes, such as pounds of pollutant removed, nationwide, by potential applications of the technology
- Environmental and human health outcomes, such as cases of disease or death avoided, nationwide, by potential 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 potential applications of the technology.

Within each outcome category, the ETV Program made every effort to quantify, that is, place a numerical value on, the outcome. Where insufficient data were available to quantify an outcome, the case studies present information about that outcome and describe its potential significance qualitatively.

Each case study is written to stand on its own, so that readers interested in only one technology category (or a few categories) can comprehend the section(s) of interest without needing to review this 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 different types of outcomes and attempted, within the limits of the available data, to quantify each outcome. This section identifies the types of outcomes associated with each case study and provides examples of the most significant quantifiable actual and potential outcomes. Exhibit 1.3-1 lists the eight case studies, along with the types of outcomes identified in each. It also indicates which of the outcomes the ETV Program was able to quantify.

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

- The ETV-verified diesel engine retrofit technologies could reduce particulate matter (PM) emissions by approximately 9,000 to 31,000 tons over seven years, if 10% of the current fleet of heavy-duty diesel trucks

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 Compliance	Technology Acceptance & Use	Scientific Advancement
Air and Energy Technologies							
2.1 Diesel Engine Retrofit Technologies	Q	Q		Q	X	Q	X
2.2 Eductor Vapor Recovery Unit (EVRU)	Q	Q		Q	Q	Q	
2.3 Microturbine/Combined Heat and Power (CHP) Technologies	Q	X	X	X		X	X
2.4 Laser Touch Spray Painting Targeting Device	Q	X	X	Q	X	X	
2.5 Portable Technologies for Measuring Lead in Dust		X		X	Q	X	X
2.6 Ambient Ammonia Monitors	X (a)	X		X	Q	X	X
Water Technologies							
3.1 Arsenic Drinking Water Treatment Technologies		Q		Q	Q	Q	
3.2 Residential Nutrient Reduction Technologies	Q	X			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
(a) ETV estimates that information provided by the monitors ultimately can assist in reduction of ammonia emissions

and buses use ETV-verified devices. These emissions reductions could result in human health and environmental benefits, including 680 to 2,400 avoided instances of premature mortality, with an associated economic value of $4.4 to $15.5 billion.

- The ETV-verified Eductor Vapor Recovery Unit (EVRU) technology could reduce methane emissions by 2 billion to 6 billion standard cubic feet per year and recover natural gas with a potential economic value of $41 million to $120 million per year.
- The ETV-verified microturbine/combined heat and power (CHP) technologies could reduce carbon dioxide (CO_2) emissions by 70,000 to 127,000 tons per year and nitrogen oxide (NO_X) emissions by 410 to 440 tons per year, with associated climate change, environmental, and human health benefits.
- The ETV-verified Laser Touch technology could reduce volatile organic compound (VOC) emissions from the automobile refinishing industry by approximately 1,100 to 2,700 tons per year and reduce solid waste generation by approximately 300 to 8,000 tons per year, with associated environmental and health benefits. The technology also can potentially reduce paint usage, resulting in cost savings that could equal up to $100 million per year for the automobile refinishing industry alone.
- The ETV-verified portable technologies for measuring lead in dust could be deployed at up to approximately 16.5 million housing units that were built before 1978. Of these pre-1978 residences, an estimated 2.6 million house young children, who are particularly at risk for exposure to lead in dust.
- The ETV-verified ambient ammonia monitors could potentially be applied at up to 975 large animal feeding operations (AFOs) to verify their compliance with current or potential future state and federal regulations and to avoid potential multimillion dollar penalties.
- The ETV-verified arsenic drinking water treatment technologies could prevent 1.3 to 4.8 cases of lung and bladder cancer and 0.7 to 2.6 deaths from these cancers per year, with an associated economic value of approximately $4.8 million to $17.1 million per year.
- The ETV-verified residential nutrient reduction technologies could reduce nitrogen loading to ground water by approximately 1,300 to 4,000 tons per year, with associated benefits of improved compliance with drinking water standards and reduction of environmental problems associated with nutrient loading.

2.
Air and Energy Technology Case Studies

2.1 Diesel Engine Retrofit Technologies

The ETV Program's Air Pollution Control Technology (APCT) Center, operated by RTI International under a cooperative agreement with EPA, has verified the performance of seven technologies designed to reduce air emissions from diesel engines. These technologies are used to retrofit older and current model heavy-duty diesel trucks, buses, and non-road equipment. When retrofitted, the technologies reduce pollutant emissions including particulate matter (PM), hydrocarbons (HCs), and carbon monoxide (CO). PM contributes to serious public health problems in the U.S., including premature mortality and respiratory problems, and has other environmental impacts, including reduced visibility. HCs can also react with nitrogen oxides (NO_X), another diesel pollutant of concern, to form ground-level ozone. Ground-level ozone, otherwise know as smog, is considered a major health and environmental problem. CO can exacerbate health effects in people with heart problems.

Based on the analysis in this case study and available sales/marketing data, at least 1,345 vehicles have or are expected to use the ETV-verified diesel engine retrofit technologies, with the following benefits:

- The technologies could reduce PM emissions by 6.4 to 9.1 tons over seven years, with associated HC and CO reductions of up to 35 tons and up to 120 tons, respectively, over the same time period (assuming 1,345 vehicles use the technologies).
- The PM emissions reductions can potentially result in human health and environmental benefits, including 0.49 to 0.70 avoided cases of premature mortality, with an economic value of \$3.2 to \$4.5 million (assuming 1,345 vehicles use the technologies).[1]
- The PM and other emissions reductions can potentially result in additional, quantifiable and non-quantifiable, human health and environmental benefits.

As market penetration increases, emission reductions and other benefits also could increase. In fact, based on the analysis in this case study, the ETV Program estimates that if 10% of the current fleet of heavy-duty diesel buses and trucks use an ETV-verified diesel retrofit technology, the following benefits could be realized:

- The technologies could reduce PM emissions by approximately 9,000 to 31,000 tons over seven years, with associated HC and CO reductions of up to 148,000 tons and up to 393,000 tons, respectively, over the same period.
- The PM emissions reductions could result in human health and environmental benefits, including 680 to 2,400 avoided instances

1 In 1999 dollars.

of premature mortality, with an associated economic value of $4.4 to $15.5 billion.[2]

- The PM and other emissions reductions could result in additional, quantifiable and non-quantifiable, human health and environmental benefits.
- The resulting PM, CO, and HC reductions also could help states and communities comply with National Ambient Air Quality Standards (NAAQSs), particularly in ten areas of the country at risk for exceeding the NAAQSs for PM and 45 areas at risk for exceeding the NAAQSs for ozone.

Other benefits of the ETV Program include the development of three well-accepted diesel retrofit technology protocols, which have advanced efforts to standardize protocols across programs. The ETV protocols are currently posted on the EPA's Voluntary Diesel Retrofit Program (VDRP) and ETV Web sites and can be used by retrofit technology manufacturers and others to generate data on the performance of diesel engine retrofit technologies. Technology vendors have submitted the data generated by ETV using these protocols to the VDRP. VDRP has used this information to determine, at least in part, whether to post ETV-verified technologies on the VDRP-verified technology list. Posting on the VDRP list is expected to reduce the amount of state- or program-specific testing needed to evaluate retrofit technologies and determine the pollutant reductions associated with their use. Ultimately, this information will assist decision makers responsible for retrofitting fleets and administering grant programs.

2.1.1 Environmental, Health, and Regulatory Background

Diesel engines used in heavy-duty trucks, buses, and non-road equipment are durable and provide good fuel economy. Heavy-duty diesel trucks and buses account for about one quarter of PM emissions from mobile sources. In some urban areas, the contribution is even greater (U.S. EPA, 2000a). Heavy-duty diesel trucks, buses, and non-road equipment also accounted for approximately 3.6% of the national emissions of fine particles (known as $PM_{2.5}$) from all sources (mobile and stationary) in 2001 (U.S. EPA, 2003a).

EPA has determined that diesel exhaust, including PM, is a likely carcinogen. PM contributes to serious public health problems in the U.S., including "premature mortality, aggravation of respiratory and cardiovascular disease, aggravation of existing asthma, acute respiratory symptoms, chronic bronchitis, and decreased lung function" (66 FR 5002). In general, children, the elderly, asthmatics, and people with heart disease, lung disease, or other respiratory problems are the most sensitive to the health effects of fine PM (U.S. EPA, 2002a).

HCs, which are a subset of volatile organic compounds, contribute to the formation of ground-level ozone. Ground-level ozone "damages lung tissue, reduces lung function, and sensitizes the lungs to other irritants" (U.S. EPA, 2005a). Like fine PM, ambient ozone levels affect children, asthmatics, and others with impaired respiratory systems, as well as healthy adults (U.S. EPA, 2005a). Additional health and environmental effects associated with HCs include cancer, anemia, disruption of production of blood components, reduction in the number of blood platelets, excessive bone marrow formation, depression of lymphocyte counts, reproductive and developmental effects, irritation of eyes and mucous membranes, asthma attacks and asthma-like symptoms, upper respiratory tract irritation and congestion, direct toxic effects to animals, and bioaccumulation in the food chain (U.S. EPA, 2002b).

Exposure to very high concentrations of CO can be fatal. At typical atmospheric concentrations, CO does not present a risk for young, healthy nonsmokers, but it can exacerbate chest pain and reduce exercise tolerance in people with existing heart problems. In urban areas, CO can either produce or destroy ozone, depending on the concentrations of other pollutants (U.S. EPA, 2000b).

In addition to human health effects, diesel emissions also contribute to a variety of environmental problems. Ozone causes forestry

2 In 1999 dollars.

and crop losses, and PM deposition blackens buildings and soils statues, monuments, and other materials. PM emissions have also impacted visibility in many areas of the country, including national parks and wilderness areas (66 FR 5002).

EPA is responsible under the Clean Air Act for setting National Ambient Air Quality Standards (NAAQSs) for pollutants considered harmful to public health and the environment. In 2001, EPA found that there were ten areas of the country, with a population of 28 million, that currently exceeded, or were at significant risk of exceeding, the NAAQSs for PM in the near future. EPA also found that there were 45 areas, with a population of 128 million people, at risk of exceeding the NAAQSs for ozone. To address the harmful effects of diesel exhaust and assist these areas in meeting the NAAQSs, EPA set new emissions standards for 2007 model year highway diesel engines on January 18, 2001 (66 FR 5002). The new standard for PM is 0.01 gram per brake horsepower-hour (g/bhp-hr), representing a significant reduction from previous standards: 0.1 g/bhp-hr for the 1994 model year, 0.25 g/bhp-hr for the 1991 model year, and 0.6 g/bhp-hr for the 1984 model year (66 FR 5002, U.S. EPA, 2005n).[3]

Although these newer standards will dramatically reduce diesel emissions, EPA anticipates that it will take a number of years to phase out older, higher-polluting diesel engines. Since existing fleets could remain in operation for another 25 to 30 years, some areas could have difficulty achieving more immediate air quality goals (U.S. EPA, 2005b). As a result, some states are including retrofit programs/projects in their State Implementation Plans (SIPs) to help them meet NAAQSs in the near-term, before vehicles that meet the new standards are phased in. A SIP contains a state's strategy for achieving the emission reductions needed to establish and maintain compliance with NAAQSs. Under EPA's Voluntary Mobile Source Emission Reduction Policy, states that utilize voluntary retrofit projects and include them in their SIP emission inventory can receive reduction credits of up to 3% of the reductions necessary to meet air quality goals. States also can include retrofit programs that achieve emissions reductions greater than 3% by working with their EPA regional office. States can calculate SIP credits for voluntary retrofit programs using methods outlined on the VDRP Web site (U.S. EPA, 2004m).

In addition, voluntary programs, like the VDRP, the SmartWay Transport Partnership, and Clean School Bus USA, have spurred the development and use of pollution-reducing retrofit devices on existing engines and vehicles. These programs are designed to encourage the use of less-polluting alternatives and control technologies. EPA has also established incentive programs that can be applied at the federal, regional, state, and local levels. These programs further reduce the initial cost of diesel retrofits and other pollution control technologies.

> "[Retrofit technologies] will be especially important in the early years of the program when new vehicles standards are just beginning to have an impact, and when states and local areas need to gain large reductions to attain air quality goals." —66 FR 5002

> "Over the last five years, EPA has brought forward a number of very successful voluntary programs all designed to reduce emissions from the diesel fleet. In conjunction with state and local governments, public interest groups, and industry partners, EPA has established a goal of reducing emissions from the over 11 million diesel engines in the existing fleet by 2014. Looking at these engines, EPA determined there were general sectors that provided the best opportunity to obtain significant reductions … These sectors are school buses, ports, construction, freight, and agriculture. Each program provides technical and financial assistance to stakeholders interested in reducing their fleets' emissions effectively and efficiently."
> —EPA's National Clean Diesel Campaign Web site (U.S. EPA, 2005p)

3 To meet the new PM standard, EPA estimates that catalyzed diesel particulate filters will be the control technology of choice (U.S. EPA, 2000c). This technology is among those that ETV verified for retrofit applications, as discussed under "Technology Description," below.

2.1.2 Technology Description

The ETV Program has verified the performance of seven diesel engine retrofit technologies listed in Exhibit 2.1-1. These technologies include exhaust treatment emission control (or "after treatment") devices, retrofit fuels, and crankcase filtration systems, although a number of the verified technologies were actually systems consisting of multiple components/elements that were tested together.

Exhaust treatment devices include diesel particulate filters (DPFs) and diesel oxidation catalyst mufflers (DOCs). DPFs and DOCs are devices that are installed in the exhaust system, similar to a muffler. In general, DPFs reduce PM emissions by physically trapping the PM and burning it in the exhaust stream, while DOCs reduce PM, HC, and CO emissions by converting them to less-harmful compounds, such as water vapor and carbon dioxide. Retrofit fuels, such as fuel reformulations and fuel additives, generally reduce NOx and/or PM emissions by modifying the fuel properties of diesel fuel (e.g., lowering the sulfur or aromatics content), thus allowing the diesel fuel to burn more cleanly and produce less air pollution. Finally, crankcase filtration systems reduce PM emissions by capturing the "blowby gases" and removing the particulate matter (e.g., using filters) before routing the gases to the engine's intake. These technologies are applicable to a relatively large number of older and current model turbocharged diesel engines that contain open crankcase systems (66 FR 5002; Northwest Air Pollution Authority, 2002; US EPA, 2005c, 2003b, 1997a, 2005a).

The ETV Program tested each of the technologies for heavy-duty diesel engine emission reductions using the ETV Test/QA Plan for the Verification Testing of Diesel Exhaust Catalysts, PM Filters, and Engine Modification Technologies for Highway and Nonroad Use Diesel Engines, as well as a test-specific addendum developed for each technology. The Heavy-Duty Transient Federal Test Procedure (FTP) for exhaust emissions testing was incorporated in this test/QA plan and was performed during each test condition (40 CFR Part 86). The test sequence included the baseline test condition, the degreened test condition, and the aged test condition. The baseline engines were not modified during the test sequence. Cold and hot start test conditions were used for each test condition. PM and gas pollutants were measured at each test condition. The focus of these verification tests was to determine the percent emission reduction achieved for PM, relative to the emission levels produced by the same baseline engine without the retrofit technology in place, although operating conditions and ancillary

Exhibit 2.1-1

ETV-Verified Diesel Engine Retrofit Technologies

Vendor and Technology Name	Technology Description
Clean Clear Fuels Universal Fuel Cell	A fuel cell that is a high-density magnet with a field strength of at least 1,000 gauss.
Clean Diesel Technologies' Fuel-borne Catalyst with CleanAir System's Diesel Oxidation Catalyst Muffler	A platinum/cerium catalyst added to fuel and used in combination with a DOC for exhaust treatment.
Clean Diesel Technologies' Fuel-borne Catalyst with Mitsui/PUREarth Catalyzed Wire Mesh Filter	A platinum/cerium catalyst added to fuel and used in combination with a lightly catalyzed wire mesh filter for exhaust treatment.
Donaldson Company Diesel Oxidation Catalyst Muffler, Series 6000 Catalyst Formulation and Spiracle™ Closed Crankcase Filtration System	A DOC used in combination with a crankcase filtration system that uses two filtration stages integrated into a single, replaceable filter cartridge.
Donaldson Company Diesel Oxidation Catalyst Muffler, Series 6100 Catalyst Formulation and Spiracle™ Closed Crankcase Filtration System	A DOC used in combination with a crankcase filtration system that uses two filtration stages integrated into a single, replaceable filter cartridge.
Donaldson Company Diesel Oxidation Catalyst Muffler, Series 6100 Catalyst Formulation	A DOC used without an additional filtration system.
Lubrizol Engine Control Systems Purifilter Particulate Filter	A passively regenerated DPF made from precious and base metals.

Sources: RTI, 2005, 2004a, 2004b, 2004c, 2003a, 2003b, 2003c.

measurements were recorded. NO_X emissions also were measured, although the tested technologies are not intended to control that pollutant (RTI, 2003a).

As noted above, the seven verified technologies represent a variety of control technologies, including some that controlled crankcase emissions and some that did not. The reductions in exhaust PM emissions achieved during ETV testing ranged from 22% to 95%, or 0.016 to 0.15 g/bhp-hr, for four of the five technologies that were tested on diesel engines with open crankcase vents. These technologies also reduced HCs by 37% to 100% (or 0.045 to 0.35 g/bhp-hr) and CO by 38% to 87% (or 0.041 to 0.93 g/bhp-hr). No emission reductions were observed for the fifth technology tested on an engine with an open crankcase vent. The reductions in exhaust plus crankcase vent PM emissions for the remaining two technologies that included a crankcase vent filter ranged from 21% to 34% (or 0.019 to 0.032 g/bhp-hr). These technologies also reduced HCs by 42%[4] to 62% (or 0.12 to 0.14 g/bhp-hr) and CO by 12% to 35% (or 0.12 to 0.43 g/bhp-hr). As expected, NO_X emission reductions were none or minimal for all seven technologies and are not considered further in this case study (RTI, 2005, 2004a, 2004b, 2004c, 2003a, 2003b, 2003c). The ETV Program did not verify the cost of installing the retrofit devices, but general retrofit cost data are available from the Manufacturers of Emissions Controls Association's *Independent Cost Survey for Emission Control Retrofit Technologies* (MECA, 2000).

2.1.3 Outcomes

Based on the sales and marketing data reported below under "Technology Acceptance and Use Outcomes," at least 1,345 vehicles have or are expected to apply the ETV-verified diesel engine retrofit technologies (1,200 school buses applying Donaldson's technology, 125 vehicles applying Clean Diesel Technology's technology, and 20 vehicles applying Lubrizol's technology). Because the reports indicate additional, non-quantified applications of the technologies, this estimate represents the minimum market penetration. Based on data from U.S. EPA (1999b and 2002b), the ETV Program estimates there are currently more than 7.7 million heavy-duty diesel trucks and buses in the U.S that are eligible to be retrofitted. Appendix A describes the basis of this estimate. Many of these vehicles could apply the ETV-verified retrofit technologies. Owners of older vehicles that are due for replacement in the near future are unlikely to invest in retrofits for these vehicles. Therefore, this estimate only includes vehicles that are up to 25-years-old or less.[5]

Diesel engine in a dynamometer test cell at Southwest Research Institute

The ETV Program used this estimate of the total potential market to estimate future applications of the ETV-verified retrofit technologies based on the two market penetration scenarios identified in Exhibit 2.1-2: 10% and 25% of the total potential market. The estimates of pollutant reductions and human health, environmental, and economic outcomes shown below also are based on these market penetration scenarios.

4 Ultra-low sulfur diesel (ULSD) data were used in this case because low sulfur diesel (LSD) baseline data were not sufficient to calculate a quantitative reduction.

5 As discussed in Appendix A, the ETV Program included vehicles that are up to 25-years-old or less because diesel vehicles typically can be in service up to 30 years and retrofit technologies are recommended for vehicles with at least five years of remaining service. Thus, 25-year-old vehicles would be the oldest vehicles with sufficient service remaining for retrofit technologies.

Exhibit 2.1-2

Number of Vehicles that Could Potentially Apply ETV-Verified Diesel Engine Retrofit Technologies

Market Penetration	Number of Vehicles
Current Minimum Penetration	1,345
10%	800,000
25%	1,900,000

Values rounded to nearest 100,000, except for current minimum penetration

Pollutant Reduction Outcomes

Based on the number of vehicles in Exhibit 2.1-2 and additional data from U.S. EPA (2002b), the ETV Program estimated pollutant reductions for the current minimum and future market penetration scenarios. The upper- and lower-bound estimates reflect the differences in pollutant reduction performance among the verified technologies.

Exhibit 2.1-3 shows the pollutant reduction estimates. These estimates assume that, on average, retrofitted vehicles will use the ETV-verified technology(ies) for a period of seven years.[6] Appendix A describes the methodology and assumptions used to develop these estimates.

Exhibit 2.1-3

Estimated Potential Pollutant Reductions for ETV-Verified Diesel Engine Retrofit Technologies

Market Penetration	Pollutant Reduction (tons after seven years)		
	PM	HCs	CO
Upper Bound			
Current Minimum	9.1	35	120
10%	31,000	148,000	393,000
25%	79,000	369,000	982,000
Lower Bound			
Current Minimum	6.4	16	65
10%	9,000	NA	83,000
25%	22,000	NA	207,000

Values rounded to nearest 1,000 tons, except for current minimum penetration (rounded to two significant figures)

Environmental and Health Outcomes

Based on data from EPA's Regulatory Impact Analysis (RIA) for the new diesel emissions standards (U.S. EPA, 2000c), the ETV Program estimated the human health outcomes associated with the PM reductions (shown in Exhibit 2.1-3) that could be attributed to the use of ETV-verified diesel retrofit technologies. Appendix A describes the methodology and assumptions used in these estimates. These outcomes include avoided cases of premature mortality, acute and chronic illnesses, hospital and emergency room visits, and lost work days. 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 gross simplification of the actual relationship between these two factors for a number of reasons discussed in Appendix A. The reader should also be aware that there are a number of uncertainties, discussed in detail in the RIA, associated with the underlying air pollution exposure studies used in the RIA to estimate the PM-related effects. In spite of these limitations, the estimates here represent reasonable, conservative (low) estimates of health outcomes associated with PM reductions. Exhibit 2.1-4 shows the estimates for all the scenarios.[7] It is important to note, however, that EPA is currently looking into data on metal emissions from diesel retrofit technologies that use fuel additives.

In addition to the benefits shown in Exhibit 2.1-4, there are other, non-quantifiable health benefits associated with reductions in PM, including avoided cases of infant mortality, low birth weight, changes in pulmonary function, chronic respiratory diseases other than chronic bronchitis, morphological changes, altered host defense mechanisms, cancer, and non-asthma respiratory episodes requiring emergency room visits (U.S. EPA, 2000c). As discussed in Section

6 These are conservative (low) estimates because they do not include emissions reductions from non-road diesel equipment that can apply the retrofit technologies and because the assumption of a seven-year retrofit life is believed to be conservative (low), as discussed in Appendix A.

7 Although there are a number of uncertainties associated with these estimates, they are based on conservative (low) estimates of emissions reductions and do not include other, non-quantifiable health benefits from PM reduction. Therefore, they may be conservative (low) estimates.

Exhibit 2.1–4

Estimated Potential Human Health Outcomes for ETV-Verified Diesel Engine Retrofit Technologies

PM-related Outcomes Over Seven Years[A, B]	Current Minimum	10%	25%
	Market Penetration		
Upper Bound			
Premature mortality[C] (adults, 30 and over)	0.70	2,400	6,000
Chronic bronchitis (adults, 26 and over)	0.46	1,600	3,900
Hospital Admissions — Pneumonia (adults, over 64)	0.092	320	790
Hospital Admissions — COPD[E] (adults, 64 and over)	0.075	260	650
Hospital Admissions — Asthma (65 and younger)	0.075	260	650
Hospital Admissions — Cardiovascular (adults, over 64)	0.23	770	1,900
Emergency Room Visits for Asthma (65 and younger)	0.18	600	1,500
Asthma Attacks (asthmatics, all ages)[D]	15	50,000	130,000
Acute bronchitis (children, 8–12)	1.5	5,000	13,000
Lower respiratory symptoms (children, 7–14)	16	55,000	140,000
Upper respiratory symptoms (asthmatic children, 9–11)	16	55,000	140,000
Minor restricted activity days (adults, age 18–65)	670	2,300,000	5,700,000
Work loss days (adults, 18–65)	130	440,000	1,100,000
Lower Bound			
Premature mortality[C] (adults, 30 and over)	0.49	680	1,700
Chronic bronchitis (adults, 26 and over)	0.32	450	1,100
Hospital Admissions — Pneumonia (adults, over 64)	0.065	91	230
Hospital Admissions — COPD[E] (adults, 64 and over)	0.053	74	190
Hospital Admissions — Asthma (65 and younger)	0.053	74	190
Hospital Admissions — Cardiovascular (adults, over 64)	0.16	220	560
Emergency Room Visits for Asthma (65 and younger)	0.12	170	430
Asthma Attacks (asthmatics, all ages)[D]	10	14,000	36,000
Acute bronchitis (children, 8–12)	1.0	1,400	3,600
Lower respiratory symptoms (children, 7–14)	11	16,000	40,000
Upper respiratory symptoms (asthmatic children, 9–11)	11	16,000	40,000
Minor restricted activity days (adults, age 18–65)	470	660,000	1,600,000
Work loss days (adults, 18–65)	90	130,000	320,000

Values rounded to two significant figures.

A Outcomes were developed based on the avoided instances of the different endpoints reported in Table VII-19 of EPA (2000c). These incidences were rounded to the nearest 100 in Table VII-19 of U.S. EPA (2000c).

B PM-related benefits, as reported in Table VII-19 of U.S. EPA (2000c), are based on the assumption that Eastern U.S. nitrate reductions are equal to one-fifth the nitrate reductions predicted by the Regulatory Modeling System for Aerosols and Deposition (REMSAD) [see Chapter II of U.S. EPA (2000c) for a discussion of REMSAD and model performance].

C Premature mortality associated with ozone was not separately included in the analysis for the rule [also note that the estimated value for PM-related premature mortality assumes the 5 year distributed lag structure described in Section D-3 of U.S. EPA (2000c)].

D A detailed listing of unquantified PM, ozone, CO, and non-methane hydrocarbon related health effects associated with the rule is provided in Table VII-1 of U.S. EPA (2000c). For some endpoints such as asthma attacks, EPA was able to quantify the reduction in incidence, but presented the monetization as an alternative calculation.

E COPD: chronic obstructive pulmonary disease.

Note: Footnotes A – D were taken from EPA 2000c, with minor changes.

2.1.1, PM reductions can also result in non-health-related environmental benefits, including improved visibility. The ETV Program's estimates of visibility benefits are included under Economic Outcomes, below.

Quantitative data are not available to estimate the environmental and health outcomes associated with reductions in HCs and CO. As discussed in Section 2.1.1, however, HCs and CO can impact ground-level ozone, and HCs have significant direct health effects. Therefore, the benefits of reducing HCs and CO also could be significant.

Economic Outcomes

The human health and environmental benefits discussed above have an economic value. Based on the unit values (e.g., per avoided case of chronic bronchitis) provided in EPA's RIA for the new diesel emissions standards (U.S. EPA, 2000c), the ETV Program estimated the monetary value associated with the human health outcomes associated with the use of ETV-verified diesel retrofit technologies (shown in Exhibit 2.1-4). The ETV Program also added the estimated monetary value associated with visibility improvements, assuming a straight line relationship between PM reductions and the monetary benefits estimated for this outcome in the RIA.

Exhibit 2.1-5 shows the total estimated economic benefits for all of these outcomes for all the scenarios.[8] Appendix A describes the methodology and assumptions used in these estimates. In addition, there would be further, significant economic benefits associated with the non-quantifiable health benefits from PM reductions and the health and environmental benefits from HC reductions. Quantitative data, however, are not available to estimate these additional economic benefits.

Regulatory Compliance Outcomes

As discussed in Section 2.1.1, ten areas of the country are at significant risk for exceeding the NAAQSs for PM and 45 areas are at significant risk for exceeding the NAAQSs for ozone.

Exhibit 2.1-5

Estimated Potential Economic Benefits from ETV-Verified Diesel Engine Retrofit Technologies

	Million dollars over seven years	
Market Penetration	**Lower Bound**	**Upper Bound**
Current Minimum	3.2	4.5
10%	4,400	15,500
25%	11,100	38,700

Values rounded to nearest $100 million, except for current minimum penetration (rounded to two significant figures)

Although EPA's new emissions standards for diesel exhaust will assist these areas in meeting the NAAQSs, the new standards do not take effect until the 2007 model year. Even when the standards take effect, older, higher-polluting vehicles will remain in service for as long as 25 to 30 years. In the interim, retrofit technologies can be used to gain the emission reductions and SIP credits needed to attain state and local air quality goals.

To help states, cities, and other entities select retrofit technologies that could be used to generate SIP credits, EPA has developed a list of technologies that have been verified by the EPA Office of Transportation and Air Quality's (OTAQ's) VDRP and certified under the EPA Urban Bus Retrofit Program (UBRP). Vendors have submitted data collected during ETV testing to VDRP, and VDRP has used these data, at least in part, to determine whether to post the technologies on the VDRP-verified technology list (U.S. EPA, 2004a).[9] Since this list is widely used, ETV expects that posting on the VDRP list will reduce the need for state- or program-specific testing to assess the performance of retrofit technologies and calculate emission reductions for credits towards compliance with NAAQS limits, as well as facilitate states claiming the same reductions for the same devices. Ultimately, this information will assist state and local personnel responsible for achieving near-term compliance with NAAQS limit, as well as decision makers responsible for retrofitting fleets and administering grant programs.

8 These may be conservative (low) estimates, for the same reasons discussed above and because they are in 1999 dollars.

9 Vendors interested in potentially pursuing VDRP verification using ETV data can request VDRPs involvement early in the verification process, thus increasing the likelihood that data are collected that meet both ETV's and VDRP's verification needs.

Technology Acceptance and Use Outcomes

Recent information indicates that ETV-verified diesel technologies are being used to reduce emissions by a number of federal, regional, local, and state diesel retrofit programs. For example, Donaldson, Inc. will provide approximately 100 ETV-verified diesel emission control devices under a grant to the New York State Energy Research and Development Authority (NYSERDA) from EPA's Clean School Bus USA Program, a voluntary program designed to reduce pollution from public school buses (NYSERDA, 2004). These devices are in addition to the 1,100 ETV-verified emission control technologies Donaldson announced it would be providing to 41 New York schools under the New York State Clean Air School Bus Program sponsored by NYSERDA (Donaldson, Inc., 2004).

Companies participating in the SmartWay Transport Partnership Program, a voluntary partnership between EPA and various sectors in the freight industry sectors, also plan to use verified diesel retrofit technologies. In December 2003, Clean Diesel Technologies received commercial orders from Coca Cola Enterprises, a SmartWay Transport Partner, to retrofit beverage delivery trucks in Louisiana, Pennsylvania, and Texas with the ETV-verified Platinum Plus Purifier (CDT, 2003). Clean Diesel Technologies also retrofitted 125 waste-hauling and beverage delivery trucks and landfill equipment owned and operated by Waste Management, Inc. and Coca Cola Enterprises Inc. in Pennsylvania under two State of Pennsylvania projects (PADEP, 2004; CDT, 2005, 2004). Clean Diesel Technologies also recently announced that both of its ETV-verified technologies have been selected by the State of Massachusetts for use with municipal and public vehicles and buses, as well as two demonstration programs with the Texas Council of Environmental Quality and NYSERDA, respectively (CDT, 2005).

Lubrizol Engine Control Systems is partnering with the Pennsylvania Department of Environmental Protection (PADEP), Sunoco, and the Philadelphia Diesel Difference to retrofit 20 of the City of Philadelphia's 6,000 diesel powered vehicles with its ETV-verified technology (Brown, K., 2005). Lubrizol also is partnering with the PADEP to retrofit several vehicles at Temple University's Philadelphia campus (PADEP, 2004).

> "Obtaining EPA's ETV Verification has enabled Donaldson to participate in many national voluntary retrofit programs … being listed on EPA's VDRP Web site has led to a number of bid invitations and supply contracts for retrofit programs." *—Julian Imes, Director, Exhaust Emissions Control at Donaldson Company, Inc. (U.S. EPA, 2004a)*

Scientific Advancement Outcomes

According to Glen Reid of Clean Diesel Technologies, when the company's technology was in a pre-commercial stage, there was no single established protocol for retrofit devices, so the company could not demonstrate its technology's performance in a way that was representative of real life. The company also "found that the testing protocol for fuel additives was inappropriate for products which required a conditioning period or provided a residual performance when discontinued." The protocol that ETV developed "leveled the playing field" (U.S. EPA, 2004a). In addition to developing an appropriate testing protocol, the ETV Program has advanced efforts to standardize testing through the stakeholder relationship it maintains with OTAQ, the California Air Resources Board, and other groups that are involved in verifying diesel retrofit technologies. The three testing protocols are currently available on the ETV and VDRP Web sites.

> "Verification under the ETV Program has generated considerable commercial interest in our technology from end users, as well as regulators and potential distribution partners … . There has also been a significant increase in the requests for proposals from school districts and commercial fleets since our system was posted to the EPA's diesel retrofit Web site." *—James Valentine, President and Chief Operating Officer of Clean Diesel Technologies (U.S. EPA, 2004a)*
>
> "A small company would never be able to access Coca-Cola if they did not go through the ETV process." *—Glen Reid, Vice President of Sales and Marketing for Clean Diesel Technologies (U.S. EPA, 2004a)*

Acronyms used in this case study:

APCT Center	ETV's Air Pollution Control Technology Center	NYSERDA	New York State Energy Research and Development Authority
CO	carbon monoxide	OTAQ	EPA's Office of Transportation and Air Quality
COPD	chronic obstructive pulmonary disease	PADEP	Pennsylvania Department of Environmental Protection
DOC	diesel oxidation catalyst muffler	PM	particulate matter
DPF	diesel particulate filter	REMSAD	Regulatory Modeling System for Aerosols and Deposition
FTP	Federal Test Procedure	RIA	Regulatory Impact Analysis
g/bhp-hr	grams per brake horsepower per hour	SIP	State Implementation Plan
HCs	hydrocarbons	UBRP	EPA's Urban Bus Retrofit Program
LSD	low sulfur diesel	ULSD	ultra-low sulfur diesel
NAAQSs	National Ambient Air Quality Standards	VDRP	EPA's Voluntary Diesel Retrofit Program
NO_X	nitrogen oxides		

2.2 Eductor Vapor Recovery Unit (EVRU)

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 the Eductor Vapor Recovery Unit (EVRU) manufactured by COMM Engineering of Lafayette, Louisiana. The EVRU is a technology designed to recover gas from storage tank vents and other low-pressure hydrocarbon vent sources for utilization or sale. The technology reduces emissions of pollutants including methane, hazardous air pollutants (HAPs), and volatile organic compounds (VOCs). Methane is a greenhouse gas linked to global climate change. HAPs and VOCs have significant human health effects.

Available sales and marketing data indicate that at least 11 U.S. facilities have installed the ETV-verified EVRU technology. These facilities selected the technology, at least in part, because of the verification results and outreach conducted by ETV. Based on the analysis in this case study, the estimated benefits of these existing installations include the following:

- ❖ Emissions reductions of 280 million standard cubic feet per year (MMscfy) of methane, 1,700 tons per year of HAPs, and 21,600 tons per year of VOCs, with associated climate change and human health benefits
- ❖ Increased recovery of natural gas with a potential economic value of approximately $6.3 million per year.

As described in this case study, the total potential market for the EVRU technology is much larger than 11 facilities. Based on the analysis in this case study, the ETV Program estimates that:

- ❖ The EVRU technology could assist up to 120 facilities in complying with EPA's National Emission Standards.
- ❖ Up to 3,170 facilities (out of an estimated potential market of 12,670) could voluntarily install the EVRU, in part because of the technology's economic benefits.
- ❖ The EVRU technology could reduce methane emissions by 2 billion to 6 billion standard cubic feet per year (bscfy), HAPs by 11,300 to 33,200 tons per year, and VOCs by 142,000 to 416,000 tons per year, with associated climate change and human health benefits (assuming that technology is installed by 1,000 to 3,170 facilities).
- ❖ The estimated economic value of the recovered natural gas (which equals the emission reduction estimates listed previously) could equal $41 million to $120 million per year.

Furthermore, additional (unquantified) maintenance cost savings also could be realized by the facilities that install the EVRU.

2.2.1 Environmental, Health, and Regulatory Background

Oil and natural gas condensate storage tank batteries at production and processing facilities in the United States emit an estimated 23.3 bscfy of methane.[10] U.S. EPA (1997d) estimated that these batteries also emit 7,000 tons per year of HAPs, and more than 22,000 tons per year of VOCs.[11] Each of these pollutants can have significant environmental and health effects.

Methane is a greenhouse gas that has had a 150-fold increase in atmospheric concentration since pre-industrial times. Although it is removed from the atmosphere by reaction with the hydroxyl radical, there are no other significant "sinks" (i.e., mechanisms that remove methane from the atmosphere). Approximately 50% of methane emissions are the result of human actions. Because its greenhouse potential is 23 times more potent than carbon dioxide and it has an atmospheric lifetime of about 12 years, methane is an important contributor to global climate change (U.S. EPA, 2004i). The Intergovernmental Panel on Climate Change (IPCC) has concluded that the 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 frame. 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 methane, can have potential 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 could result in increased deaths, injuries, and illnesses (U.S. EPA, 1997b). Many of the potentially most important impacts, however, depend upon 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, 2000d).

The HAPs emitted by the oil and gas industries include benzene, toluene, ethyl benzene, and xylene (known collectively as BTEX compounds), plus n-hexane. These pollutants have a range of carcinogenic and toxic effects on humans. Benzene is a known human carcinogen that causes leukemia in exposed populations. Other health effects associated with these HAPs include the following: irritation of the skin, eyes, and upper respiratory tract; blood disorders; reproductive disorders in women; nervous system effects; abnormal heart function; and effects on kidneys (U.S. EPA, 2004i).

VOCs contribute significantly to ozone formation and thus to both human health and environmental degradation. Adverse health effects include: transient changes in pulmonary function, transient respiratory symptoms and effects on exercise performance, increased airway responsiveness, transient pulmonary inflammation, increased susceptibility to respiratory infection, increased hospital admissions and emergency room visits, and, possibly, premature mortality (U.S. EPA, 1997c). For crops, trees, and forested ecosystems, elevated ozone levels can inhibit growth and yield, create leaf damage, increase susceptibility to pests and disease, and affect long-term survival (IPCC, 2001a).

To address the effects of HAPs and other pollutants emitted by the oil and gas industries, on June 17, 1999, EPA issued National Emission Standards for oil and natural gas production. Among other requirements, the standards call

10 See Appendix B for the basis of this estimate.

11 Note that, as discussed in Appendix B, there is some uncertainty about national emissions estimates of these pollutants for this specific source category. Because of this uncertainty, the ETV Program did not use the estimates of HAP and VOC emissions from U.S. EPA (1997d) in estimating outcomes.

for operators to install control devices to reduce vent gas emissions from certain storage tanks (64 FR 32610). EPA estimated that 120 storage tank batteries would be required to install control devices (U.S. EPA, 1997d).[12]

In addition, to address emissions of methane from the oil and natural gas industry, EPA has established the Natural Gas STAR Program. This program is "a voluntary partnership that encourages companies across the natural gas and oil industries to adopt cost-effective technologies and practices that improve operational efficiency and reduce emissions of methane" (U.S. EPA, 2005d). Under the Natural Gas STAR Program, partner companies voluntarily implement Best Management Practices (BMPs) to reduce methane emissions, when these BMPs are cost-effective for the partners (U.S. EPA, 2005d).

2.2.2 Technology Description

The EVRU is a technology designed to recover gas from storage tank vents and other low-pressure hydrocarbon vent sources for utilization or sale. The EVRU is a non-mechanical eductor (or jet pump) that recovers vent gas by using high-pressure motive gas to entrain hydrocarbon vapors from low-pressure sources. The facility's existing dehydrated high-pressure natural gas pipeline supplies the motive gas. The recovered gas can serve as fuel onsite or be repressurized with a booster compressor and injected into a natural gas transmission line for sale. It is a closed-loop system designed to reduce or eliminate emissions of greenhouse gases (methane and carbon dioxide), VOCs, HAPs, and other constituents present in vent gas. Unlike conventional vapor recovery systems, the system has no moving parts to maintain, resulting in lower maintenance costs and less operational downtime (and, therefore, greater vent gas recovery over the course of a given period).

The ETV Program conducted testing of the EVRU at TotalFinaElf's El Ebanito exploration and production facility 30 miles northwest of McAllen, Texas. The facility handles separation of natural gas and crude oil condensate product, gas compression, and gas dehydration from wells within a 5-mile radius. Typically, crude oil production ranges between 900 and 1,200 barrels per day. The EVRU was installed to recover vent gas from a battery of seven storage tanks (Southern Research Institute, 2002).

The ETV Program verified that the EVRU was capable of capturing all of the tank

A schematic diagram of the EVRU

12 EPA has not published more recent data on the number of regulated facilities in this category.

The COMM Engineering EVRU installed

battery emissions. During the five month test, the EVRU operated 99.91% of the time and recovered 100% of the vent gas during the time it was operating. Methane emissions were reduced by 32.1 MMscfy, HAPs were reduced by 1.5 MMscfy or 176 tons per year, and other hydrocarbon emissions were reduced by 30.1 MMscfy. In comparison, prior to the test, the site's conventional system was estimated to recover no more than 90% of the vent gas (Southern Research Institute, 2002).

Analyses showed the average lower heating value of the vent gas to be 1,919 British Thermal Units per standard cubic foot (BTU/scf). At the average vent gas recovery rate of 174,855 scf per day (as compared to no control system at all), this would amount to 335 million BTU per day (MMBTU/day) recovered (Southern Research Institute, 2002). At today's natural gas price, the value of the recovered gas would be greater than $650,000 per year.[13] The total capital, labor, and materials costs for purchase and installation of the EVRU were $107,958 (Southern Research Institute, 2002). At today's natural gas price, the payback period would be less than two months. Since, in this case, the EVRU replaced an existing emissions control system, a longer payback period is expected. Clearly, when the value of the recovered gas is a major consideration, the economics of installing EVRUs at uncontrolled sites are much more favorable.

2.2.3 Outcomes

As discussed below under "Technology Acceptance and Use Outcomes," COMM Engineering has installed 11 EVRU units in the United States since ETV verification was completed, and projects sales of 1,000 units in the U.S. and overseas over the next two to three years (U.S. EPA, 2004a, 2004i). The ETV Program estimates there are 12,670 storage tank batteries with the potential to benefit from application of the EVRU. This estimate includes the 120 storage tank batteries that might need to install control devices like EVRU to comply with National Emission Standards (U.S. EPA, 1997d), as well as batteries that might replace existing controls with the EVRU (e.g., to lower maintenance costs, to replace a system that is not operating properly, to increase vapor recovery), including batteries not regulated under the National Emission Standards. Appendix B explains the derivation of this estimate, which ETV used to define the potential market for the ETV-verified technologies.[14]

The ETV Program used this estimate of the total potential market to estimate the number of facilities that could apply the EVRU in the future (i.e., beyond the time frame of the vendor projection) based on the two market penetration scenarios identified in Exhibit 2.2-1: 10% and 25% of the total potential market. The ETV

Exhibit 2.2-1

Number of Facilities that Could Apply the COMM Engineering EVRU

Market Penetration	Number of Facilities
Current Penetration	13
COMM Projection	1,000
10%	1,270
25%	3,170

Values rounded to nearest 10, except for current market penetration

13 Assumes $5.49 per thousand scf (U.S. DOE, 2005) and 1,027 BTU per scf for typical purchased wellhead natural gas (U.S. DOE, 2003). See Appendix B for details on calculating the value of recovered gas.

14 As discussed in Appendix B, this is a conservative (low) estimate.

Program also used these market penetration scenarios to estimate the pollutant reductions and financial and economic outcomes shown below.

Emissions Reduction Outcomes

The net emissions reduction from application of the EVRU at a given site depends on (a) emissions quantities at the site, and (b) whether the site previously was uncontrolled or installed the EVRU to replace an existing control device. Since the quantities of vent gas generated by the test facility might not be representative of an "average" facility, the ETV Program estimated the percent of tank batteries in the market that have existing controls and then calculated the average potential emissions, with no controls in place, on a per facility basis.[15] ETV then applied these estimates and assumptions to the vent gas recovery rate measured during ETV testing and developed total emissions reduction estimates. Appendix B presents the methodology used in more detail.

Exhibit 2.2-2 shows the estimated emissions reductions for all the scenarios.[16] Quantitative data are not available to estimate the environmental and health outcomes associated with these emissions reductions. As discussed in Section 2.2.1, however, methane contributes to global climate change and the health effects of HAPs and VOCs are significant. Therefore, the benefits of reducing these emissions also could be significant.

Financial and Economic Outcomes

Vent gas recovered by the EVRU has a significant economic value to the facilities applying the technology. Using the methodology discussed in Appendix B, the ETV Program estimated the annual value of the vent gas that could be recovered by the EVRU. Exhibit 2.2-3 shows this estimate for all the scenarios.[17]

Exhibit 2.2-3

Estimated Potential Value of Recovered Gas from the COMM Engineering EVRU

Market Penetration	Annual Value ($ millions)
Current Penetration	6.3
COMM Projection	41
10%	52
25%	120

Values rounded to nearest $1 million, except for current market penetration (rounded to nearest $100,000)

In addition to the value of the recovered gas, there are potential savings associated with the lower maintenance requirements of the EVRU compared to conventional vapor recovery units. Quantitative data, however, are not available to estimate these savings.

Regulatory Compliance Outcomes

As noted in Section 2.2.1, EPA estimated that 120 storage tank batteries would install control devices like the EVRU to comply with the National Emission Standards (U.S. EPA, 1997d).

Exhibit 2.2-2

Estimated Potential Pollutant Reductions for the COMM Engineering EVRU

Market Penetration	Annual Pollutant Reduction: Methane (MMscfy)	HAPs (tons per year)	VOCs (tons per year)
Current Penetration	280	1,700	21,600
COMM Projection	2,000	11,300	141,900
10%	2,500	14,100	177,400
25%	6,000	33,200	416,100

Values rounded to nearest 100, except for methane in the current market penetration scenario (rounded to nearest 10)

15 As discussed in Appendix B, this assumption results in a conservative (low) estimate of outcomes.

16 Appendix B presents the specific data and assumptions used to develop these estimates. These estimates are conservative (low), as discussed in that section.

17 Appendix B presents the specific data and assumptions used to develop these estimates. These estimates are conservative (low), as discussed in that section.

> "We present ETV performance data at every sales call, and we direct potential customers to EPA's Web site so they can see for themselves the detailed verification reports. The technical performance data is good, but it's ETV's independent verification of our system's economic payback period that gets the most attention by our customers. ETV verification, and the outreach conducted by ETV, has been a major factor in the success of this technology. The technology has been an economic success for COMM, but it also provides new revenue streams for our customers and big benefits to the environment." *—Mark Goodyear, President of COMM Engineering (Southern Research Institute, 2004b; U.S. EPA, 2004i)*

Because they are regulated, these facilities likely have existing controls in place. As demonstrated in the verification test, the EVRU offers lower maintenance costs and greater vapor recovery than conventional controls. Therefore, regulated facilities might replace their existing controls with the EVRU, thereby allowing continued regulatory compliance with greater economic benefits.

Technology Acceptance and Use Outcomes

COMM Engineering has installed 11 EVRU units in the United States since ETV verification was completed, and it projects sales of 1,000 units in the U.S. and overseas over the next two to three years (Southern Research Institute, 2004b; U.S. EPA, 2004a, 2004i; Boyer, 2005). According to the vendor (see quote at left), ETV verification appears to be a factor in customers' decision to purchase the technology.

In addition, the EVRU has been among the technologies highlighted at technology transfer workshops sponsored by EPA's Natural Gas STAR Program (e.g., Devon et al., 2005; Pioneer et al., 2004). The Natural Gas STAR Program has publicized ETV verification of the EVRU in its Partner Update (U.S. EPA, 2004b), increasing awareness of the technology.

Acronyms used in this case study:

BMPs	Best Management Practices	HAPs	hazardous air pollutants
bscfy	billion standard cubic feet per year	IPCC	Intergovernmental Panel on Climate Change
BTEX	benzene, toluene, ethyl benzene, and xylene	MMBTU/day	million British Thermal Units per day
BTU/scf	British Thermal Units per standard cubic foot	MMscfy	million standard cubic feet per year
EVRU	Eductor Vapor Recovery Unit	VOCs	volatile organic compounds
GHG Center	ETV's Greenhouse Gas Technology Center		

2.3 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.

Available sales data indicate that a capacity of at least 7.7 megawatts (MW) of ETV-verified microturbines[18] have been installed in CHP applications in the United States in the last year. Based on the analysis in this case study, the estimated benefits of these existing installations include:

- Emissions reductions of 12,000 to 21,000 tons per year of CO_2 and approximately 70 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 market penetration increases, emission reductions and other benefits also could increase. In fact, based on the analysis in this case study and without assuming any growth from current sales levels, the ETV Program estimates the total installed capacity of ETV-verified microturbine/CHP systems could reach 46.3 MW in the next five years,[19] with the following estimated benefits:

- Emissions reductions of 70,000 to 127,000 tons per year of CO_2 and 410 to 440 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

18 This estimate is based on sales from only one vendor in one year and represents 110 to 130 installations.

19 This estimate includes the 7.7 MW that the ETV Program estimates have already been installed. It represents between approximately 660 and 770 installations total. It is a conservative (low) estimate, as discussed in Appendix C.

- 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 microturbine and CHP applications.

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, 2004c). 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 frame. 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 potential 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, 1997b). Many of these impacts, however, depend upon 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, 2000d).

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 wide variety of health and environmental impacts. These impacts include the following (U.S. EPA, 1998; U.S. EPA, 2003d):

- 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.

Each of the other pollutants emitted during electricity generation also can have significant

20 Values converted from gigagrams as reported in U.S. EPA, 2004.

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. THCs and CO can impact ground-level ozone formation, and CO can be fatal at high concentrations. PM can cause premature mortality and a variety of respiratory effects. Finally, ammonia can contribute to PM levels and result in a number of adverse heath effects.[21]

As discussed in detail in Sections 2.3.2 and 2.3.3, distributed generation technologies have the potential to 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 like 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, 2005e).

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, 2004d), to assist in developing output-based regulations for power generators (U.S. EPA, 2005f).

"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, 2005e)*

2.3.2 Technology Description

"Large- and medium-scale gas-fired turbines have been used to generate electricity since the 1950s, but recent developments have enabled the introduction of much smaller turbines, known as microturbine/CHP systems" (U.S. EPA, 2002h). 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-

A typical microturbine CHP installation (Capstone 60 microturbine and Unifin Heat Exchanger)

21 Please note that this paragraph is meant as an overview only. It does not represent a comprehensive list of the pollutants emitted during electricity generation or their environmental and health effects. For discussion of the health and environmental effects of CO and PM, see Section 2.1.1. For discussion of the health and environmental effects of ammonia, see Section 2.6.2.

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 would otherwise go unused because it is traditionally flared or vented to the atmosphere.

Because they are a relatively new technology, reliable performance data are needed on microturbine/CHP technologies. The ETV Program responded to this need by verifying the performance of six microturbine technologies (see Exhibit 2.3-1), four of which include heat recovery. Residential, commercial, institutional, and industrial facilities were used as test sites. One of the technologies tested operated on biogas recovered from animal waste.

During each test, the ETV Program verified heat and power production performance, power quality performance, and emissions performance. Heat and power production performance 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, verified electrical efficiencies ranged from 20.4% to 26.2%. For systems with heat recovery, verified thermal efficiencies at full load and normal operation ranged from 7.2% to 47.2%. For these systems, verified total system efficiencies ranged from 33.4% to 71.8%.[22] 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.

EXHIBIT 2.3-1

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 PowerWorksTM 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, 2004.
Note: The two verified Honeywell products are no longer sold.

22 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%.

Power quality performance tests measured electrical frequency, voltage output, power factor, and voltage and current total harmonic distortion (THD). The ETV Program found that all of the technologies maintained continuous synchronization with the utility grid throughout the corresponding test periods. Verified average electrical frequencies ranged from 59.999 to 60.001 hertz (Hz). Verified average voltage outputs ranged from 215.21 to 494.75 volts. For all technologies, the power factor remained relatively constant, and ranged from 62.7% to 99.98%. In all but one of the tests, voltage and current THD were below the threshold specified in the Institute of Electrical and Electronics Engineers (IEEE) guidelines.

Emissions performance 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 x 10^{-5} to 4.48 x 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 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, 2004).

2.3.3 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, at least 7.7 MW of ETV-verified microturbines have been installed for CHP applications in the United States in the last year. Because this estimate includes sales from only one vendor during the last year, it likely is conservative (low) and represents the minimum market penetration.

The ETV Program used the estimate of current market penetration to estimate the capacity of ETV-verified microturbine/CHP systems that could be installed in the near future. Specifically, ETV estimated that 38.6 MW could be installed in the next five years, for a total installed capacity, including the current minimum penetration, of 46.3 MW, as shown in Exhibit 2.3-2. Appendix C explains the derivation of this estimate of future market penetration.[23] The ETV Program used the current minimum and future market penetration scenarios to estimate the emissions reduction outcomes shown below.

Exhibit 2.3-2: Capacity of ETV-Verified Microturbine/CHP Systems Potentially Installed

Market Penetration	Total Capacity (MW)
Current Minimum	7.7
Future Penetration	46.3

Values rounded to nearest 0.1 MW

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 microturbine replaces, such as an electric utility power plant or hot water heater. These factors vary geographically and by specific application. Given this variation, quantitative data are not available to characterize these factors for every potential ETV-verified microturbine/CHP application. Therefore, this analysis uses model facilities developed by Southern Research Institute for the test sites to estimate emissions reductions for

23 As discussed in Appendix C, this is a conservative (low) estimate.

each market penetration scenario. Appendix C describes the model sites and the methodology for using the model facilities to estimate nationwide emissions reductions for the microturbine capacities shown in Exhibit 2.3-2. Exhibit 2.3-3 shows upper- and lower-bound estimates of annual CO_2 and NO_X reductions generated using this methodology for each market penetration scenario. The upper-bound estimates assume each ETV-verified microturbine/CHP application is represented by the model site that achieves the greatest reduction for that compound. The lower-bound estimates assume each ETV-verified microturbine/CHP application 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 2.3-3, 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. Quantitative data are not available, however, to estimate these reductions. Quantitative data also are not available to estimate the environmental and health outcomes associated with the reductions in CO_2, NO_X, or other emissions. As discussed in Section 2.3.1, however, the environmental and health effects of these emissions are significant. Therefore, the benefits of reducing these emissions also could be significant.

Resource Conservation, Economic, and Financial Outcomes

Section 2.3.2 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). Also, as shown in one of the verification tests, microturbines can be fueled by biogas, a renewable resource. Therefore, 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. Quantitative data are not available to estimate these resource conservation outcomes or associated cost savings, although 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 2.3-3

Estimated Potential Emissions Reductions for ETV-Verified Microturbine/CHP Systems[24]

Market Penetration	Annual Pollutant Reduction: CO_2 (tons per year) (1)	NO_X (tons per year) (2)
Upper Bound		
Current Minimum	21,000	70
Future Penetration	127,000	440
Lower Bound		
Current Minimum	12,000	70
Future Penetration	70,000	410

(1) Rounded to nearest 1,000

(2) Rounded to nearest 10

24 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 sold more than 16.5 MW of ETV-verified microturbines in the last year. Of these sales, approximately 7.7 MW were for CHP applications in the United States.[25] Also, 11% of last year's 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, resulting in 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 (i.e., 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 Generic Verification 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, 2002h)*

"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
Hz	hertz	THCs	total hydrocarbons
IEEE	Institute of Electrical and Electronics Engineers	THD	total harmonic distortion
IPCC	Intergovernmental Panel on Climate Change		

25 See Appendix C for detailed derivation of this estimate.

2.4 Laser Touch Spray Painting Targeting Device

The ETV Program's Coatings and Coating Equipment Pilot (CCEP), operated by Concurrent Technologies Corporation (CTC) under a cooperative agreement with EPA, has verified the performance of a laser targeting device for spray painting. The Laser Touch technology helps spray painters maintain a consistent distance to the surface being coated, thus improving transfer efficiency, reducing paint overspray (i.e., paint solids that are not transferred to the object being painted), and ultimately reducing paint usage. Since less paint is used and ultimately lost as overspray, the technology also reduces paint mist and other painting-related air emissions, including volatile organic compounds (VOCs) and hazardous air pollutants (HAPs). VOCs and HAPs have significant environmental and human health effects. Paint mist and toxic pollutants also cause occupational health concerns. The technology is applicable to a variety of industries that use manual spray painting equipment.

Based on the analysis in this case study, the ETV Program estimates that:

- The ETV-verified Laser Touch technology could reduce VOC emissions from the automobile refinishing industry by approximately 1,100 to 2,700 tons per year, resulting in associated environmental and health benefits and increased compliance with state and federal air emissions regulations.
- The Laser Touch technology could reduce solid waste generation from the automobile refinishing industry by approximately 300 to 8,000 tons per year, with associated environmental and health benefits and resulting in cost savings for the user.
- The Laser Touch technology can potentially reduce emissions of HAPs and paint spray mist in the workplace, resulting in associated health benefits and potentially assisting in compliance with state and federal occupational safety and health regulations.
- The Laser Touch technology can potentially reduce paint usage, resulting in cost savings for the user. Although there is considerable uncertainty in estimating these savings, savings up to $100 million per year could be realized by the automobile refinishing industry alone.
- The Laser Touch technology can improve the visual appearance of painted products, providing a potential economic advantage for the user.[26]

Verification of this technology also has increased awareness among state regulatory agencies and potential users of the Laser Touch technology and its benefits. This awareness has

26 The numerical estimates found in this case study assume that Laser Touch technology is used by 10% to 25% of the surface coating operations in the automobile refinishing industry. The estimates are conservative (low) because reductions from other industries that have surface coating operations also are possible.

streamlined the technology review, acceptance, and permitting process, and increased opportunities for use in federal- or state-sponsored training programs.

2.4.1 Environmental, Health, and Regulatory Background

Spray painting results in a number of environmental, health, and regulatory impacts. Paint contains VOCs, HAPs, and other chemicals that present occupational concerns. During spray painting, these pollutants are emitted to the air and workspace. In 2002, nationwide VOC emissions from all sources were 16,544,000 tons. Surface coating applications are estimated to account for 2,049,000 tons, or 12% of the nationwide total (U.S. EPA, 2005g). Industries that use manual spray coating and could benefit from the ETV-verified technology include wood furniture coating, auto refinishing, miscellaneous metal parts and products, and plastic parts and products. Wood furniture coating and auto refinishing are among the largest sources of VOCs from surface coating applications (U.S. EPA, 2005g). Architectural coatings also account for significant VOC releases and use manual spray techniques to some extent. Architectural application, however, is conducted in field settings, which were not evaluated in the ETV program.

VOCs from coating operations and other sources contribute to the formation of ground-level ozone, which is a criteria pollutant under the Clean Air Act. Ozone can irritate lung airways and cause inflammation. At very low levels, ground-level ozone triggers a variety of health problems including aggravated asthma, reduced lung capacity, and increased susceptibility to respiratory illnesses like pneumonia and bronchitis. Repeated exposure to ozone can cause permanent damage to the lungs. Ozone also interferes with the ability of plants to produce and store food, making them more susceptible to disease, insects, and harsh weather. Resulting detrimental effects are crop or forest yield losses, aesthetic losses, and ecosystem damage (U.S. EPA, 2004e).

Some of the VOCs emitted by surface coating operations are also classified as HAPs. The Clean Air Act Amendments of 1990 designate approximately 189 chemicals as HAPs, which are chemicals that cause a wide range of serious health and environmental effects such as cancer or illness. HAPs emitted from surface coating operations include toluene, xylene, glycol ethers, methyl ethyl ketone, methyl isobutyl ketone, ethylbenzene, and methanol. Adverse health effects associated with these pollutants include respiratory effects, effects on the central nervous system, and damage to the liver (69 FR 22602).

Spray painting also presents occupational health concerns. Paint mist itself is a hazard, and certain polyurethane coatings can contain toxics such as isocyanates, which can lead to asthma. Isocyanates (several of which are also HAPs) are present predominantly as polyisocyanates, with low levels of residual monomer. The Occupational Safety and Health Administration (OSHA) has established occupational exposure limits for certain isocyanate monomers. Some states, such as Oregon, have established occupational exposure limits for polyisocyanates (Heitbrink et al., 1995). Reducing paint mist generation assists in reducing exposure to these chemicals.

In recognition of these issues, a number of federal, state, and local programs have sought to reduce VOC and other surface coating emissions through regulation, voluntary programs, and other means. Currently, EPA regulations limit the VOC content of coatings in a number of industries, such as automobile refinishing and architectural coatings. EPA also has finalized New Source Performance Standards for some industries using surface coating. Also, sites that emit more than a certain quantity of VOCs or HAPs are subject to federal permitting requirements. For example, a site located in an ozone attainment area with a potential to emit more than 100 tons per year VOCs, 10 tons per year of a single HAP, or 25 tons per year of total HAPs is a "major source" under the Clean Air Act and requires a Title V operating permit. Finally, EPA implements national emission standards for HAPs relevant to a number of industries using surface coatings; "major sources" are subject to these additional requirements.

In addition to federal requirements, surface coating operations also can be required to comply with state requirements or initiatives developed to reduce emissions. For example, New York requires that all auto body shops use high-efficiency, high-volume, low-pressure (HVLP) spray guns, in addition to using coatings with specified VOC content. Several northeastern states and many California air districts have adopted more stringent limits on the VOC content of architectural coatings (New York State Small Business Assistance Program, 2004; CARB, 2000).

California also conducts independent third-party verification of equipment with air quality benefits (such as technologies that reduce VOCs from coating operations) to promote the use of innovative equipment. This pre-certification program provides marketing benefits for the vendor and enables the air quality management districts to become more familiar with the technology (CARB, 2002).

2.4.2 Technology Description

Spray painting requires the transfer of liquid paint to an object. The effectiveness of this transfer is measured as transfer efficiency. A high, and desirable, transfer efficiency (TE) results when relatively little of the paint solids are lost as overspray (waste). One key to reducing overspray and improving TE during manual spray painting operations is to eliminate the variability in the operator's coating technique, although other factors are important as well. A reduction of overspray and an increase in TE can reduce air emissions and solid waste generation.

The Laser Touch technology is a battery-operated device that can be fastened to a manual paint spray gun with an adapter bracket. It emits two laser light beams, which meet when the gun is being held at the desired distance and orientation to the target (CTC, 2000). If used properly, it will help the spray painter maintain a consistent distance to the target and proper gun orientation. It should also help minimize unnecessary overlap and improve targeting, thus minimizing paint use and helping the painter to achieve a high finish quality. The verified technology is applicable for any use in which paint or other surface coating is applied using a manually operated spray gun. Examples of potential applications include small- and medium-sized businesses engaged in automobile refinishing, equipment manufacturing, and similar industries where spray painting occurs.

The ETV Program's CCEP verified the pollution prevention potential of the Laser Touch model LT-B512 spray painting targeting device in May 2000. The test was conducted at the Iowa Waste Reduction Center's (IWRC's) Painting and Coating Compliance Enhancement Facility in Cedar Falls, Iowa. During testing, 10 painters coated panels with and without the Laser Touch device under representative factory conditions using a common industrial coating (CTC, 2000). The test verified the following performance parameters:

- *Relative Transfer Efficiency (TE) Improvement:* In comparison to unassisted paint spraying, the verified technology provided a relative increase in TE at an average of 11.1%.[27]
- *Emissions Reduction:* The improvement in TE resulted in a 10% reduction of volatile emissions when compared to the unassisted baseline.

The laser targeting technology applied to a fender

27 The amount of TE improvement would be different at different test conditions, e.g., lower solids coating or lower baseline TE conditions. In general, the specific quantitative reduction depends on numerous factors such as paint formulation, process line and paint booth design, and the products being coated.

- *Cost Savings:* Economic benefits were realized by improving the TE and reducing paint usage and solid waste generation and disposal. In the verification test, the technology resulted in a reduction of 0.2 liters of paint used per kilogram of solids applied and a 25% reduction in solid waste generation when compared to the unassisted baseline.[28]
- *Visual Appearance:* The verification test assessed visual appearance for all parts sprayed by each painter. The visual appearance of the parts sprayed using the verified technology was determined to be better than that of the unassisted baseline parts, with more even coating coverage and reduced appearance of striping (CTC, 2000).

Advantages of the technology were identified as decreased variability and pollution prevention benefits, while disadvantages were identified as increased weight of the paint sprayer (6.5 ounces). The technology cost $799 at the time it was verified (CTC, 2000).

2.4.3 Outcomes

The verified technology is applicable to a wide variety of industries where manual spray painting occurs. For example, U.S. EPA (2005g) identifies more than 20 industries contributing VOCs from surface coating operations. These surface coating applications result in approximately 2 million tons of VOC air emissions nationwide. Not all of these emissions, however, result from manual spray painting.

To simplify the outcomes analysis, and to ensure that relatively conservative estimates were developed, the ETV Program limited the analysis to the automobile refinishing industry. ETV selected this industry because its VOC emissions from surface coating are significant (based on U.S. EPA, 2005g), and manual spray painting contributes a significant fraction of the industry's VOC emissions (based on general industry information). Since the ETV Program does not have access to a comprehensive set of sales data for this technology, pollutant reductions and other outcomes are based on two market penetration scenarios within the automobile refinishing industry, 10% and 25%.

Pollutant and Solid Waste Reduction Outcomes

The ETV Program estimated the potential VOC reductions that could be experienced if 10% and 25% of the surface coating operations in the automobile refinishing industry used the ETV-verified Laser Touch devices. These estimates are based on the verified TE improvement for the Laser Touch technology and estimated VOC emissions from the automobile refinishing industry from U.S. EPA (2005g). Since a reduction in solid waste generation is an additional benefit of using the Laser Touch technology, the ETV Program also used data from CTC (2000) to estimate solid waste reductions for the various market penetration scenarios. Appendix D presents the methodology used in more detail. Exhibit 2.4-1 shows the estimated pollutant and solid waste reductions.[29]

In addition to the VOC reductions shown in Exhibit 2.1-1, the ETV-verified technology also can reduce HAP emissions, although quantitative data are not available to estimate these reductions. Quantitative data also are not available to estimate the environmental and health outcomes associated with the pollutant and solid waste reductions. As discussed in Section 2.1.1, the environmental and health effects of HAPs and VOCs are significant. Therefore, the benefits of reducing these pollutants also could be significant.

Exhibit 2.4-1

Estimated Potential Pollutant and Solid Waste Reductions for the Laser Touch Spray Painting Technology

Market Penetration	Reduction (tons per year)	
	VOCs	Solid Waste
10%	1,100	300 to 3,100
25%	2,700	700 to 7,800

Values rounded to nearest 100 tons

28 The estimated solid waste reduction is based on an unassisted TE of 60% and a relative TE improvement of 11.1%. Percent solid waste reduction would be reduced at lower baseline TE values for the same amount of TE improvement.

29 As discussed in Appendix D, these are conservative (low) estimates.

Resource Conservation, Economic, and Financial Outcomes

The ETV-verified technology also reduces paint usage, conserving resources and resulting in cost savings for the user. By extrapolating from IWRC data (Little, 2004) for its spray paint training program, the ETV Program estimated potential cost savings from reduced paint usage for the various market penetration scenarios, as shown in Exhibit 2.4-2. Appendix D presents the methodology used in more detail. Although there is considerable uncertainty in this extrapolation, ETV included these very rough estimates to highlight potential impacts that could be realized from the use of the Laser Touch technology.

Although quantitative data are not available to estimate the savings, reductions in solid waste generation also could result in lower waste disposal costs. By improving the visual appearance of painted products, the ETV-verified technology also could provide an economic advantage to the user. Finally, the environmental and health benefits of reduced VOC and HAP emissions and solid waste disposal have an economic value.

Regulatory Compliance Outcomes

As discussed in Section 2.4.1, sites that emit VOCs and HAPs, including surface coating facilities, can be subject to state and federal permitting requirements and emissions standards. They also can be subject to OSHA and state occupational safety and health requirements for workplace concentrations of toxic chemicals. Because it reduces emissions of paint mist, VOCs, HAPs, and other toxics, use of the ETV-verified technology could assist facilities in complying with these regulatory requirements. Data are not currently available to quantify these outcomes.

Verification has also streamlined the technology review, acceptance, and permitting process, and increased opportunities for use in federal or state-sponsored training programs. The California Air Resources Board (CARB) has accepted CCEP data when reviewing technologies for use. CARB used ETV verification data in its decision to issue an equipment pre-certification certificate for Laser Touch. This action familiarizes local air district governments in California with the technology (CARB, 2004).

Exhibit 2.4-2

Estimated Potential Cost Savings from Reduced Paint Usage for the Laser Touch Spray Painting Technology

Market Penetration	Cost Savings (million dollars per year)
10%	50
25%	120

Values rounded to nearest $10 million

Technology Acceptance and Use Outcomes

Verification has also increased technology awareness and has served as a useful marketing tool. Laser Touch and Technologies, LLC, the technology vendor at the time of verification,[30] reported that sales increased immediately upon release of the Laser Touch verification report, estimating a sales increase of 10% to 15% as a result of ETV verification (U.S. EPA, 2004a, 2004k). Furthermore, the pollution prevention findings appear to be the most valuable results to the end users, and evaluation by the California Environmental Technology Certification Program, supported by ETV data, enabled Laser Touch to penetrate into California markets (U.S. EPA, 2004k). Finally, the IWRC, which worked with CCEP on the verification, is using the Laser Touch technology in a training program for the Department of Defense (U.S. EPA, 2004a).

"I use the ETV report in every packet of information I send out to potential clients. The purchasing clients often comment on the importance of the ETV report, which I believe has indicated an increase in sales. It is a wonderful sales tool." *—Patti Schmidt, Director of Marketing, Laser Touch and Technologies, LLC (U.S. EPA, 2004a, 2004k)*

30 At the time of verification, Laser Touch and Technologies was the technology vendor under license from the University of Northern Iowa. The University has since terminated this license and the IWRC is in the process of manufacturing Laser Touch units for sale in the near future.

Future markets are being actively targeted for the technology. The University of Northern Iowa's Research Foundation is currently renegotiating its license agreements related to its laser guided application technologies and expects to have new agreements in place within the near future. Potential markets to be targeted once negotiations are complete include the automotive, aerospace, military and other industries. The technology also could enter the general consumer market, following the possible development of a residential version (Calhoun, 2005).

Acronyms used in this case study:

CARB	California Air Resources Board	IWRC	Iowa Waste Reduction Center
CCEP	ETV's Coatings and Coating Equipment Pilot	OSHA	Occupational Safety and Health Administration
HAPs	hazardous air pollutants	TE	transfer efficiency
HVLP	high-volume low-pressure	VOCs	volatile organic compounds

2.5 Portable Technologies for Measuring Lead in Dust

The ETV Program's Site Characterization and Monitoring Technologies (SCMT) Pilot, which was operated by Oak Ridge National Laboratory under an interagency agreement with EPA and was an element of the Advanced Monitoring Systems (AMS) Center, has verified the performance of six field screening analyzers for lead in dust. These portable analyzers report lead levels in dust more quickly than traditional fixed-site laboratory analysis methods. The presence of lead in soil, dust, and paint is a major health risk for children. These technologies can be used onsite, allowing the user to quickly identify whether a hazardous level of lead is present in dust and enabling them to react to any potential health risks in a timely manner.

Based on the analysis in this case study, the ETV Program estimates that:

- The ETV-verified portable measurement technologies could be deployed at up to approximately 16.5 million housing units out of an estimated potential market of 66 million that were built before 1978 to:
  - Screen for lead hazards (e.g., as part of a lead hazard screen) and assess potential risks (e.g., during a risk assessment)
  - Investigate instances of elevated blood lead levels in children
  - Clear residences for occupation following future abatements or future applications of lead hazard controls, provided the technology is used by a portable laboratory or field service and measurement organization that has been accredited by the National Lead Laboratory Accreditation Program (NLLAP)
  - Identify lead hazards after renovation and remodeling
  - Assist prospective purchasers in identifying lead hazards
  - Develop a focused and cost-effective sampling and analysis strategy when combined with confirmatory fixed-site laboratory analysis.[31,32]
- Ultimately, the information provided by these technologies can assist in the reduction of lead exposure, with associated human health and economic benefits, particularly for children. Of the 16.5 million pre-1978 residences where the technologies could be used, an estimated 2.6 million might house young children.

31 Note that, as detailed in Section 2.5.2, technology performance varied during testing. Some of the technologies are intended to replace laboratory analysis. Others are intended as a screening tool, to complement laboratory analysis. Thus, not all of the technologies are suited for all of the uses listed.

32 Although the use of lead-based residential paint was banned in 1978, many of the 66 million housing units built prior to 1978 are still in use and could have interior or exterior paint that contains lead, although no one knows for sure which units contain lead and which do not. ETV based the outcomes estimates found in this case study on the hypothetical assumption that the ETV-verified technologies could potentially be used to measure for lead in up to 25% of these homes (i.e., 16.5 million housing units).

ETV verification also can potentially increase acceptance and use of the portable measurement technologies. It could also potentially help portable laboratories and field service and measurement organizations obtain accreditation under the NLLAP in the near future. Previous ETV verifications of similar technologies have assisted in the development of approved EPA methods for using field portable measurement technologies and promoted the use of these technologies.

2.5.1 Environmental, Health, and Regulatory Background

Lead is a hazard to both adults and children and has been associated with anemia, kidney damage, and adverse nervous system effects. Despite efforts to reduce its use, however, lead and lead poisoning continue to be a consistent, but preventable, hazard. While all humans are at risk when exposed to lead, children are at the greatest risk. According to the most recent estimates, about 1.6% of children aged 1 to 5 years (310,000 children) have elevated blood lead levels (BLL), based on a survey conducted from 1999 to 2002 (CDC, 2005).

As determined by the Centers for Disease Control and Prevention (CDC), children with a BLL of 10 micrograms per deciliter (μg/dL) or higher are considered to have elevated levels, which are associated with adverse health effects (CDC, 2004). High levels of exposure can result in brain damage or death. At lower levels of exposure, lead can affect a child's mental and physical growth. Fetuses exposed to lead in the womb can be born prematurely and have lower weights at birth. Exposure in the womb, in infancy, or in early childhood also can slow mental development and lower intelligence later in childhood (ATSDR, 1999).

Lead-based paint, interior settled dust, tracked-in contaminated soil, and exterior soil are the primary sources of exposure to lead (CDC, 2004). As lead-based paint deteriorates, lead dust and paint chips can accumulate on interior surfaces and deposit in the soil surrounding a home. Lead dust can also be released during house renovation. Lead-contaminated dust and soil are easily ingested through hand-to-mouth activity. Lead also can be ingested when children chew accessible areas such as window sills (U.S. EPA, 2001b).

The use of lead in U.S. residential paint was banned in 1978 (U.S. EPA, 2001b). Many homes built prior to 1978, however, are still in use and have interior or exterior paint that contains lead. A recent survey sponsored by the U.S. Department of Housing and Urban Development (HUD) estimates that 66 million housing units were constructed prior to 1978. These housing units (one estimate is 24 million of them) could have significant lead-based paint hazards (Jacobs et al., 2002). A lead-based paint hazard is defined as paint, dust, or soil that equals or exceeds standards specified by EPA.

In 1992, Congress enacted the Residential Lead-Based Paint Hazard Reduction Act (Title X of the Housing and Community Development Act of 1992), the most comprehensive federal legislation ever passed regarding lead. This act is usually referred to as "Title X," although it also added Title IV to the Toxic Substances Control Act (TSCA). EPA and other federal agencies, such as HUD, continue to proceed according to the mandates of Title X, including the following:

- Establishing numerical standards for hazardous levels of lead in dust for pre-1978 housing and child-occupied facilities. These levels also are used for establishing clearance or "clean-up" levels following abatement activities. The clearance levels are: 40 micrograms per square foot ($\mu g/ft^2$) for floors, 250 $\mu g/ft^2$ for window sills, and 400 $\mu g/ft^2$ for window troughs (66 FR 1206).
- Requiring the disclosure of known lead-based paint and lead-based paint hazards to buyers and tenants. The Residential Lead-Based Paint Disclosure Act requires landlords and sellers to share any information pertaining to any known lead-based paint and lead-based paint hazards in housing constructed before the phase out of residential lead-based paint use in 1978, and allows a buyer of a pre-1978 house a period of time to test the house for lead-based paint and lead-based paint hazards (61 FR 9064).

- Providing grants for low-income families. HUD provides grants to localities to address lead-based paint hazards in private housing occupied by low-income families. The scope of the grants includes cleanup/control, testing, awareness, and training (U.S. HUD, 2002).

2.5.2 Technology Description

There is a need for field-portable monitoring devices that can test or at least quickly screen samples for lead. Conventional laboratory analytical methods (e.g., EPA SW 846 3050B/6010B) for determining trace metals are time consuming: samples must be collected by field personnel, packaged, shipped, and analyzed, and results must be communicated back to the risk assessment personnel. Equally critical, results of these analyses might trigger remediation decisions or further sampling needs and require multiple trips to a site or delays in remediation. Portable monitoring devices could address these shortcomings. Some of these technologies are intended to completely replace laboratory analysis, and others are complementary technologies that can provide screening information at the site for subsequent laboratory confirmation (U.S. EPA, 2001c).

Each of the technologies verified by the ETV Program is portable and designed to be used to analyze dust samples for lead in the field. These devices can be used to test or screen a relatively large number of samples at a given site to identify areas of concern. While some of the verified technologies can be used to analyze other metals as well, the verification tests evaluated performance for lead only. The ETV-verified technologies use one of two analysis methods: X-ray fluorescence (XRF) or anodic stripping voltammetry (ASV). At the time of the evaluation, vendors of other technologies for dust testing chose not to participate. XRF allows for non-destructive analysis of a sample. This technique uses a radioisotope source or X-ray tube to excite lead atoms within a test sample. The atoms, in turn, emit characteristic X-rays that are detected, identified, and quantified by the spectrometer. ASV is a destructive analysis method. A test sample is contacted with nitric acid to release elemental lead, which is subsequently dissolved in a salt solution. Lead in the solution is plated on and then stripped off an electrode. Each metal will strip from the electrode at a different potential, allowing for its identification, while the amount of current produced is quantified and correlated to sample concentration. Advantages of the ETV-verified technologies include field portability and the ability to measure 40 to 80 samples per day. An additional advantage of technologies based on XRF is that the analysis is non-destructive, allowing confirmation by laboratory methods on the same sample that was analyzed in the field (Battelle, 2004h).

To date, the ETV Program has verified the performance of six instruments by four different vendors for lead in dust. These technologies were verified in collaboration with Oak Ridge National Laboratory (ORNL). Exhibit 2.5-1 identifies the ETV-verified technologies.

A primary objective of the ETV test was to assess whether the participating field portable technologies produce results that are comparable to NLLAP-recognized data (Battelle, 2004h). Accordingly, an NLLAP-recognized laboratory also analyzed samples of the material measured during field testing (Battelle, 2004h). The verification test provided information on the

Exhibit 2.5-1

ETV-Verified Portable Technologies for Measuring Lead in Dust

Vendor	Verified Technology	Technology Type
Key Master Technologies	X-Ray Fluorescence Instrument Pb-Test	XRF
Monitoring Technologies International	PDV 5000 Trace Element Analyzer	ASV
Thermo Electron Corporation, NITON Analyzers Business Unit (formerly NITON LLC)	X-Ray Fluorescence Spectrum Analyzer XLt 700 Series	XRF
	X-Ray Fluorescence Spectrum Analyzer XL 700 Series	XRF
	X-Ray Fluorescence Spectrum Analyzer XL 300 Series	XRF
Palintest	Scanning Analyzer SA-5000 Sy	ASV

Sources: U.S. EPA, 2001c, 2001d, 2001e, 2001f, 2001g, 2002c.

potential applicability of field technologies for dust testing in a risk assessment, lead hazard screen, or clearance testing. The experimental design was developed based on the dust-lead hazard/clearance levels contained in the January 2001 final EPA regulations (66 FR 1206) for floors (i.e., 40 µg/ft^2), window troughs (i.e., 400 µg/ft^2), and window sills (i.e., 250 µg/ft^2) (Battelle, 2004h). During verification testing, 160 dust wipe samples were analyzed. These wipes contained between 2 and 1,500 micrograms of lead per dust wipe, which is representative of levels found in house dust wipe samples collected using ASTM methods specified in 40 CFR 745.63 EPA regulations (66 FR 1206).

The ETV Program evaluated the technologies on the following performance parameters: precision, accuracy, comparability to NLLAP-recognized laboratory results, detectable blanks (i.e., whether samples with non-detectable levels of lead were identified as containing lead), false positive results (i.e., whether samples containing lead under a limit were identified as containing lead over the limit), false negative results (i.e., whether samples containing lead over a limit were identified as containing lead under the limit), and other parameters. Exhibit 2.5-2 summarizes some of the performance data for the individual verified technologies. Because the ETV Program does not compare technologies, the performance results shown in Exhibit 2.5-2 do not identify the vendor associated with each result and are *not* in the same order as the list of technologies in Exhibit 2.5-1.

The ETV Program verified that the average relative accuracy, calculated as percent recovery, for the technologies ranged from 80% to 189%. A result of 100% indicates perfect accuracy relative to the tested lead concentration. The precision (relative standard deviation) ranged from 5% to 22%. A result of 0% indicates perfect precision. The number of false positive responses ranged from 0 of 50 samples to 27 of 46 samples. The number of false negative responses ranged from 4 of 54 samples to 39 of 50 samples. The ETV Program used linear regression analysis to evaluate comparability of the technologies to the standard test method. The slope values ranged from 0.662 to 1.206; the intercept values ranged from -14 to 121 µg; and the r^2 values ranged from 0.967 to 1.000.[33] The cost to purchase the verified analyzers ranged from $3,850 to $40,000. The verification tests, however, did not include an overall cost estimate for use of portable technologies versus use of the NLLAP laboratory because of the

Two of the ETV-verified lead in dust analyzers
(R. Jenkins, ORNL. Library of Lead in Dust Monitor Verification Photographs.)

33 Slope and intercept are measures of the relationship between technology response and the standard or 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 the 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 comparability to the standard test method.

Exhibit 2.5-2

Performance of ETV-Verified Portable Technologies for Measuring Lead in Dust[34]

Vendor	Average relative accuracy	Average relative precision	Rate of false positives	Rate of false negatives	Comparability (slope, intercept, r^2)
A	168 to 189%	15 to 18%	26 of 50	15 of 50	Slope: 0.662 to 1.060 Intercept: 66 to 121 r^2: 0.967 to 0.989
B	88 to 93%	21 to 22%	7 of 41	19 of 57	Slope: 0.885 to 1.074 Intercept: –14.345 to 15.633 r^2: 0.988 to 0.999
C	91 to 97%	7 to 8%	0 of 42	36 of 58	Slope: 0.849 to 0.936 Intercept: 7.495 to 11.262 r^2: 0. 999
D	107 to 119%	8%	27 of 46	4 of 54	Slope: 1.112 to 1.206 Intercept: –3.29 to 13.283 r^2: 0.999
E	80 to 91%	5 to 8%	0 of 50	39 of 50	Slope: 0.839 to 0.926 Intercept: 5.539 to 6.506 r^2: 0.995 to 1.000
F	97 to 101%	11%	9 of 49	18 of 51	Slope: 0.977 to 0.995 Intercept: 3.076 to 4.775 r^2: 0.999

Sources: U.S. EPA, 2001b, 2001c, 2001d, 2001e, 2001f, 2001g, 2002c.

extent of variation in the different cost factors, such as the number of samples requiring analysis, the sample type, and the site location and characteristics (U.S. EPA, 2001b, 2001c, 2001d, 2001e, 2001f, 2001g, 2002c).

2.5.3 Outcomes

From a point-of-use-perspective, the potential market for the ETV-verified portable monitoring technologies includes the approximately 66 million housing units constructed prior to 1978 (Jacobs et al., 2002). From a purchaser/operator-perspective, this market includes a variety of organizations and lead inspectors responsible for measuring lead levels in these housing units, including the more than 100 NLLAP-accredited organizations and lead inspectors (NLLAP, 2005). Hazards in these housing units could range from no hazard (e.g., instances where paint, dust, and soil hazards are not present at all) to a significant hazard (e.g., instances where there is significant deterioration of lead-based paint, hazardous levels of lead in dust, and/or hazardous levels of lead in bare soil). Any housing unit constructed prior to 1978 is generally considered "at risk" for the possible presence of lead and could apply the ETV-verified technologies as part of a lead risk assessment or lead hazard screen.

Because the ETV Program does not have access to a comprehensive set of sales data for the ETV-verified technologies, the ETV Program used two market penetration scenarios, 10% and 25% of the total potential market, to estimate the number of housing units where the verified technologies could be used, as shown in Exhibit 2.5-3.[35] The ETV Program also used these market

Exhibit 2.5-3

Number of Housing Units that Could Apply ETV-Verified Portable Technologies for Measuring Lead in Dust

Market Penetration	Number of Pre-1978 Housing Units: Total	Number of Pre-1978 Housing Units: With Young Children (1)
10%	6,600,000	1,100,000
25%	16,500,000	2,600,000

Values rounded to nearest 100,000.
(1) Young children are defined as those less than six years old, an age that HUD uses in its lead-based paint regulations to identify certain actions.

34 Because the ETV Program does not compare technologies, the performance results shown in Exhibit 2.5-2 do not identify the vendor associated with each result and are *not* in the same order as the list of technologies in Exhibit 2.5-1.

35 The estimates shown in Exhibit 2.5-3 are based on data from Table 5 of Jacobs, et al. (2002).

penetration scenarios to estimate the regulatory compliance outcomes shown below. Potential applications of the verified technologies in pre-1978 housing include use in risk assessments, lead hazard screens, clearance testing, testing by potential buyers, investigations of children with elevated blood lead levels, and testing after renovation and remodeling.

Environmental, Health, and Economic Outcomes

The successful identification and control of lead hazards in housing reduces the likelihood of future lead exposures and future cases of lead poisoning (CDC, 2004). Field portable technologies, like those verified by the ETV Program, can rapidly, accurately, and cost-effectively provide information on potential lead hazards, enabling users to quickly decide whether further analysis, evacuation, and/or abatement is warranted. Thus, the data provided by the verified monitors could lead to reduced lead exposures and human health benefits, particularly for children.

Because lead adversely affects children's cognitive and behavioral development, reductions in lead exposure also can have a significant impact on their future productivity and earnings potential (CDC, 2004). In fact, a recent CDC-authored study estimates that two-year old children in 2000 would gain aggregate present value earnings of $110 to $318 billion over two-year old children from the mid-1970's, as a direct result of reduced lead exposure (Grosse et al., 2002).[36] Thus, any reductions in exposure resulting from use of the verified technologies also could yield significant economic benefits in terms of increased earnings.

Regulatory Compliance Outcomes

ETV-verified technologies can be used (in conjunction with other methods for assessing lead hazards) to support lead risk assessments or lead hazard screens at up to 16.5 million of the 66 million pre-1978 housing units, any of which could have significant lead-based paint hazards. Field personnel/assessors can potentially use the ETV-verified technologies to help them quickly and cost-effectively assess the extent of metals contamination at a site. Although screening data might not completely replace laboratory methods during a risk assessment, they can provide immediate feedback on potential health risks associated with the site. They also can permit the development of a focused and cost effective sampling and analysis strategy for the laboratory methods (Battelle, 2004h). Ultimately, however, portable technologies that can completely replace laboratory methods are the most desirable in terms of time and cost savings.

Eventually, NLLAP-accredited organizations or lead inspectors could potentially use the ETV-verified technologies during inspections, risk assessments, lead hazard screens, and clearance testing after abatement.[37] EPA has established the NLLAP to recognize laboratories that demonstrate the ability to accurately analyze paint chip, dust, or soil samples for lead. Federal regulations require that an NLLAP-certified laboratory analyze samples collected during inspections, risk assessments, lead hazard screens, and clearance testing after abatement. State and tribal regulations can be somewhat different, but in most cases will be similar to the federal regulations. Although at present, ETV believes that no organizations or lead inspectors are accredited or in the process of becoming accredited for using the portable technologies, the recent revision to EPA's Laboratory Quality System Requirements (LQSR) (U.S. EPA, 2005h) for laboratories that participate in NLLAP might make it possible or easier for portable laboratories and field service and measurement organizations with portable dust testing technologies to apply for and obtain NLLAP accreditation in the future. The draft LQSR was developed, at least in part, to encourage portable laboratories and field service and measurement organizations to obtain NLLAP accreditation. A pilot program is planned to evaluate how the revised LQSR works in practice. It also is possible that ETV verification could potentially encourage such accreditation in the future, by serving as a source of performance data on the applicable technologies.

36 This estimate was based on reductions in average BLL in children since the late 1970's. Historical biomonitoring data shows that the average BLL in children aged 1 to 5 years has declined between 12 and 15 µg/dL since the late 1970's.

37 One of the goals of the ETV-verification was to assess and compare the results obtained from an NLLAP accredited laboratory with results from ETV-verified technologies (Battelle, 2004h).

Technology Acceptance and Use Outcomes

The results of the ETV testing have been utilized and cited in multiple references, thus expanding the awareness of the technologies and their performance. EPA's EMPACT Program (Environmental Monitoring for Public Access and Community Tracking) promotes approaches to collecting, managing, and communicating environmental information to the public and has cited the ETV reports as a resource for promoting the use of XRF instruments for lead in residential soil testing and residential lead dust testing (U.S. EPA, 2003e; U.S. EPA, 2001c).

Verification data have also helped potential users assess the capabilities of the verified monitors. For example, the National Institute for Occupational Safety and Health (NIOSH), part of the CDC, used the web-posted ETV results to assess whether a verified lead-in-dust analyzer could meet their objectives. CDC/NIOSH eventually decided to purchase a participating vendor's verified technology (Monitoring Technologies International) for research, rather than regulatory compliance, purposes. The participating vendor subsequently uses CDC/NIOSH as a referral for new customers (MTI, 2004). The vendor sees the ETV Program as a tremendous advantage for small businesses (U.S. EPA, 2004a).

Another participating vendor, NITON, cited several advantages to ETV participation. First, end-users have a means of evaluating alternative technologies under clear, established conditions with expert oversight (Shein, 2005). Second, the vendor retains samples from verification testing for use in the future (U.S. EPA, 2004a).

"ETV is a tremendous advantage to a small business; it creates technology awareness and provides a quality, credible referral — that is the greatest thing that a vendor can get from the program." *—Felecia Owen, Vice President of U.S. Operations for Monitoring Technologies International (U.S. EPA, 2004a)*

"The advantage of the ETV Program to a manufacturer is being able to prove the viability of their technology." *—Debbie Schatzlein, NITON LLC (U.S. EPA, 2004a)*

Scientific Advancement Outcomes

On a related note, field XRF analyzers are well established commercially and were previously tested under the ETV Program for a related application of measuring metals including lead in soil. Verification reports evaluating the performance of seven XRFs for the analysis of metals in soil, including lead, were made available in March 1998. Some of the same vendors participating in the more recent ETV verification test participated in the 1998 verification test as well, although the evaluated technologies were not the same. A few months later, in May 1998, EPA's SW-846 Program announced the release of a new method (Method 6200) for using field portable XRFs for measuring metals in soil and sediment, based in part on the 1998 ETV reports (Battelle, 2004h). The release of this EPA method helped standardize and promote the use of XRF systems (Lesnick and Fordham, 2000).

ACRONYMS USED IN THIS CASE STUDY:

AMS Center	ETV's Advanced Monitoring Systems Center	NIOSH	National Institute for Occupational Safety and Health
ASV	anodic stripping voltammetry	NLLAP	National Lead Laboratory Accreditation Program
BLL	blood lead level	ORNL	Oak Ridge National Laboratory
CDC	Centers for Disease Control and Prevention	XRF	X-ray fluorescence
EMPACT Program	EPA's Environmental Monitoring for Public Access and Community Tracking Program	µg/dL	micrograms per deciliter
HUD	Department of Housing and Urban Development	$\mu g/ft^2$	micrograms per square foot
LQSR	Laboratory Quality System Requirements		

2.6 Ambient Ammonia Monitors

The ETV Program's Advanced Monitoring Systems (AMS) Center, operated by Battelle under a cooperative agreement with EPA, has verified the performance of seven ambient ammonia monitors for use at animal feeding operations (AFOs). These monitors may serve as an alternative to the standard method for measuring ambient ammonia, which is time consuming, labor intensive, and not well suited for conducting continuous measurements. Ammonia in the atmosphere contributes to the production of particulate matter, which has significant adverse human health effects. AFOs are regarded as representing the largest single source of ammonia in the United States. EPA has issued an Air Quality Compliance Agreement with the industry to improve ammonia emissions measurements and promote compliance with federal regulations.

Based on the analysis in this case study, the ETV Program estimates that:

- The ETV-verified ambient ammonia monitors can potentially be applied in response to EPA's Voluntary Air Compliance Agreement over the next two years.
- The monitors could potentially be applied in the future at up to 975 large AFOs (out of an estimated potential market of 3,900) to verify their compliance with current or potential future state and federal regulations, and to avoid potential multimillion dollar penalties.
- The monitors can help address the significant research needs identified by the National Academies of Science and others associated with improving ammonia emissions data.
- The monitors can allow researchers to update current ammonia emission estimation methodologies, provide accurate input for computer models, and advise facility owners and regulatory agencies regarding the need for ammonia emission reduction efforts.
- The monitors can assist in the evaluation of the effectiveness of ammonia emission reduction methods, leading to more cost-effective selection of methods.
- The information provided by the monitors ultimately can assist in reduction of ammonia emissions, with associated human health, environmental, and economic benefits.

2.6.1 Environmental, Health, and Regulatory Background

EPA estimates that nationwide ammonia emissions from animal husbandry operations, which include AFOs, totaled 2,200 thousand metric tons in 2002. Ammonia is produced as a by-product of the microbial decomposition of the organic nitrogen compounds in manure and urine (U.S. EPA, 2004f). Although EPA's emission estimation methodologies for ammonia are being refined, this source is regarded as representing the largest single source of ammonia in the United States.

Ammonia is volatile and easily emitted from animal wastes. Anaerobic lagoons and waste storage ponds are commonly used to manage animal wastes at AFOs and are significant sources of ammonia and other nitrogen compound releases. EPA estimates that a typical five-acre hog waste lagoon can release between 15 and 30 tons of ammonia into the air each year (U.S. EPA, 2004g).

Approximately half of the ammonia that is released into the atmosphere from the surface of ponds or lagoons falls in rain or fog to the surface within 50 miles of these sources. The remainder is transformed into particulate matter through rapid conversion to ammonium aerosol by reaction with acidic species, such as nitric acid and sulfuric acid; such particles can travel up to 250 miles (U.S. EPA, 2004g). Through this conversion process, ammonia contributes to the production of particulate matter, specifically the fine particulates known as $PM_{2.5}$. Particulate matter in the atmosphere produces regional haze and decreased visibility and has been linked to health effects such as increased rates of cardiovascular disease and mortality. Both ammonia gas and ammonium aerosol can enter natural water systems through deposition from the atmosphere (Battelle, 2004i). In water, ammonia can contribute to eutrophication of surface waters and can result in fish kills and reduced biodiversity.

Ammonia also can present adverse health effects to workers and animals at AFOs. The Occupational Safety and Health Administration (OSHA) has established a permissible exposure limit of 50 parts per million (ppm) (time weighted average over an 8-hour period) for ammonia. Ammonia is considered a human toxin and can be quickly absorbed in the human upper airways, causing damage to the upper airway epithelium (U.S. EPA, 2004g). Like many compounds, the human health effects of ammonia vary with concentration. At concentrations of less than 100 ppm, exposure can cause skin and respiratory membrane irritation (U.S. EPA, 2004g). More severe health effects can be experienced, however, as concentrations rise, including lower lung inflammation, pulmonary edema, and chemical burns to the eyes and skin (U.S. EPA, 2004g). Ammonia can be fatal at very high concentration exposures of around 500 ppm. Chronic exposures to airborne ammonia also can affect the course of infectious disease and influence livestock growth (U.S. EPA, 2004g). Exposure to both dust and ammonia simultaneously, which is common in livestock operations, has a synergistic effect and increases the risks of respiratory dysfunction more than exposure to ammonia alone (Donham et al., 2002).

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Emergency Planning and Community Right-to-Know Act (EPCRA) require reporting of large ammonia releases of 100 pounds per day or more. These limits are applicable to AFOs, as well as many other types of facilities. Lunder et al (2004) recently recommended that ammonia be evaluated for possible addition to the Clean Air Act list of hazardous air pollutants, which would reduce the regulation limit for a single facility to 10 tons per year. The recently promulgated Consolidated Emissions Reporting Rule (CERR) now requires that states include ammonia and $PM_{2.5}$ in point source reporting beginning with the 2002 inventory year (Battelle, 2004i).

State-level regulation of emissions from AFOs is becoming more common, but there is uncertainty regarding the applicability of federal Clean Air Act, CERCLA, and EPCRA requirements to AFOs. Ambiguity regarding the magnitude of ammonia emissions is one of the contributing factors in the difficulty of determining whether or not a particular AFO is in compliance with these federal laws (70 FR 4958). Current estimates of ammonia emissions from AFOs, including those of U.S. EPA (2004f), apply generic emissions factors (i.e., pounds of ammonia per animal per day) to estimates of livestock population. The National Academies of Science identified these estimation methods as generally inadequate and recommended improvement in measurement protocols for ammonia (NAS, 2003).

To address the uncertainties associated with estimates of AFO emissions and the applicability of federal regulations, EPA has announced a voluntary air quality compliance agreement with animal producers. Under the compliance agreement, producers who sign up to participate agree to fund a monitoring study at AFOs. U.S. EPA expects each selected AFO to be monitored for two years to obtain credible data. Within 18 months of completing the monitoring study under the compliance agreement, EPA will develop emissions estimating methods based on monitoring results and other available data to assist AFOs in estimating annual emissions. The participating AFOs will then apply for applicable air permits and submit required CERCLA or EPCRA notification reports (70 FR 4958). As of August 15, 2005, more than 2,000 AFOs from over 37 states had signed agreements (U.S. EPA, 2005i).

2.6.2 Technology Description

To address the concerns of the National Academies and others, the ETV Program decided to verify the performance of ambient ammonia monitors for use at AFOs. The standard method for measuring ambient ammonia, EPA Compendium Method IO 4.2: Determination of Reactive Acidic and Basic Gases and Strong Acidity of Atmospheric Fine Particles (<2.5 μm), is widely used for sampling acidic and basic gases in the atmosphere. The method, however, is time consuming, labor intensive, and not well suited for conducting continuous measurements (Battelle, 2004i, 2004j).

Ambient ammonia monitors utilize a wide range of analytical methods. These methods include direct detection by spectroscopic techniques or indirect detection of ammonia using selective membrane permeation with conductivity detection, catalytic conversion with chemiluminescence detection, treatment with a chemical dopant followed by ion mobility detection, or other techniques. Ambient ammonia monitors also can provide specialized features that can be valuable in specific uses, such as long-term monitoring or determining ammonia fluxes and emission rates. For example, monitors that collect high-speed (sub-second response time) ammonia concentration data and three-dimensional wind speed/direction data simultaneously can be used to determine ammonia flux. Alternatively, open-path monitors can be used to calculate emission rates from AFOs, since these monitors measure the average ammonia concentration over a 1 to 100 meter path. Some monitors also are suitable for long-term monitoring, since they can be operated without user intervention for weeks at a time (Battelle, 2004i, 2004j).

To date, the ETV Program has verified the performance of seven ambient ammonia monitors. These monitors were verified in collaboration with the U.S. Department of Agriculture (USDA). Exhibit 2.6-1 contains a short description of the monitors that have been verified by the ETV Program.

The verification test was conducted in two phases, each at separate AFOs. Not all technologies were evaluated in both phases. Phase I was conducted at a swine finishing farm and

EXHIBIT 2.6-1

ETV-VERIFIED AMBIENT AMMONIA MONITORS

Technology Name	Description
Aerodyne Research, Inc. QC-TILDAS	An infrared laser spectrometer, based on pulsed quantum cascade laser technology; continuous.
Bruker Daltonics OPAG 22 Open-Path Gas Analyzer	A broadband, open-path, Fourier transform infrared spectrometer for remote sensing.
Molecular Analytics IonPro-IMS Ammonia Analyzer	An ion mobility spectrometer; continuous.
Omnisens SA TGA310 Ammonia Analyzer	A trace gas analyzer that uses photoacoustic spectrometer; continuous.
Ammonia Analyzer	A resonant photoacoustic spectrometer with a line-tunable carbon dioxide (CO2) laser; continuous.
Mechatronics Instruments BV AiRRmonia Ammonia Analyzer	A single-point monitor composed of a membrane diffusion sampler, a detector block with a diffusion membrane, and two conductivity cells; continuous.
Thermo Electron Corp. Model 17C Ammonia Analyzer	A chemiluminescence analyzer that uses nitric oxide (NO) and ozone (O3) reactions; time-averaged.

Sources: Battelle, 2004a, 2004b, 2004c, 2004d, 2004e, 2004f, 2004g.

An Ambient Ammonia Monitor at an AFO

Phase II was conducted at a cattle feedlot. These sites were selected to provide realistic testing conditions and were expected to exhibit a wide range of ammonia concentrations during the test periods. The sites also were expected to allow evaluation of potential interferences with other gas-phase chemicals, such as hydrogen sulfide, common to AFOs. The verification test evaluated relative accuracy, linearity, precision, response time, calibration and baseline drift, interference effects, comparability, ease of use, and data completeness for each technology. Exhibit 2.6-2 summarizes some of the performance data for the individual verified technologies. Because the ETV Program does not compare technologies, the performance results shown in Exhibit 2.6-2 do not identify the vendor associated with each result and are *not* in the same order as the list of technologies in Exhibit 2.6-1.

The ETV Program found that the average relative accuracy for the monitors ranged from 2.2% to 44%. A result of 0% indicates perfect accuracy relative to the tested ammonia concentration. The measured relative precision ranged from 0.2% to 2.5%. A result of 0% indicates perfect precision. The measured response times to a sudden change in ammonia concentration ranged from less than one second to more than one hour. The ETV Program used

Exhibit 2.6-2

Performance of ETV-Verified Ambient Ammonia Monitors[38]

Vendor	Testing	Average relative accuracy	Relative precision	Response time (95%)	Linearity (slope, Intercept, r^2)	Comparability (slope, intercept, r^2)
A	Phase I & Phase II	3.7 to 10.5%	0.3%	3 to 76 min	Slope: 0.90 to 1.03 Intercept: -24 to -0.6 r^2: 1.000	Slope: 0.86 to 1.20 Intercept: -0.5 to 16 r^2: 0.984 to 0.990
B	Phase I & Phase II	2.4 to 34%	0.7 to 2.1%	8 to 20 min	Slope: 1.02 to 1.28 Intercept: -2.4 to 136 r^2: 0.9957 to 0.9999	Slope: 0.41 to 1.18 Intercept: -1.4 to 58 r^2: 0.538 to 0.9755
C	Phase I & Phase II	10 to 44%	0.2 to 1.3%	1 to 32 min	Slope: 0.716 to 1.25 Intercept: -58.5 to 167 r^2: 0.9854 to 0.9997	Slope: 0.646 to 1.83 Intercept: -6.7 to 21.6 r^2: 0.9794 to 0.9842
D	Phase II	2.2%	0.9%	2 to 2.6 min	Slope: 0.966 Intercept: 15.9 r^2: 1.000	Slope: 1.15 Intercept: -4.1 r^2: 0.994
E	Phase II	18.3%	1.0%	2.5 to 17 mi	Slope: 0.815 Intercept: 1.08 r^2: 1.000	Slope: 1.565 Intercept: -16.5 r^2: 0.994
F	Phase II	26%	1.8%	4 to 14 sec rise	Slope: 0.583 Intercept: 24.9 r^2: 0.9144	Not reported
G	Phase I & Phase II	4.7 to 10%	1.9 to 2.5	0.8 to 66 sec	Slope: 0.840 to 0.962 Intercept: -8.8 to 35 r^2: 0.9989 to 0.9998	Slope: 0.984 to 1.09 Intercept: -9.5 to 14.4 r^2: 0.9943 to 0.9982

Sources: Battelle, 2004a, 2004b, 2004c, 2004d, 2004e, 2004f, 2004g

38 Because the ETV Program does not compare technologies, the performance results shown in Exhibit 2.6-2 do not identify the vendor associated with each result and are *not* in the same order as the list of technologies in Exhibit 2.6-1.

linear regression analysis to evaluate (1) linearity of the monitors over the range of ammonia concentrations tested, and (2) comparability of the monitors to the standard test method. For linearity, the slope values range from 0.583 to 1.28; the intercept values range from -59 to 167 parts per billion (ppb); and the r^2 values range from 0.914 to 1.000. For comparability, the slope values range from 0.41 to 1.83; the intercept values range from -17 to 58 ppb; and the r^2 values range from 0.538 to 0.998.[39] The monitors vary in price from less than $30,000 to more than $100,000 (Battelle, 2004a, 2004b, 2004c, 2004d, 2004e, 2004f, 2004g).

2.6.3 Outcomes

The potential market for the ETV-verified ambient ammonia monitors includes AFOs. EPA estimates there are approximately 450,000 AFOs in the U.S. (U.S. EPA, 2004h). Any of these facilities could apply the ETV-verified ambient ammonia monitors to measure their emissions. Some reasons for monitoring could include the factors discussed above in Section 2.6.1, such as (1) to better quantify emissions or concentrations which are at or near federal regulatory limits; (2) to comply with state-level regulation; or (3) to comply with possible future regulations or monitoring programs.

Given the limitations of current estimates of ammonia emissions, quantitative data are not available to identify the population of facilities that emit ammonia above certain thresholds. However, larger facilities are more likely to have higher ammonia emissions, be subject to regulation (either present regulation or possible future monitoring requirements), and, therefore, be more likely to implement monitoring technologies. To estimate the population of "larger" facilities, the ETV program adopted definitions from EPA's water program. In the background document for its AFO effluent guideline regulations, U.S. EPA (2002d) estimated there were 3,900 large AFOs and 9,900 medium AFOs. Continuous onsite monitoring might not be required for all sites and, if monitoring were to be required, there would have to be adequately trained staff and quality assurance/data reporting provisions. Therefore, the ETV Program has restricted its estimate of the total potential market for the ETV-verified monitors to the 3,900 large facilities only.[40] This estimate does not represent the total population that will conduct monitoring using the ETV technologies. It represents an estimate of the population that could implement, or benefit from, the verified technologies (e.g., the total potential market), given the above assumptions.

Because the ETV Program does not have access to a comprehensive set of sales data for the ETV-verified monitors, ETV used two market penetration scenarios, 10% and 25% of the total potential market, to estimate the number of facilities that could potentially apply the technologies, as shown in Exhibit 2.6-3.

Environmental, Health, and Economic Outcomes

It is anticipated that accurate ammonia measurement data and identification of effective reduction methods ultimately will result in emissions reductions. Reductions in ammonia emissions carry significant benefits to the communities immediately surrounding AFOs and also on regional and national scales. As discussed above, ammonia can adversely impact human health and the environment through the

Exhibit 2.6-3

Number of Facilities that Could Apply ETV-Verified Ambient Ammonia Monitors

Market Penetration	Number of Facilities
10%	390
25%	975

39 Slope and intercept are measures of the relationship between analyzer response and the gas standard or 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 the data fit a linear relationship. Values of r^2 range from zero to one, with higher values indicating a better fit. Thus, a higher r^2 value indicates a higher linearity over the range of concentrations tested and higher comparability to the standard test method.

40 This may be a conservative (low) estimate because it includes only large AFOs, as defined in U.S. EPA (2002d). Other users of the ETV-verified technologies might include facilities other than AFOs that emit ammonia, research institutions, and regulatory agencies.

> "A 10% reduction in livestock ammonia emissions can lead to over $4 billion annually in particulate-related health benefits."
> —*McCubbin et al. (2002)*

formation of fine particulate matter. This pollutant appears to affect certain subpopulations (e.g., children, the elderly, and those with pre-existing cardiopulmonary problems) more than others. EPA estimates that the reduction of ambient particulate matter concentrations achieved under current regulations results in the avoidance of premature mortality. EPA has estimated the economic value of this human health benefit at $100 billion per year. Additional benefits, such as reducing illness and minimizing the number of lost workdays and the consequences of restricted activity, could have an economic value of around $10 billion per year (U.S. EPA, 1999a).

Reducing ammonia from AFOs would have economic value in addition to that achieved by current regulations. McCubbin et al. (2002) provide a specific estimate of this potential economic value (see quote above). This estimate includes the value of premature mortality only. Other benefits that were not included, such as reduced hospital visits, work time missed, improved quality of life, and increased property value, would be expected to increase the overall benefit of ammonia emission reduction (Battelle, 2004i, 2004j).

Regulatory Compliance Outcomes

With over 2,000 signed agreements from AFOs located around the country, EPA anticipates that a number of facilities will be selected for inclusion in a monitoring study under the Air Quality Compliance Agreement (U.S. EPA, 2005i, 2005j). The study protocol identifies that ammonia should be measured using chemiluminescence or photoacoustic infrared techniques for mechanically ventilated buildings. It identifies open-path Fourier transform infrared (FTIR) and ultraviolet differential optical absorption spectroscopy (UV-DOAS) technologies for uses in measuring ammonia emissions from naturally ventilated buildings, open manure piles, and lagoons (70 FR 4958). The ETV-verified monitors include examples of these technologies. EPA expects the participating facilities will use a variety of monitor types. Some, but not all, of the types of monitors likely to be used in the monitoring study were evaluated in the ETV verification program (Harris, 2005).

As ammonia emission rates are better defined by the results of the Compliance Agreement's monitoring program, it is possible that additional facilities might conduct monitoring to verify their compliance with the federal regulations identified in Section 2.6.1. Facilities also might conduct monitoring to comply with state regulations. Without measurement data, facilities run the risk of violating federal statues without their knowledge, leaving them vulnerable to federal and civil lawsuits that can carry multi-million dollar penalties. For example, enforcement of CERCLA, EPCRA, the CAA, and other statutes in a case against a large Midwestern meatpacker resulted in a settlement including approximately $10 million for environmental improvements and a $4.1 million civil penalty (U.S. DOJ, 2001).

Scientific Advancement Outcomes

The availability of ammonia monitor performance verification data is expected to promote the growth in the number and quality of research activities in the area of agricultural air quality, especially those research areas recommended by the National Academies. These research areas include ammonia measurement campaigns at or near AFOs, accurately quantifying ammonia emission rates, and evaluating and implementing control technologies, among others (NAS, 2003). Improved AFO ammonia measurement techniques are expected to provide benefits such as the following:

- *Aiding Research and Reducing Uncertainties.* Ammonia monitoring data, such as that provided by the ETV-verified technologies, will assist agricultural air quality researchers in updating current ammonia emission estimation methodologies, providing accurate input or field verification data for computer models, and advising owners and regulatory agencies regarding the need for ammonia emission reduction efforts (Battelle, 2004i). Addressing these research needs will help resolve the significant uncertainties regarding the characterization of ammonia emissions from AFOs. In turn, this improved characterization will address uncertainties regarding the formation of particulate matter, health outcomes, and health effects on susceptible subpopulations.

- *Evaluating Reduction Efforts.* The National Academies recommended application of measures to reduce ammonia emissions at AFOs (see quote at right). More accurate ammonia measurement data could greatly improve the ability to evaluate the effectiveness of these measures.

> "Best management practices aimed at mitigating AFO emissions should continue to be improved and applied as new information is developed on the character, amount, and dispersion of these air emissions, and on their health and environmental effects." —*The National Academies of Science (NAS, 2003)*

Acronyms used in this case study:

AFO	Animal Feeding Operation	FTIR	Fourier transform infrared
AMS Center	ETV's Advanced Monitoring Systems Center	OSHA	Occupational Safety and Health Administration
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act	ppm	parts per million
CERR	Consolidated Emissions Reporting Rule	USDA	U.S. Department of Agriculture
EPCRA	Emergency Planning and Community Right-to-Know Act	UV-DOAS	ultraviolet differential optical absorption spectroscopy

3.
Water Technology Case Studies

3.1 Arsenic Drinking Water Treatment Technologies

The ETV Program's Drinking Water Systems (DWS) Center, operated by NSF International under a cooperative agreement with EPA, has verified the performance of eight technologies for removing arsenic from drinking water. These technologies are easily transportable, package systems designed for small drinking water systems. Arsenic is a known carcinogen with additional, non-cancer human health effects. To protect the public from the adverse health effects of arsenic, EPA recently lowered the drinking water standard for arsenic to 10 parts per billion (ppb). As a result, several thousand small drinking water systems will need to install arsenic treatment technologies like those verified by the ETV Program.

Based on the analysis in this case study, the ETV Program estimates that:

- The ETV-verified arsenic drinking water treatment technologies can potentially assist up to 980 small drinking water systems (out of a potential market of 3,900) in complying with the new arsenic standard.
- The technologies could prevent 1.3 to 4.8 cases of lung and bladder cancer and 0.7 to 2.6 deaths from these cancers per year, assuming 390 to 980 small drinking water systems apply the technologies. The technologies can potentially prevent other negative human health effects, including other types of cancer.
- The technologies could result in economic benefits of approximately $4.8 million to $17.1 million[41] per year due to the prevention of the above cases of lung and bladder cancer.

Verification also has increased the awareness of the ETV-verified arsenic drinking water technologies and their benefits among state regulatory agencies and potential users. The following benefits have been or can potentially 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 at least one vendor has reported this result. The State of Utah's drinking water regulations specifically identify the ETV Program as a source of performance verification data.
- Assuming 390 to 980 systems use ETV data to reduce pilot testing requirements, these systems can potentially save approximately $800,000 to more than $14 million in pilot testing costs, depending on the degree to which the reduction in requirements leads to cost savings.
- The reduction in pilot testing length also could lead to systems achieving the above health benefits sooner than would otherwise be possible.

41 In May 1999 dollars.

3.1.1 Environmental, Health, and Regulatory Background

Arsenic occurs naturally in rocks, soil, water, air, plants, and animals. It can be released into water, including drinking water, through natural processes, such as erosion, or through human actions, including agricultural applications (fungicides or rodenticides), mining, or disposal of arsenic-laden consumer products (wood preservative, paints, dyes, soaps, and semi-conductors). Studies have linked long-term exposure to arsenic at various levels in drinking water to cancer of the bladder, lungs, skin, kidney, nasal passages, liver, and prostate. Non-cancer effects of ingesting arsenic include cardiovascular, pulmonary, immunological, neurological, and endocrine (e.g., diabetes) effects (U.S. EPA, 2001h).

In 1975, EPA set its drinking water standard for arsenic at 50 ppb, based on the level recommended by the Public Health Service in 1942. The 50 ppb standard was based on health effects from short-term exposure to high doses of arsenic (U.S. EPA, 2001h). A March 1999 report by the National Academies of Science (NAS), however, concluded that the drinking water standard of 50 ppb of arsenic did not achieve EPA's goal of protecting public health. The NAS recommended the standard be lowered as soon as possible (NAS, 2001).

Based in part on the NAS recommendation and to protect consumers against the effects of long-term, chronic exposure to arsenic in drinking water, EPA set a new drinking water standard for arsenic at 10 ppb on January 22, 2001 (U.S. EPA, 2001h). All public water systems must comply with the 10 ppb standard beginning January 23, 2006 (66 FR 6976). The new standard will apply to about 74,000 water systems, approximately five percent of which will have to take actions, such as installing treatment equipment, to meet the new standard. Of the systems that will need to take action to meet the new standard, EPA estimates that 97% (or about 3,900) are small systems that serve fewer than 10,000 people each (U.S. EPA, 2001h). The ETV-verified technologies are designed for use by these small systems.

3.1.2 Technology Description

Since most of the systems that will need to take some type of action to meet the new arsenic standard are small, the ETV Program has focused on verifying easily transportable drinking water treatment technologies that are designed for small system applications (U.S. EPA, 2004j).[42] As of August 2005, the ETV Program had verified eight such arsenic drinking water treatment technologies. The verified technologies include examples of three different technology classes as follows:

- Coagulation/Filtration is a traditional treatment process that adds a chemical coagulant (typically ferric sulfate or ferric chloride) to contaminated water. The coagulant modifies the physical or chemical properties of dissolved or suspended contaminants so that they will settle out of solution by gravity or can be removed by filtration (U.S. EPA, 2000e). EPA has designated coagulation/filtration a Best Available Technology (BAT) for removal of arsenic (66 FR 6976).
- Adsorptive Media processes pass contaminated water through a bed of media on which the contaminants are adsorbed. EPA has designated one type of adsorptive media, activated alumina, a BAT for removal of arsenic (U.S. EPA, 2000e; 66 FR 6976). More recently developed adsorptive media, however, also have proven effective for arsenic removal.
- Reverse Osmosis is a treatment process traditionally used for the desalination of brackish water and sea water. Reverse osmosis produces nearly pure water by maintaining a pressure gradient across a membrane with very small pores (U.S. EPA, 2000e). EPA has designated reverse osmosis a BAT for removal of arsenic (66 FR 6976).

42 Researchers from EPA NRMRL are also working in partnership with municipalities and equipment producers to demonstrate the effectiveness of a variety of treatment technologies at reducing arsenic levels in local drinking water at 40 locations throughout the United States. These demonstrations include some of the ETV-verified technologies (U.S. EPA, 2005o).

Exhibit 3.1-1 identifies the ETV-verified technologies and provides a description of each. The ETV Program conducted verification testing for four of the technologies at the Park City Spiro Tunnel Water Filtration Plant on ground water from an abandoned silver mine, representing one of the sources of drinking water for the City of Park City, Utah. The ETV Program verified the other four technologies in Alaska, Pennsylvania, or California, using groundwater from these areas. The tests lasted between two weeks and six months. Each of the tests measured water quality results and observed system operation and maintenance. Most of the tests also measured consumables and waste generation (NSF, 2004a, 2004b, 2004c, 2004d, 2001a, 2001b, 2001c, 2001d).

The ETV Program verified that most of the technologies reduced arsenic to 5 ppb or less, and many of them reduced arsenic to the minimum detection limit of 1 to 2 ppb. Average removal efficiencies ranged from 50% to almost 95% (NSF, 2004a, 2004b, 2004c, 2004d, 2001a, 2001b, 2001c, 2001d). All of the technologies verified by ETV are designed for small system applications.

3.1.3 Outcomes

Small drinking water systems that will have to install or modify treatment processes to comply with the new arsenic standard are the most likely market for the ETV-verified technologies. Accordingly, the ETV Program used data from the Economic Analysis (EA) for the new arsenic standard to estimate the total potential market for the technologies (U.S. EPA, 2000f). The net result of this analysis, which is described in more detail in Appendix E, is a total potential market of 3,900 small systems. It is a conservative (low) estimate of the total potential market, because the technologies also can be scaled up for use by larger systems.

EXHIBIT 3.1-1

ETV-VERIFIED ARSENIC DRINKING WATER TREATMENT TECHNOLOGIES

Technology Name	Description
Kinetico Incorporated Macrolite® Coagulation and Filtration System, Model CPS100CPT	A coagulation/filtration technology that utilizes sodum hypochlorite and ferric chloride and a proprietary ceramic filtration material specifically. The test unit is self-contained, skid-mounted and transportable by truck.
Watermark Technologies, LLC eVOX® Model 5	A coagulation/filtration technology that uses sodum hypochlorite and ferric chloride to produce an insoluble large particle hydroxide precipitate that can be removed using a simple non-proprietary media filter or clarification. The test unit is self-contained, skid-mounted and transportable by truck.
Delta Industrial Services, Inc. CampWater Porta-5 System	A coagulation/filtration technology that uses ozone to oxidize naturally occurring iron to form a ferric hydroxide solid, which is filtered directly without additional flocculation, solid separation, or clarification. The system is transportable and is designed to fit into a standard pickup truck or small aircraft.
Kinetico Inc. and Alcan Chemicals Para-Flo™ PF60 Model AA08AS with Actiguard AAFS50	An adsorptive media technology that uses a proprietary granular iron-enhanced activated alumina media. The treatment unit is suitable for very small to small communities and is scaled up to serve larger communities (see Note 2).
ADI Pilot Test Unit No. 2002-09 with MEDIA G2® (see Note 1)	An adsorptive media technology that uses a proprietary media consisting of an inorganic, natural substrate upon which iron (ferric hydroxide) is chemically bonded. The treatment unit is intended for very small to medium size systems (see Note 2).
Watts Premier M-Series M-15,000 Reverse Osmosis Treatment System	Reverse osmosis technologies designed to reject dissolved salts and ionic solids, such as arsenic, sodium, chloride, and other dissolved materials from drinking water.
KOCH Membrane Systems TFC® —ULP4 Reverse Osmosis Membrane Module	
Hydranautics ESPA2-4040 Reverse Osmosis Membrane Element Module	

Note 1: Phase 1 verification complete; Phase 2 verification is expected in 2005.
Note 2: 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/vcenter2-14.html
Sources: NSF, 2001a, 2001b, 2001c, 2001d, 2004a, 2004b, 2004c, 2004d.

Exhibit 3.1–2

Number of Systems that Could Apply ETV-Verified Arsenic Drinking Water Treatment Technologies

Market Penetration	Number of Systems (1)	Population Served (number of people) (2)
10%	390	400,000
25%	980	1,100,000

(1) Rounded to nearest 10
(2) Rounded to nearest 100,000

Because the ETV Program does not have access to a comprehensive set of sales data for the ETV-verified technologies, the ETV Program used two market penetration scenarios, 10% and 25% of the total potential market, to estimate potential health, economic, and financial outcomes.

Exhibit 3.1-2 lists the number of systems that could apply the ETV-verified technologies based on these market penetration scenarios, as well as the populations that could be served. The ETV Program also used these market penetration scenarios to estimate the environmental, health, economic, and regulatory compliance outcomes shown below.

Environmental and Health Outcomes

A number of human health benefits can result from removing arsenic from drinking water, including the prevention of bladder and lung cancer.

Exhibit 3.1–3

Estimated Number of Cancer Cases and Cancer Deaths per Year Potentially Prevented by ETV-Verified Arsenic Drinking Water Treatment Technologies

Market Penetration	Total Cases Prevented per Year	Deaths Prevented per Year
	Lower Bound	
10%	1.3	0.7
25%	3.2	1.8
	Upper Bound	
10%	1.9	1.0
25%	4.8	2.6

Values rounded to nearest 0.1

The ETV Program estimated the number of cases of lung and bladder cancer that could be avoided by using ETV-verified technologies (see Exhibit 3.1-3) based on data from the EA for the new arsenic standard and the market penetration scenarios described in the previous section (U.S. EPA, 2000f).

Exhibit 3.1-3 includes upper- and lower-bound estimates because the EA presents both upper- and lower-bound data.[43] Appendix E presents the assumptions used in this analysis in greater detail.

Two of the ETV-verified arsenic drinking water treatment technologies

43 These estimates (both upper- and lower-bound) are conservative (low) because they are based on the conservative (low) estimates of the market for ETV-verified technologies. In addition, many of the ETV-verified technologies consistently reduce arsenic to levels well below the new standard and, thus, could provide even greater benefits.

In addition to the prevention of lung and bladder cancer quantified above, the ETV-verified technologies can prevent other negative human health outcomes associated with exposure to arsenic. These include the following: skin cancer, kidney cancer, cancer of the nasal passages, liver cancer, prostate cancer, cardiovascular effects, pulmonary effects, immunological effects, neurological effects, endocrine effects, and reproductive and developmental effects (U.S. EPA, 2000f). Quantitative data are not available to estimate these other human health outcomes.

The estimates in Exhibit 3.1-3 are based on the assumption that only small systems will apply the ETV-verified technologies. This assumption is conservative because the technologies can be scaled up for use by larger systems. If large systems are considered, the estimated benefits would increase to 3.7 to 5.6 cases and 2.1 to 3.0 deaths prevented per year at 10% market penetration, with associated economic benefits.

Financial and Economic Outcomes

In addition to personal and societal impacts, cancer prevention also has an economic impact. The ETV Program estimated the economic impacts associated with the human health outcomes shown in Exhibit 3.1-3 based on the economic data (e.g., per avoided case of non-fatal cancer) provided in EPA's EA for the new arsenic standard (U.S. EPA, 2000f).

Exhibit 3.1-4 presents these estimates.[44] Appendix E presents the assumptions used in this analysis in greater detail. Additional economic benefits could result from the prevention of the other, non-quantifiable human health outcomes discussed above and by including potential impacts from large system applications.

EXHIBIT 3.1-4

ESTIMATED POTENTIAL ECONOMIC BENEFITS OF LUNG AND BLADDER CANCER PREVENTION BY ETV-VERIFIED ARSENIC DRINKING WATER TREATMENT TECHNOLOGIES

	Million dollars per Year	
Market Penetration	**Lower Bound**	**Upper Bound**
10%	4.8	6.8
25%	12.1	17.1

Values rounded to nearest $100,000

Regulatory Compliance and Technology Acceptance 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 need to be tested before plans can be approved for their use. It also mentions how 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). Citations of this nature 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 one vendor, who reports that ETV data significantly reduced the amount of pilot testing needed for state drinking water agency approval (Latimer, 2004; U.S. EPA, 2004j). In addition, the results of a 2003 Association of State Drinking Water Administrators (ASDWA) survey indicate that a majority of states responding use ETV verification data to reduce the frequency and/or length of site-specific pilot tests. Specifically, 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 this report does not

44 These estimates are conservative (low) because: (1) they are based on the conservative (low) estimates of the number of cases prevented, and (2) they are in May 1999 dollars.

specifically mention the applications described in this case study, it is reasonable to assume that ETV verification has the potential to reduce pilot study costs for arsenic drinking water treatment systems.

To estimate potential national pilot study cost savings, the ETV Program assumed an individual pilot study cost of $20,000 (Adams, 2005). To bound the estimates, the ETV Program developed two scenarios. The lower bound assumes that 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 that assumes ETV verification eliminates the need for pilot studies for 75% of systems installing ETV-verified technologies (or reduces pilot study costs by 75%).

Exhibit 3.1-5 presents the estimated pilot testing cost savings depending on market penetration scenario.[45] Appendix E presents the assumptions used in this analysis in greater detail.

Exhibit 3.1-5

Estimated Potential Pilot Testing Savings for ETV-Verified Arsenic Drinking Water Treatment Technologies

Market Penetration	$ Millions Lower Bound	Upper Bound
10%	0.8	5.9
25%	2.0	14.7

Values rounded to nearest $100,000

In addition to potential cost savings, reducing the length of site-specific pilot tests provides an opportunity for water systems to meet compliance with the new arsenic standard more quickly. Shorter pilot tests potentially could result in systems achieving health benefits sooner than would otherwise be possible.

Acronyms used in this case study:

ASDWA	Association of State Drinking Water Administrators	NAS	National Academies of Science
DWS Center	ETV's Drinking Water Systems Center	ppb	parts per billion
EA	Economic Analysis		

45 These estimates (both upper- and lower-bound) are conservative (low) because they are based on the conservative (low) estimates of the market for ETV-verified technologies.

3.2 Residential Nutrient Reduction Technologies

The ETV Program's Water Quality Protection (WQP) Center, operated by NSF International under a cooperative agreement with EPA, has verified the performance of six technologies for reducing the nutrient nitrogen in domestic wastewater discharged from single-family homes. These technologies are designed for homes that rely on onsite wastewater disposal, and remove total nitrogen from the wastewater by biological nitrification and denitrification. Most onsite systems consist of septic tanks with soil absorption systems, which are not designed to reduce nitrogen. Thus, unlike traditional septic systems, the verified technologies are designed to reduce nitrogen loading to ground and surface waters. While nitrogen is an essential nutrient for plants, excessive levels in surface waters can have detrimental ecological effects, such as algae formation leading to oxygen depletion. EPA has also established drinking water quality standards for nitrogen species such as nitrate and nitrite because of human health concerns.

Based on the analysis in this case study, the ETV Program estimates that:

- The ETV-verified residential nutrient reduction technologies could be applied at approximately 260,000 to 640,000 homes nationwide where nitrogen could be a threat to ground water or surface water (out of an estimated potential market of 2.6 million homes).[46]
- The technologies could reduce nitrogen loading to ground water by 1,300 to 4,000 tons per year (assuming they are applied by 260,000 to 640,000 homes), with associated benefits of improved compliance with drinking water standards and reduction of environmental problems associated with nutrient loading.

The technologies also can address public policy concerns associated with nitrogen and nutrient releases to ground and surface waters from non-point sources such as septic systems. Other benefits include the establishment of a well-accepted protocol that has advanced efforts to standardize protocols across programs. At least four states (North Carolina, Massachusetts, Pennsylvania, and Florida) are currently using, or might use in the future, ETV protocols in the evaluation of alternative technologies for the management of septic systems or discharge of nitrogen.

3.2.1 Environmental, Health, and Regulatory Background

EPA and states recognize septic systems as major sources of ground water contamination. States

46 Note that these estimates are based on a rough assumption about the percent of homes with septic systems that represent a threat to ground water or surface water, as discussed in Section 3.2.3.

Exhibit 3.2-1

Major Sources of Ground Water Contamination in the United States[47]

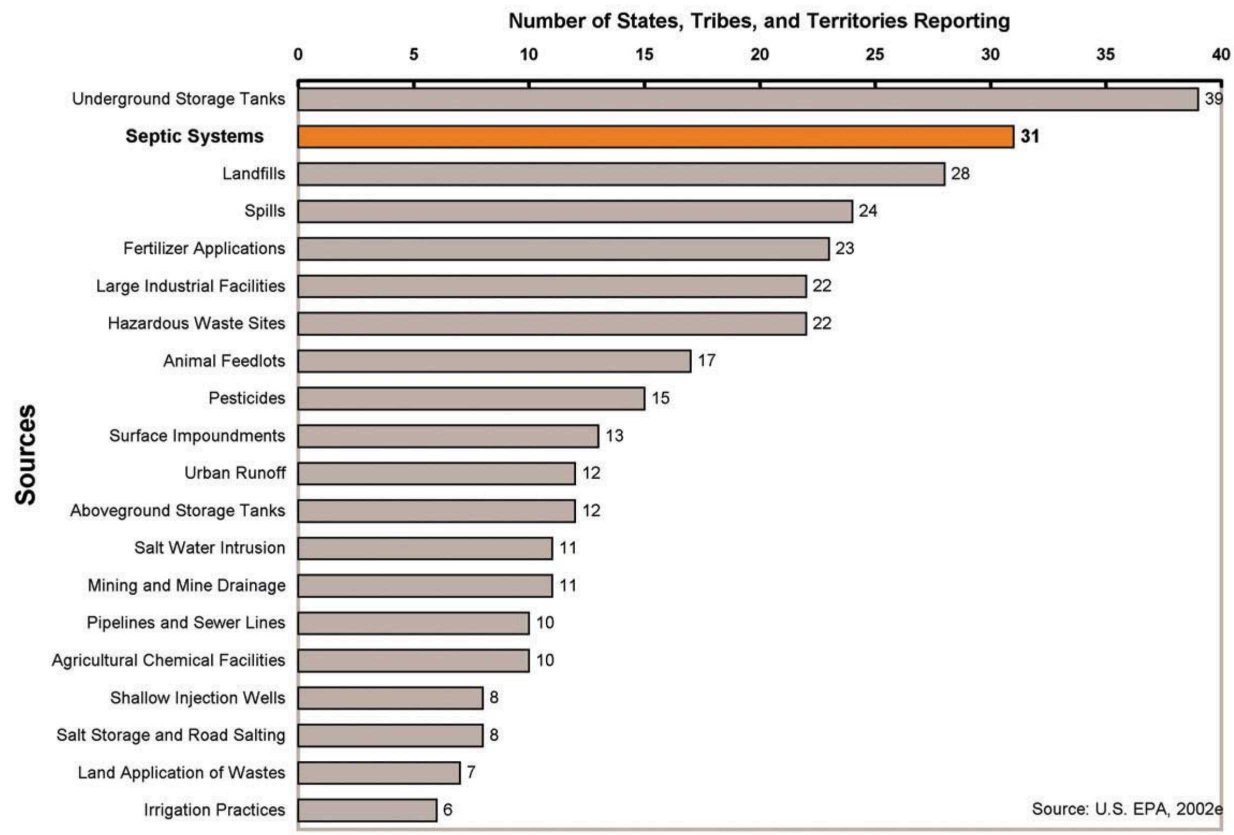


Exhibit 3.2-2

Leading Pollutants in Impaired Lakes in the United States

47 This figure represents contamination from all sources and includes both nitrogen species and other pollutants not evaluated through the ETV verification testing.

have identified septic systems as the second most frequently reported contaminant source, as shown in Exhibit 3.2-1 (U.S. EPA, 2002e). EPA has recently reiterated this concern (U.S. EPA, 2005k). The specific contaminants causing these concerns are not comprehensively identified, but typical pollutants from septic systems include suspended solids, biodegradable organics, bacteria and other pathogens, nitrogen and phosphorus, and other inorganic and organic chemicals (U.S. EPA, 2003f).

Nitrogen compounds also present concerns to the nation's surface water. EPA and states have identified nutrients, which include both nitrogen and phosphorus, as the leading pollutant in lakes, reservoirs, and ponds, as shown in Exhibit 3.2-2 (U.S. EPA, 2002e). Nutrients are also identified as impairing other surface waters such as rivers, streams, estuaries, coastal resources, and wetlands. Septic systems indirectly impact lakes and other surface waters through the process of ground water recharge, in which impacted ground water discharges to the surface water. For surface water, no data are available concerning the nation-wide distribution of either nutrient or nitrogen loading by source, but septic systems are thought to represent a significant source of nutrients. For example, the State of Delaware estimates that nutrient loading from septic systems accounts for 19% to 45% of non-point source loading to one of its nutrient-sensitive estuaries, the Inland Bays (Jones, undated).

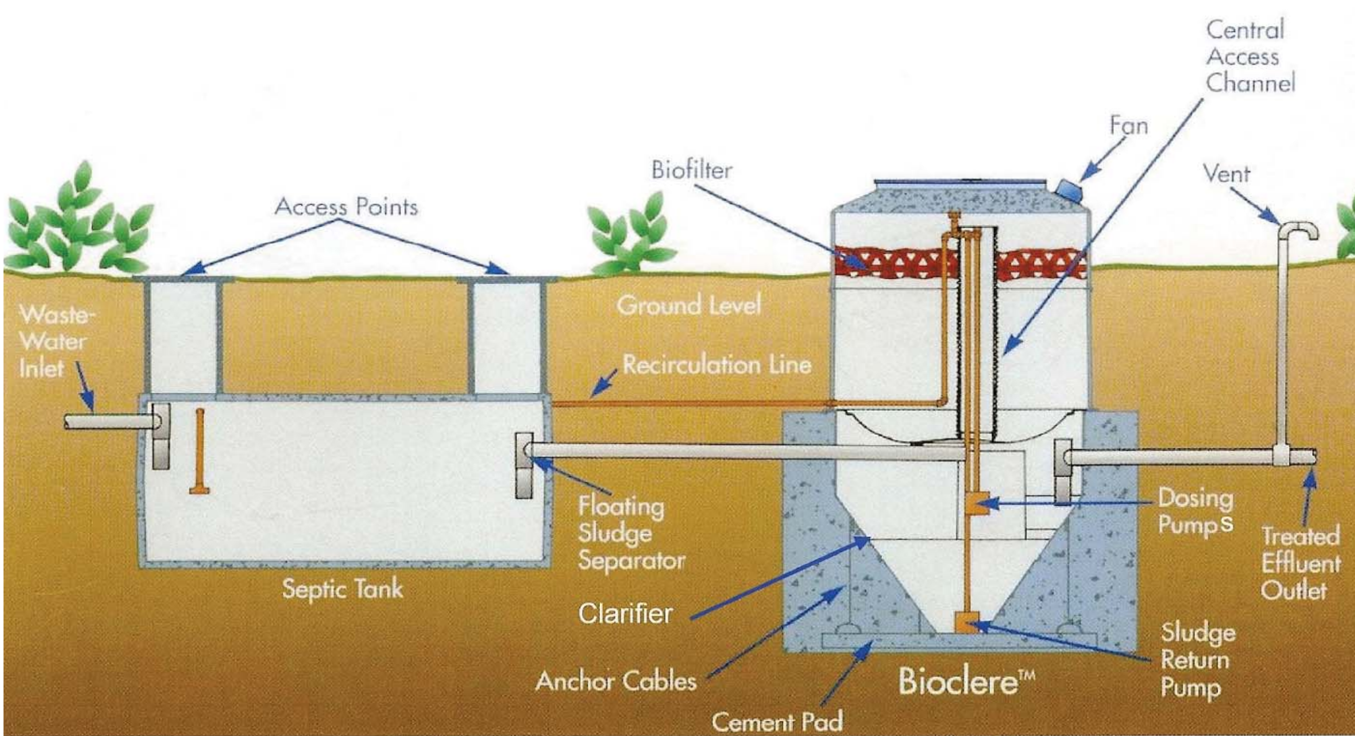
In surface waters, nutrients cause nuisance overgrowth of algae as well as noxious aquatic plants, which leads to oxygen depletion via plant respiration and microbial decomposition of plant matter by bacteria. The bacteria consume dissolved oxygen and, as dissolved oxygen is depleted, fish kills and foul odors can result. Therefore, excess nutrients can present losses to ecological, commercial, recreational, and aesthetic uses of surface waters (NSF, 2003a).

To address human health concerns, EPA has established drinking water standards for several nitrogen compounds, including those generally present in domestic wastewater or septic system discharges, such as nitrates and nitrites. The maximum contaminant level (MCL) for nitrates is 10 milligrams per liter (mg/L) and the MCL for nitrites is 1 mg/L (each measured as mg/L as nitrogen, or "mg/L as N"). The primary health risks of nitrates and nitrites in drinking water are to infants. Drinking nitrite or nitrate-containing water can result in increased incidence of methemoglobinemia, a blood disorder that interferes with the body's processes for carrying sufficient oxygen to cells and tissues (U.S. EPA, 2002f).

To mitigate risks of water quality degradation from onsite treatment systems, regulatory oversight typically is provided at the local level. Most septic systems are not regulated at the federal level. Instead, EPA works with organizations, local governments, and states in information exchange and technical assistance. For example, EPA has recently signed a memorandum of understanding with eight organizations involved in various facets of septic tank regulation, operation, and environmental effects to facilitate this exchange (U.S. EPA, 2005k). EPA also has developed voluntary guidelines for the management of septic systems and similar decentralized wastewater treatment facilities (U.S. EPA, 2003g). The guidelines provide management models based on environmental sensitivity, as determined by the locality, but do not provide detailed information regarding nutrient reduction goals or applicable technologies. As of September 2004, five states (Arizona, Florida, New Jersey, North Carolina, and Rhode Island) had adopted these management guidelines (U.S. EPA, 2005l). In addition, at least four states (Florida, Pennsylvania, Massachusetts, and Rhode Island) include specific regulations for nitrogen discharge in areas that impact sensitive ecosystems (Pinelands Commission, 2001). Section 3.2.3, below, discusses how some of these programs incorporate ETV information.

3.2.2 Technology Description

To reduce the discharge and impacts of nitrogen compounds to the environment, the ETV Program's WQP Center verified six technologies designed to reduce nutrients from domestic wastewater. Conventional septic system technology relies on primary treatment (settling) for solids and organic reduction prior to dispersion in the ground. The verified technologies combine



A schematic diagram of one of the ETV-verified residential nutrient reduction technologies

the primary treatment with biological treatment to achieve a higher level of treatment. Biological processes used by the verified technologies include aerobic trickling filters, aerobic submerged media filters, and sand filters, to promote removal of nitrogen from the wastewater through the multi-step bacterial conversion of ammonia and organic nitrogen compounds to nitrates, and reduction of nitrates to gaseous nitrogen.

While the verified technologies could have additional benefits (e.g., phosphorus reduction) or applications (e.g., commercial, industrial, or larger residential), the ETV Program specifically verified the nitrogen reduction performance of systems designed to treat residential wastewater. The design capacities of the tested units represent installations that would be appropriate for a single-family home. Further, some of the verified technologies can be used for either new installations or to retrofit existing septic systems. Readers are encouraged to review the verification statements and reports (NSF, 2003a, 2003b, 2003c, 2003d, 2003e, 2004e) for a description of the technologies and their applications.

Each verification test consisted of a 12- or 13-month test period, incorporating five sequences with varying stress conditions to simulate real household conditions. Exhibit 3.2-3 identifies the six verified technologies. The verified technologies use various biological processes, but have a common three-stage approach to achieve nitrogen reduction. In the first stage, raw wastewater flows to an anaerobic/anoxic pretreatment tank where solids are settled and some reduction of organic matter is achieved. Conversion of ammonia nitrogen to nitrate nitrogen is accomplished in the second stage by aerobic treatment of the pretreatment tank discharge. The verified

Exhibit 3.2–3

Vendor & Model	Design Capacity (gallons per day)
Aquapoint, Inc. (AQP)—Bioclere Model 16/12	400
Bio-Microbics—RetroFAST® 0.375 System	375
F.R. Mahony & Associates, Inc.—Amphidrome Model Single Family System	400
SeptiTech, Inc.—SeptiTech Model 400 System	440
Waterloo Biofilter Systems, Inc. (WBS)—Waterloo Biofilter Model 4-Bedroom	440
BioConcepts, Inc.—ReCip RTS–500 System	500

Sources: NSF, 2003a, 2003b, 2003c, 2003d, 2003e, 2004e technologies all provided a surface for growth of biomass, which converts organic matter to new cell mass and completes the conversion of ammonia to nitrate. The final stage of treatment is accomplished by recycling a portion of the nitrified wastewater to the pretreatment tank, where anoxic conditions result in reduction of nitrates to nitrogen gas (U.S. EPA, 2004l).

The ETV Program verified that each of the six technologies reduced influent total nitrogen by approximately 50% to 65%, resulting in effluent total nitrogen concentrations of 14 to 19 mg/L as N. Exhibit 3.2-4 summarizes the results. Because the ETV Program does not compare technologies, the performance results shown in Exhibit 3.2-4 do not identify the vendor associated with each result and are *not* in the same order as the list of technologies in Exhibit 3.2-3.

Exhibit 3.2-4

Performance of ETV-Verified Residential Nutrient Reduction Technologies[48]

Vendor & Model	Average Total Nitrogen, mg/L as N		% Reduction
	Influent	Effluent	
A	36	15	58%
B	37	14	62%
C	39	14	64%
D	37	15	59%
E	39	19	51%
F	37	16	57%

Sources: NSF, 2003a, 2003b, 2003c, 2003d, 2003e, 2004e

3.2.3 Outcomes

The most recent available U.S. Census data estimate that 25,741,000 homes used septic tanks as of 2003, representing 21% of homes (U.S. Census Bureau, 2004a). Onsite treatment systems continue to be used in new construction, with an estimated 33% of new housing and commercial development reportedly relying on onsite treatment systems (U.S. EPA, 2005k). The number of homes that might utilize a verified technology, however, is expected to be substantially less than the Census estimate. Homeowners and builders that need to utilize septic systems in areas where they might present a threat to ground water or surface water quality due to nitrogen are those most likely to benefit from the technology, as are the communities in which these homes are located.

The ETV Program does not have access to a comprehensive set of sales data for the ETV-verified technologies. Also, no reliable estimate exists for the number or percent of septic systems that represent a threat to ground water or surface water quality because of nitrogen. Therefore, this analysis relies on a rough assumption that 10% of the 2003 Census estimate of homes with septic systems are candidates for the ETV-verified technologies. This very rough approximation is intended to represent areas where treatment using the ETV technology would be advantageous because surface or ground water quality is sufficiently threatened. The approximation also assumes that it is more cost-effective to incorporate verified technologies in new housing than to retrofit existing septic systems.[49] This approximation is not intended to imply that 10% of all homes are, in fact, located in impaired areas; instead it is intended to provide an approximation for the total potential market given a lack of available quantitative estimates. Based on this assumption and the 2003 Census estimate, the ETV Program estimates that the total potential market for the nutrient reduction technologies is about 2.6 million homes.

The ETV Program used this estimate of the total potential market to estimate the number of homes that could utilize the verified technologies based on two market penetration scenarios, 10% and 25% of the total potential market, as shown in Exhibit 3.2-5. The ETV Program also used these market penetration scenarios to estimate the pollutant reduction outcomes shown below.

48 Because the ETV Program does not compare technologies, the performance results shown in Exhibit 3.2-4 do not identify the vendor associated with each result and are *not* in the same order as the list of technologies in Exhibit 3.2-3.

49 As discussed in Section 3.2.2, however, some of the ETV-verified technologies can be used to retrofit existing septic systems. Therefore, the estimate of the total potential market could be conservative (low).

Exhibit 3.2-5

Number of Homes that Could Apply ETV-Verified Nutrient Reduction Technologies

Market Penetration	Number of Homes
10%	260,000
25%	640,000
Values rounded to nearest 10,000	

Pollutant Reduction Outcomes

Using assumptions regarding daily water use, nitrogen concentration, and nitrogen reduction, the ETV Program estimated the annual pollutant reductions from potential application of the ETV-verified nutrient reduction technologies.[50] Exhibit 3.2-6 shows these estimates. The reductions illustrated in Exhibit 3.2-6 account only for the reductions observed in the ETV verification testing, and do not account for nitrogen reduction processes that can occur in leach field soils to which septic tanks commonly drain.

Exhibit 3.2-6

Estimated Potential Nitrogen Reduction for the ETV-Verified Residential Nutrient Reduction Technologies

Market Penetration	Nitrogen Reduction (tons per year)	
	Lower Bound	Upper Bound
10%	1,300	1,600
25%	3,100	4,000
Values rounded to nearest 100		

Quantitative data are not available to estimate the environmental and health outcomes associated with these pollutant reductions. As discussed in Section 3.2.1, however, nutrient loadings are a significant environmental concern and nitrates and nitrites have human health impacts. Therefore, the benefits of reducing nitrogen loading also could be significant.

Regulatory Compliance Outcomes

States establish water quality standards to ensure that a water body will sustain its uses for drinking water, recreation, and/or ecological activity. States also can calculate a Total Maximum Daily Load (TMDL), which is the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources. Approximately 360 TMDLs have been established for nitrogen-containing nutrients (e.g., total nitrogen, nitrate) from 1996 to 2005. States could consider the use of the ETV technologies to assist in meeting these objectives.

The Safe Drinking Water Act requires that contaminants (such as nitrate and nitrite) must be below their respective MCL in public drinking water supplies. During EPA's fiscal year ending September 30, 2004, a total of 546 systems serving a total population of more than 200,000 persons reported at least one violation of the MCL for nitrates (U.S. EPA, 2005m). This includes community water systems (e.g., city or town) and non-transient non-community water systems (e.g., school or factory). These data suggest that nitrogen levels in some drinking water supplies are of concern. Improving the quality of the drinking water source is an important component to ensuring continued compliance. The reduction of nitrogen loading from septic systems through the application of ETV technologies could assist drinking water systems in complying with drinking water standards for nitrates and nitrites.

Nitrates and nitrates also could affect private drinking water wells, in addition to public water supplies. Approximately 15 percent of Americans rely on private supplies. Although EPA does not regulate private drinking water supplies, some states and localities do (U.S. EPA, 2005q). Application of the ETV technologies could assist private parties in complying with these state and local regulations. Data are not available, however, to estimate how many private wells might be threatened by nutrients from septic systems.

As discussed in Section 3.2.1, a number of states have adopted regulations or guidelines for the management of septic systems or discharge

50 These estimates assume average water usage of 187.1 gallons per-day per-septic tank, based on the following data: average flow of 69.3 gallons per person per day (U.S. EPA, 2002c, Table 3-2) and 2.57 people per household (U.S. Census Bureau, 2004b). They assume minimum influent nitrogen concentration of 36 mg/L (the concentration used in ETV verification testing). For the upper and lower bound, respectively, they assume the maximum (64%) and minimum (51%) nitrogen reduction efficiency achieved by the technologies. Because the calculation uses a minimum influent concentration and is based on a conservative estimate of the total potential market, these estimates are conservative (low).

of nitrogen. Such regulations and guidelines rely, in part, on the use of alternative technologies that are, in some cases, approved by the states. In the residential wastewater treatment industry, regulators rely on third-party testing and standards, such as ANSI/NSF Standard 40 for Residential Wastewater Treatment Systems. In addition, some states have processes that allow for innovative approvals of systems that perform outside the scope of the existing certification protocols (U.S. EPA, 2004l). At least four states are currently using, or might use in the future, ETV protocols in the evaluation of alternative technologies:

- North Carolina has indicated that vendors requesting innovative approval can use ETV verification protocols to support their request (U.S. EPA, 2004l). The state additionally suggests that data gathered outside of these protocols might not be considered equally valid (Jeter, 2001).
- In Massachusetts, Barnstable County has operated the Massachusetts Alternative Septic System Test Center since 1998, where ETV testing was conducted for five of the six evaluated technologies. The Massachusetts Department of Environmental Protection (DEP) approves alternative septic system technologies on a case-by-case basis based, in part, on a review of ETV protocol data. As of January 2005, the Massachusetts DEP has issued certifications for four of the six evaluated technologies to allow for general use wherever a conventional system would be installed (MADEP, 2005).
- Pennsylvania and Florida are looking at the ETV protocols to see if there is a way to incorporate the information contained in the protocols for evaluation of these systems in their states (U.S. EPA, 2004a).

Technology Acceptance and Use Outcomes

Vendor information indicates that ETV-verified technologies are being installed in field applications to reduce pollution. One vendor, SeptiTech, has reported that verification led to sales of its technology (see quote below). In one example, SeptiTech had an opportunity to bid on a large system and the award of the project to SeptiTech was directly tied to the ETV testing. SeptiTech also indicated that ETV verification is making a "huge difference" in obtaining approvals outside of New England, and they expect that approvals will be expedited (U.S. EPA, 2004a). Although quantitative data are unavailable, this information provides evidence that the ETV-verified technologies are being applied in practice.

> "SeptiTech's business tripled last year. At least one-third of that growth was because we were involved in the ETV Program and could demonstrate that our product was effective." —*Dan Ostrye, Vice President, SeptiTech (U.S. EPA, 2004a)*

Acronyms used in this case study:

DEP	Department of Environmental Protection	mg/L as N	milligrams per liter as nitrogen
MCL	maximum contaminant level	TMDL	Total Maximum Daily Load
mg/L	milligrams per liter	WQP Center	ETV's Water Quality Protection Center

4.
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Appendices

Appendix A. Methodology for Diesel Engine Retrofit Outcomes

Number of Heavy Duty Diesel Vehicles

To estimate the potential market for the ETV-verified technologies, the ETV program estimated the number of vehicles by age and category using the following equation:

$$HDDV_{age,engine} = HDV_{engine} \times PCT_{age} \times PCT_{diesel}$$

Where:

- $HDDV_{age,engine}$ is the number of heavy-duty diesel vehicles by age in each of ten categories [eight truck engine categories, plus one category each for school buses and transit buses, as defined in U.S. EPA (2001a)]
- HDV_{engine} is the number of heavy-duty vehicles (gasoline and diesel) in each of the ten categories in 2005 from Table 17 of U.S. EPA (2001a)
- PCT_{age} is the percentage distribution of vehicles by age from Table 5 of U.S. EPA (2001a). (This distribution ranges from new to 25-year-old vehicles.)
- PCT_{diesel} is the percentage of trucks with diesel engines from Table 18 of U.S EPA (2001a), and a percentage of buses with diesel engines imputed from Tables 4, 5, and 6 of U.S. EPA (2002b)

ETV then estimated the number of vehicles in each class, by summing across all ages for each engine category/class. In the sum, the ETV Program only included vehicles that are up to 25-years-old or less. ETV chose this age limit because diesel vehicles typically can be in service up to 30 years and retrofit technologies are recommended for vehicles with at least five years of remaining service. Thus, 25-year-old vehicles would be the oldest vehicles with sufficient service remaining for retrofit technologies.

The values for the number of heavy-duty diesel vehicles were used in subsequent pollutant reduction calculations. ETV also estimated the total market for the ETV technologies by summing $HDDV_{age,engine}$ across all ages and categories.

Pollutant Reductions

The ETV program used the equation below to estimate pollutant reductions for each vehicle category (e.g., 2B, 3, 4, 5, 6, 7, 8A, 8B, and school and transit buses) based on the remaining miles each class is expected to travel after being retrofitted:

$$TR_{pollutant,engine} = (CL_{pollutant} \times \% R_{pollutant} \times VMT_{engine} \times CF_{engine} \times Y) / 454 / 2{,}000$$

Where:

- $TR_{pollutant,engine}$ is tons per year of pollutant reduced by each vehicle category (e.g., 2B, 3, 4, 5, 6, 7, 8A, 8B, and school and transit buses) in the current fleet (which includes vehicles up to 25 years of age).
- $CL_{pollutant}$ is the composite weighted emission level for each pollutant in g/bhp-hr obtained

during baseline ETV testing using LSD fuel and without the technology in place.[51]

- ❖ $\%R_{pollutant}$ is average percent pollutant emission reduction achieved by the diesel retrofit technology during testing. These reductions were determined by comparing baseline emission levels (obtained using LSD fuel and without the retrofit technologies in place) with retrofitted emission levels (obtained using ULSD fuel, after the retrofit technologies were installed and degreened).
- ❖ VMT_{engine} is the number of vehicle miles traveled (VMT) each year by the different heavy-duty vehicle categories. These estimates were based on the National Emission Inventory VMT estimates, which are developed using 2002 Federal Highway Administration measurements of VMT by vehicle category (Brzezinski, 2004).
- ❖ CF_{engine} is the conversion factor for bhp-hr to miles. It is calculated for each engine category using the following formula:

$$CF_{engine} = FD / (BSFC \times FE_{engine})$$

Where:

- ❖ FD is the fuel density (in grams/gallon) determined during ETV testing.
- ❖ BSFC is the average brake specific fuel consumption (g/bhp-hr) determined during baseline ETV testing using LSD fuel.
- ❖ FE_{engine} is average fuel economy in miles per gallon for the each engine category in the current fleet of heavy-duty vehicles (up to 25 years old). It was calculated from the fuel economies in Tables 16 & 20 of EPA (2002b), using estimates of the number of heavy-duty diesel vehicles by age and engine category (see $HDDV_{age,engine}$ text listed previously).
- ❖ Y is the number of years of service after being retrofitted, which ETV assumed would be seven years.

Since six retrofit technologies/systems achieved emission reductions during ETV testing, six sets of pollutant reduction scenarios were developed for the current fleet using data obtained from the six verification tests (emission levels, fuel densities, etc.), as well as data from the MOBILE6 literature and other sources. Although each set of ETV test data was obtained from a single engine (using a specific retrofit technology/system), the ETV Program assumed that similar results would be observed across the different engine categories and model years found in the current fleet heavy-duty diesel vehicles. This assumption was made to maximize the use of ETV test data within the calculations. Total reductions, in tons per seven years, were developed for each pollutant by summing the reductions achieved for each vehicle class ($TR_{pollutant,engine}$) for each of the six sets of calculations. The highest and lowest removals obtained using the six sets of data were then reported in Exhibit 2.1-3 and used as the basis for estimating the human health outcomes in Exhibit 2.1-4.

For those tests that were performed using a 1990 model year engine, the ETV Program replaced the baseline PM emission value measured during ETV testing with a weighted average (calculated using MOBILE 6 certification levels for different vehicle classes) when calculating potential emission reductions for 1994 and newer model year heavy-duty diesel trucks and buses. This was done to account for the fact that 1994 and newer model year heavy-duty diesel trucks and buses need to meet a lower emission standard (i.e., 0.10 g/bhp-hr) than earlier model year engines. This weighted average was developed using engine certification levels reported for 1994 and higher model year vehicles found in Tables 19 and 23 of EPA (1999b). Although certification levels can differ from real-world emissions (e.g. due to maintenance issues, fuel variation, and engine deterioration over time), in this case certification levels should produce a more conservative estimate of the potential pollutant reductions from 1994 and newer model vehicles than the baseline PM emissions obtained during testing using a pre-1994 engine. For consistency, VMT associated with 1994 and higher model year vehicles was determined and used during calculations involving the weighted average.

In calculating pollutant reductions, the ETV Program chose a seven-year retrofit life. Although

51 Typically the CL for PM is modified to reflect a fuel sulfur adjustment factor (FSAF) in g/bhp-hr. In this case, however, the FSAF for PM was assumed to be zero, since emission levels were obtained from engines using lower sulfur fuel. FSAFs are not used when calculating HC and CO removals.

this life is greater than minimum remaining life for vehicles recommended for retrofitting, this assumption still is believed to be conservative (low). Although the verifications did not consider the expected life of the retrofit equipment, most of the vehicles being retrofitted will have a remaining service life much longer than seven years. The choice of this conservative assumption helps account for the decline in benefits over time due to vehicle "scrappage" (i.e., replacement of older, retrofit vehicles with newer vehicles that meet the new emissions standards).

Human Health Outcomes

The ETV Program estimated the human health outcomes associated with the PM reductions by assuming a straight-line relationship between each human health endpoint and the total estimated PM reduction in EPA's RIA for the new diesel emissions standards. That is, the ETV Program applied the following equation:

$$Outcome_{ETV} = (Outcome_{RIA} / TR_{PM,RIA}) \times TR_{PM,ETV}$$

Where:

- $Outcome_{ETV}$ is the quantified measure for a given human health endpoint (e.g., avoided cases of premature mortality over seven years) attributable to PM reductions from the ETV-verified technologies
- $Outcome_{RIA}$ is the quantified measure for the same PM-related human health endpoint from Table VII-19 of U.S. EPA (2000c)
- $TR_{PM,RIA}$ is 109,000 tons per year, the total reduction in PM estimated for the new diesel emissions standards
- $TR_{PM,ETV}$ is the total reduction in PM in tons over seven years for a given scenario, estimated as discussed above

This methodology is most likely a gross simplification of the actual relationship between these two factors. First, it assumes that the relationship between tons of emissions reduced and the ambient concentration of PM in a given area is linear. Second, it assumes that the relationship between ambient PM concentrations and human health effects is linear. In fact, both of these relationships are complex and subject to external factors (e.g., 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 between emissions reductions and human health effects is to linear. Finally, the methodology assumes that the nationwide distribution of PM reductions from the ETV technologies would be similar to that from the new diesel emissions standards. 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.

This methodology does not account for the fact that human health benefits attributable to retrofit technologies are expected decline over time due to vehicle "scrappage" (i.e., replacement of older, retrofit vehicles with newer vehicles that meet the new emissions standards). The effect of this limitation on the outcomes estimates, however, might be offset by the conservative assumptions used to estimate the number of vehicles and emissions reductions.

Economic Outcomes

To estimate the economic value of human health benefits, the ETV Program used unit values from Table VII-15 of EPA's RIA for the new diesel emissions standards (U.S. EPA, 2000c). Specifically, the ETV Program multiplied the appropriate unit value (e.g., dollars per avoided case of chronic bronchitis) by the corresponding quantified outcome (e.g., avoided cases per year of chronic bronchitis) for each human health effect estimated above, except for asthma attacks and work loss days. The RIA did not include an economic value for asthma attacks in its primary benefits analysis, so the ETV Program did not include this outcome in its estimate of economic value. For work loss days, the RIA performed a more complex analysis that incorporated regional variations in wages. Because data were not available to estimate the regional distribution of work loss days, the ETV Program applied the national median daily wage reported on page VII-62 of the RIA.

The ETV Program also added the economic benefits associated with visibility improvements by assuming a linear relationship between tons per year of PM reduction and the total visibility benefit reported in Table VII-22 of the RIA. This calculation is similar to that described above for human health outcomes, with similar limitations.

The RIA's estimates of total benefits incorporated an adjustment to account for growth in real income over time. This adjustment reflects the economic theory that willingness to pay for most goods (including environmental protection) increases if real incomes increase (U.S. EPA, 2000c). This adjustment was significant in the RIA, because it estimated total benefits at full phase-in of the new standards (i.e., in 2030), at a time when projected real incomes would be much higher. Because the benefits from retrofit technologies would occur sooner, while the new standards are still being phased in, the ETV Program did not employ a similar adjustment. The unit values for human health outcomes and the total benefits of visibility increases used here are unadjusted for growth in real income.

The economic outcomes estimates also are in 1999 dollars, as reported in the RIA. Therefore, they provide a conservative (low) estimate of economic outcomes in current year dollars.

Appendix B. Methodology for Eductor Vapor Recovery Unit (EVRU) Outcomes

Number of Facilities and Current Emissions

U.S. EPA (1997d) estimates there are 12,670 condensate storage tank batteries in the United States. The ETV Program used these data as its estimate of the total potential market for the EVRU. This is a conservative (low) estimate because it includes only storage tank batteries. The EVRU also is appropriate for other low-pressure hydrocarbon vent sources such as heater treaters, gas-dehydration units, water-polishing operations, low-pressure separators, and compressors.

Devon et al. (2005) estimate 23,000 MMscfy methane emissions from condensate storage tank batteries at production facilities. Pioneer et al. (2004) estimate an additional 300 MMscfy in methane emissions from condensate storage tank batteries at processing facilites. Combining these two estimates, the ETV Program estimates current methane emissions from these facilities at 23,300 MMscfy.

Recent data for HAP and VOC emissions from this source category are not available, but U.S. EPA (1997d) estimates 7,000 tons per year of HAPs and more than 22,000 tons per year of VOCs from these facilities. These estimates, however, were made using model facilities extrapolated up to a national level. An alternate source, 64 FR 32610, estimates that the NESHAP for Oil & Natural Gas Transmission and Storage would reduce HAP and VOC emissions by 33,000 and 67,100 tons per year.[52] Also, the technology vendor estimates that the 11 existing EVRU installations in the United States *alone* recover considerably more than 22,000 tons per year of VOCs (Boyer, 2005).

Given the uncertainties surrounding the available national estimates of HAP and VOC emissions from this source category, the ETV Program estimated national emissions of these pollutants based on the national methane emissions estimate and the characteristics of the vent gas at the test site, reported in Southern Research Institute (2002), as follows:

- 23,300 MMscfy methane total x (176 tons per year HAPs at test site / 32.1 MMscfy methane at the test site) = 128,000 tons per year HAPs total
- 23,300 MMscfy methane total x (2,203 tons per year VOCs at test site / 32.1 MMscfy methane at the test site) = 1,600,000 tons per year VOCs total[53]

Existing Emissions Controls and Total Potential Emissions

A number of facilities currently have emissions control devices (e.g., conventional VRUs) in place. The emissions estimates, above, account for these

52 Converted from megagrams per year in 64 FR 32610.

53 Assumes nearly all of the "other hydrocarbons" reported in Table 2-4 of Southern Research Institute (2002) are VOCs, based on Table 2-3 of the same source.

control devices. To estimate EVRU's impact at facilities that currently have emission control devices in place, these emissions estimates need to be translated into total potential emissions estimates (i.e., emissions that would occur in the absence of existing controls). To do this, the number of facilities with controls in place needs to be estimated. U.S. EPA (2003d) estimates that, currently, 8,000 to 10,000 VRUs are in place at storage tank batteries. Using the upper end of this range, the ETV Program estimates that approximately 79% (or 10,000 of the 12,670 total batteries) of facilities have existing controls.

The ETV Program assumed that the vent gas recovery rate for the existing control devices is 95%. The ETV Program chose 95% because this is the efficiency required by the National Emission Standards (66 FR 32610). This is a reasonable estimate because reported efficiencies for conventional vapor recovery devices are from 90% to 98% (U.S. EPA, 1995). Using this assumption, for controlled facilities, current emissions equal 5% (100%–95%) of total potential emissions for a facility. For uncontrolled facilities, current emissions equal total potential emissions for a facility.

Given 95% recovery, if 10,000 facilities have controls in place, the average facility has total potential emissions of:

- 23,300 MMscfy total / (2,670 uncontrolled facilities + 0.05 x 10,000 controlled facilities) = 7.35 Mmscfy methane
- 128,000 tons per year total / (2,670 uncontrolled facilities + 0.05 x 10,000 controlled facilities) = 40.3 tons per year HAPs
- 1,600,000 tons per year total / (2,670 uncontrolled facilities + 0.05 x 10,000 controlled facilities) = 504 tons per year VOCs

To calculate total potential vent gas from an average facility, the ETV Program assumed that the vent gas is 50% methane. This assumption is approximately equal to the percentage observed at the test facility and within the range (40% to 60%) reported in U.S. EPA (2003d). Therefore, total potential vent gas from an average facility is:

- 7.35 MMscfy methane / 50% methane = 14.7 MMscfy total vent gas

Because larger sites (like the test site) would be more likely to install the EVRU because of the greater quantity (and therefore value) of vent gas available to be recovered, this value is considered relatively conservative (i.e., low). Emission data observed at the test site and reported for the other existing EVRU installations support the conclusion that this average is conservative.

Pollutant Reductions and Vent Gas Recovery

The net pollutant reduction from application of the EVRU at a given site depends on (a) total potential emissions quantities at the site, and (b) whether the site previously was uncontrolled or installs the EVRU to replace an existing control device. In comparison to total reported emissions for storage tank batteries, emissions at the ETV test site (and other existing EVRU applications) appear relatively high. Thus, extrapolating the test site pollutant reduction quantities to even a moderate number of facilities would result in total reductions greater than the estimated national emissions total reported for methane (Devon et al., 2005; Pioneer et al., 2004) and calculated for HAPs and VOCs in the beginning of this appendix. Therefore, ETV Program assumed that additional facilities (after the test facility and the other existing EVRU installations) have average total potential emissions, as calculated above.

The ETV Program converted total potential emissions to net emissions reductions using the following equation:

$$NR_{pollutant} = (\%R_{EVRU} - \%R_{existing}) \times PE_{pollutant}$$

Where:

- $NR_{pollutant}$ is the net reduction per year of a given pollutant (or total vent gas) per facility.
- $\%R_{EVRU}$ is the vent gas recovery rate for the EVRU, or 99.91%.
- $\%R_{existing}$ is the vent gas recovery rate for the existing control device that the EVRU replaces. For controlled facilities, the ETV Program chose 95%, as discussed above. For uncontrolled facilities, the ETV Program assumed no existing controls were in place and, therefore, used 0% for this variable.

- $PE_{pollutant}$ is the total potential emissions per year of a given pollutant (or total vent gas) per facility, calculated as discussed above.

Application of the above equation results in the values for $NR_{pollutant}$ shown in Exhibit B-1. For the ETV test site, the ETV Program obtained net emissions reductions for methane (3.2 MMscfy) and HAPs (17.6 tons per year) from Table 2-4 of the verification report (Southern Research Institute, 2002). For net VOC reductions at the test site, the ETV Program assumed all of the "other hydrocarbons" (220.3 tons per year) listed in Table 2-4 of the verification report were VOCs. This assumption appears reasonable given the vent gas composition listed in Table 2-3 of the verification report. For net vent gas recovery at the test site, the ETV Program used the value shown on page 2-10 of the verification report (6.4 MMscfy). In addition to the test site, the technology vendor reports it has installed the EVRU at 10 other facilities in the United States. Based on data provided by the vendor (Boyer, 2005), the additional facilities were previously uncontrolled and currently are recovering 273 MMscfy of methane and a total of 620 MMscfy of vent gas. To estimate HAP and VOC recovery at the 10 additional sites, the ETV Program used the characteristics of vent gas at the test site (i.e., the ETV Program applied the same methodology described above for total national emissions).[54]

For each market penetration scenario, the ETV Program assumed 79% of facilities (other than the test site) have existing controls in place, based on the data presented above. The ETV Program estimated the total reduction for a given market penetration scenario by multiplying the values shown in Exhibit 2.2-4 times the number of additional facilities applying the EVRU, plus reductions from the ETV test site and the 10 additional facilities.

Exhibit B-1: Net Emissions Reductions for Average Facilities Applying the COMM Engineering EVRU

	Uncontrolled Facility	Controlled Facility
Methane (MMscfy)	7.34	0.361
HAPs (tons per year)	40.3	1.98
VOCs (tons per year)	504	24.8
Total Vent Gas (MMscfy)	14.7	0.722

By limiting the total potential market for the EVRU to storage tank batteries,[55] and by using average total potential emissions estimates that are most likely lower than the emissions expected from the facilities that initially install the EVRU (e.g., larger sites with higher emissions), the estimates of net emissions reductions are considered relatively conservative (low). The approach used to estimate net emissions reductions also assumes that EVRUs would be installed at both uncontrolled and controlled sites (in proportion to the existing number of uncontrolled and controlled sites). Since, intuitively and based on the data from the vendor (Boyer, 2005), the EVRU is more likely to be installed at uncontrolled sites (e.g., with higher emissions than controlled sites), this assumption also helps to make the estimates for net emission reductions relatively conservative.

Financial and Economic Outcomes

To estimate the value of recovered gas, the ETV Program estimated the net quantity of gas recovered using the methodology discussed above. U.S. DOE (2005) reports the average annual wellhead price for natural gas for 2004 was \$5.49 per thousand cubic feet. Vent gas recovered by the EVRU, however, typically has a higher than average heating value. Therefore, the ETV Program calculated the value of the recovered gas using the following equation:

$$\$Value = QR \times (1{,}860 / 1{,}027) \times \$5.49$$

54 Note that the vendor also provided an estimate of VOC recovery for the existing installations, using an alternate methodology (Boyer, 2005). The ETV Program did not use the vendor's estimate for VOCs. Instead ETV used the relative vent gas compositions seen during testing to calculate VOC recoveries, because this approach built upon the ETV-verified data and resulted in more a conservative estimate of total VOCs recovered.

55 The EVRU also is appropriate for other low-pressure hydrocarbon vent sources such as heater treaters, gas-dehydration units, water-polishing operations, low-pressure separators, and compressors.

Where:

- $Value is the total value of recovered vent gas.
- QR is the quantity of vent gas recovered by application of the EVRU in thousand cubic feet.
- 1,860 is an average heating value for recovered vent gas from Boyer (2005) in BTU/scf. The ETV Program used this value (which was provided by the vendor), rather than the value reported for the test site (1,919 to 2,089 BTU/scf), because it results in a conservative (low) estimate of the value of recovered vent gas.
- 1,027 is an average heating value in BTU/scf for purchased natural gas from U.S. DOE (2003). The Department of Energy's Energy Information Administration routinely uses this value in calculating and reporting natural gas prices.
- $5.49 is the average annual wellhead price for natural gas for 2004 per thousand cubic feet from U.S. DOE (2005).

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

Microturbine/CHP Markets

As discussed in Section 2.3.3, one vendor reported worldwide sales of 16.5 MW of ETV-verified microturbines in the last year. Of these sales, the vendor reported that 52% were in the United States and 90% were for CHP applications (ETV Vendor, 2005). Based on these data, the ETV Program calculated current minimum market penetration as follows:

$$16.5 \text{ MW} \times 52\% \times 90\% = 7.7 \text{ MW}$$

This is a conservative (low) estimate because it includes sales by only one vendor during one year. The ETV Program used this minimum market penetration to calculate future penetration over the next five years as follows:

$$(16.5 \text{ MW} \times 52\% \times 90\%) \times 5 \text{ years} = 38.6 \text{ MW}$$

Adding this value to the current minimum penetration of 7.7 MW results in a total installed capacity of 46.3 MW. This estimate also is conservative (low) because it is based on the conservative estimate of current sales and assumes no growth in sales. The vendor forecasts sales will double this year and double again the following year (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.[56] 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,

56 These capacity estimates assume 100% utilization of installed capacity, and are, therefore, low.

EXHIBIT C-1

Source	Sales per year (MW)	Total over five years (MW)	Comments/Limitations
FIVE-YEAR MICROTURBINE/CHP MARKET ESTIMATES			
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	7.7	38.6	Based on 2004 sales by a single vendor (ETV Vendor, 2005). 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 range from the economic analyses.

Emissions Reductions

Emissions reductions from microturbine applications vary on a site-by-site basis. Because of this variation, quantitative data are not available to produce detailed nationwide estimates. To produce a rough estimate, 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

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

Notes: (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.

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

Appendix D. Methodology for Laser Touch Spray Painting Outcomes

Pollutant Reduction

The ETV Program estimated VOC reduction for the ETV-verified technology by assuming a straight-line relationship between market penetration for the technology and the total quantity of VOC released from the automobile refinishing industry, multiplied by the anticipated percentage reduction by the ETV-verified technology. The total VOC air emissions from the automobile refinishing industry were 109,000 tons in 2002. The ETV-verified technology reduces VOC emissions 10% from the unassisted baseline.[57] Because the verified technology can be used in other industries, in addition to automobile refinishing, the estimated VOC reduction is conservative (low). The ETV Program applied the following equation:

$$\text{VOC Reduction}_{ETV} = \text{Annual VOC}_{EA} \times 10\% \times \%MP$$

Where:

- $\text{VOC Reduction}_{ETV}$ is the quantity of VOC emissions reduced per year when using the ETV-verified technology
- Annual VOCEA is the 2002 quantity of VOC emitted by the automobile refinishing industry
- 10% is the VOC reduction obtained when using the ETV-verified technology, when compared to the unassisted baseline
- %MP is the percent market penetration for the ETV-verified technology

Solid Waste Reduction

Solid waste reduction is dependent on the solids content of the paint used. During verification, ETV used a common industrial coating with a solids content of 74%. For this analysis, the overall range of the solids content of paint used in automobile refinishing was assumed to range from 20% to 74% solids, by weight. In most cases the solids content used in the industry is much greater than 20% and much less than 74%; these limits were selected in order bound the estimate. Solid waste reduction was estimated using this range of solids content and in conjunction with the VOC reduction estimate. The ETV Program applied the following equation:

$$\text{Solid Waste Reduction}_{ETV} = \text{VOC Reduction}_{ETV} \times (\%\text{ Solids}/[1\text{-}\%\text{ Solids}])$$

Where:

- $\text{Solid Waste Reduction}_{ETV}$ is the quantity of solid waste reduced per year for a given market penetration when using the ETV-verified technology
- $\text{VOC Reduction}_{ETV}$ is the quantity of VOC emissions reduced per year for a given market

57 This is equivalent to an 11.1% TE increase as cited earlier. (CTC, 2000)

penetration when using the ETV-verified technology, calculated above

- % Solids is the solids content of the paint, ranging from 20% to 74% solids, by weight

Financial and Economic Outcomes

The ETV program evaluated the economic savings resulting from material use (i.e., paint). The ETV Program used data generated by IWRC, which estimated that as a result of improved training, a typical trainee would generate a lower quantity of VOC emissions (285 pounds) during painting and annual material savings would be $6,500 (Little, 2004) This material savings was extrapolated to the VOC reduction quantities calculated above. As such, these cost savings contain significant uncertainty. The ETV Program applied the following equation:

$$\text{Benefits}_{ETV} = \text{VOC Reduction}_{ETV} \times \text{Unit Cost Savings}_{IWRC}$$

Where:

- Benefits_{ETV} is the total monetary benefit in raw material savings for a given market penetration when using the ETV-verified technology
- $\text{VOC Reduction}_{ETV}$ is the quantity of VOC emissions reduced per year for a given market penetration when using the ETV-verified technology, calculated above
- $\text{Unit Cost Savings}_{IWRC}$ is the cost savings per pound of VOC reduced ($6,500/285 lb), as estimated by IWRC

Appendix E. Methodology for Arsenic Drinking Water Treatment Outcomes

Number of Systems and Population Served

To estimate the total potential market for the ETV-verified technologies, the ETV Program used data from U.S. EPA (2000f)—specifically from Exhibit 8-3 for small community water systems (CWSs) and from Exhibit 6-14 for non-transient, non-community water systems (NTNCs). These data result in a total potential market of 3,900 small systems. The ETV Program also estimated the total population served by these systems. For CWSs, this estimate used an average population served per system, by system size category and type (ground water versus surface water), derived from Exhibits 4-1 and 4-2 of U.S. EPA (2000f). For NTNCs, the estimate used the total population served by affected NTNCs reported in U.S. EPA (2001i). These data result in a total population served of 4,400,000. To produce the estimates in Exhibit 3.1-2, the ETV Program multiplied the total number of systems and total population served by each market penetration percentage.

Human Health Outcomes

The ETV Program estimated the number of cancer cases avoided by applying the ETV-verified technologies by assuming a straight-line relationship between each human health endpoint and the total population served by systems installing or modifying treatment as a result of the new standard. That is, the ETV Program applied the following equation:

$$Outcome_{ETV} = (Outcome_{TOT} / TP_{TOT}) \times TP_{ETV}$$

Where:

- $Outcome_{ETV}$ is the quantified measure for a given human health endpoint (total avoided cases of cancer per year and fatal cases per year) attributable to the ETV-verified technologies
- $Outcome_{TOT}$ is the quantified measure for the same human health endpoint for the new standard as a whole.
- TP_{TOT} is the total population served by all systems affected by the new standard
- TP_{ETV} is the total population served by systems applying the ETV-verified technologies

$Outcome_{TOT}$ varied for the upper- and lower-bound scenarios provided in EPA's EA for the new arsenic standard (U.S. EPA, 2000f). TP_{ETV} varied by market penetration scenario. Exhibit E-1 documents the values used in each case. This methodology assumes the characteristics (arsenic concentration, average population served) of systems applying the ETV-verified technologies are distributed in the same manner as those of all affected systems. 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. There also are a number of uncertainties,

Exhibit E-1

ASSUMPTIONS USED TO DEVELOP HEALTH OUTCOME ESTIMATES

Variable	Assumption	Source and Derivation
$Outcome_{TOT}$, total avoided cancer cases, upper bound	55.7	U.S. EPA (2000f), Exhibit 5-9c
$Outcome_{TOT}$, total avoided cancer cases, lower bound	37.4	U.S. EPA (2000f), Exhibit 5-9c
$Outcome_{TOT}$, total avoided fatal cancer cases, upper bound	29.8	U.S. EPA (2000f), Exhibit 5-9c
$Outcome_{TOT}$, total avoided fatal cancer cases, lower bound	21.3	U.S. EPA (2000f), Exhibit 5-9c
TP_{TOT}	12.7 million	U.S. EPA (2001i)
TP_{ETV}, 10% market penetration	440,000	See discussion under "Number of Systems and Population Served," above
TP_{ETV}, 25% market penetration	1,100,000	See discussion under "Number of Systems and Population Served," above
TP_{ETV}, 10% market penetration with large systems included	1.27 million	See discussion under "Number of Systems and Population Served," above

discussed in detail in the EA, associated with the underlying epidemiological studies used in the EA to estimate health benefits. In spite of these limitations, the resulting estimates represent reasonable, conservative (low) estimates of human health outcomes attributable to the ETV-verified technologies.

Economic and Financial Outcomes

To estimate the economic value of human health benefits, the ETV Program used $6.1 million per fatal cancer case prevented and $607,000 per non-fatal cancer case prevented, the same values used in U.S. EPA (2000f). These unit values are in May 1999 dollars, as reported in U.S. EPA (2000f). Therefore, the resulting outcomes estimates provide a conservative (low) estimate of economic outcomes in current year dollars.

To develop the pilot cost-savings estimates, the ETV Program assumed 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 drinking water treatment technology (other than one of the ETV-verified arsenic drinking water treatment 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 typically assumed for pilot testing costs in EPA regulatory analyses. In addition, as discussed above, the ETV Program assumed a wide range of potential cost reductions (10% to 75%) in estimating total national pilot study cost savings. This wide range helps address some of the uncertainty associated with individual pilot study costs.

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