WSRC-RP--92-473

DE92 040311

**TECHNOLOGY STATUS REPORT: OFF-GAS TREATMENT
TECHNOLOGIES FOR CHLORINATED VOLATILE ORGANIC
COMPOUND AIR EMISSIONS (U)**

by

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Technical deliverable being deposited at OSTI.

Received by OSTI

1992-04-02

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INTRODUCTION AND OBJECTIVES

The purpose of this document is to review technologies for treatment of air streams that contain chlorinated volatile organic compounds (CVOCs) and to describe a Department of Energy Office of Technology Development program that is planned to demonstrate innovative technologies for the abatement of CVOC emissions. This report describes the first phase of testing of off-gas treatment technologies. At least one more phase of testing is planned. Guidance for the preparation of this document was provided by a predecisional draft outline issued by the Department of Energy's Office of Technology Development.

The report is intended to evaluate the technical and regulatory aspects, public acceptance, and estimated costs of technologies selected for development and testing. These technologies are compared to currently practiced or baseline methods for treatment of CVOC-laden airstreams. A brief overview is provided rather than detailed cost and data comparisons because many of these technologies have not yet been field tested. A description of other promising technologies for the treatment of CVOC emissions is also included.

Trichloroethylene (TCE) and perchloroethylene (PCE) were used for industrial cleaning and solvent applications for several decades. These chemicals can be classified as CVOCs. As a result of past standard disposal practices, these types of compounds are persistent groundwater and soil contaminants throughout the United States and the Department of Energy Complex. The currently preferred technology for remediating or containing these contaminants is to recover the contaminated groundwater, strip it with air, and then treat or discharge the resulting air stream. CVOC contamination of soils in the vadose zone can be removed by soil venting. In this case the CVOC is removed in the gas or air phase directly and stripping is not required. As the 1990 Clean Air Act Amendments are implemented, the allowable discharges of CVOCs will be significantly reduced. Due to these increased regulatory standards, an improvement in reduction methods would result in a significant cost savings.

Based on their stage of development, technologies for abatement of CVOC emissions can be grouped into three categories: existing technologies, emerging technologies, and evolving technologies. The existing technologies are those that are currently practiced. Emerging technologies are those that are ready or nearly ready for testing at the application or field scale, but do not have a proven history of success outside the laboratory. Therefore, it is difficult to compare emerging technologies with existing technologies. The evolving technologies are those that are technically sound, but are being researched and developed at a smaller scale than the emerging technologies.

EXISTING TECHNOLOGIES

The currently existing baseline technologies for abating CVOC emissions are: activated carbon adsorption, incineration, and catalytic destruction (Rinko and Traester, 1988; Buck and Seider, 1991; Adams and Clark, 1991).

Activated Carbon Adsorption

Activated carbon adsorption is a simple, effective process where CVOCs are adsorbed to the carbon as the contaminated gas stream contacts it. The percent removal of a contaminant depends on that contaminant's carbon adsorption isotherm (Speth and Miltner, 1990). The drawback of this process is that it is a transfer of CVOC from one phase to another without any destruction. Although processes for regenerating the carbon and destroying the adsorbed CVOC exist, these are often costly and may represent more than 50 percent of the cost of the system (Oxenford and Lykins, 1991). The established method for regeneration of the activated carbon is by thermal processes such as infrared heating, incineration or catalysis (Koffsky and Lykins, 1990; Adams and Clark, 1991). Other regeneration methods have recently been developed that have the potential to make the carbon adsorption process less expensive to operate. Methods considered emerging technologies include steam reforming (Adams and Clark, 1991; Sprung, personal communication, 1991), and bioreaction (Chozick and Irvine, 1991). Microwave regeneration (Varma et al., 1987; Varma and

Nandi, 1991) is an evolving technology that shows potential for the effective and efficient recycling of carbon. An additional option for carbon regeneration is to desorb the CVOC with an inert gas (Varma et al., 1987) and then condense the CVOC for recycling. Recycling by volatilization followed by condensation has been successfully used to recover chlorofluorocarbons (Basta, 1991). These emerging and evolving technologies must be validated by full scale demonstrations.

Incineration

Incineration, or high-temperature oxidation is a simple technology best suited for streams with high concentrations of CVOC's. Compared to existing activated carbon adsorption methods, incineration has greater initial capital costs but lower operating costs. The incineration of CVOC's requires a fuel source. Incineration can have relatively high energy demands depending upon the concentration of CVOC's in the waste stream. Total costs for incineration are approximately \$2 to \$6 per kilogram of CVOC versus approximately \$15 per kg for adsorption, and destruction efficiencies of greater than 99.9 percent can be routinely achieved. Incineration of CVOC's can produce chlorinated products of incomplete combustion such as dioxin, as well as hydrochloric acid and nitrogen oxides. However, the release of these by-products has been successfully controlled in bench scale studies using ammonia injection (Takacs and Moilanen, 1991). One of the main barriers in the use of incinerators for treating waste is public objection. Despite the large amount of technical data available indicating the advantages of incineration over many other methods with respect to destruction efficiency, safety, and cost, the general public adheres to a "not in my backyard" position when a site selection process is initiated. This position is strengthened by the public's increased awareness of environmental issues and some highly publicized environmental catastrophes (Steverson, 1991).

Catalytic Destruction

Catalytic destruction has recently emerged as an abatement method for CVOC emissions. This process has lower energy demands than incineration and is better suited for waste streams that have relatively low concentrations of CVOCs (Palazzolo et al., 1986; Herbert, 1990; Frost et al., 1991). Destruction efficiencies of 90 to 95% have been achieved, however, this process normally requires frequent recycling or regeneration of the catalyst. This is due to the permanent deactivation of the commonly employed, noble metal catalyst that is known to occur because of the presence of process-formed chlorides (Kittrell et al., 1991). A proprietary base metal catalyst has recently been tested by its manufacturer and was found to avoid the deactivation problems of the noble metal catalyst and yet it maintains a high conversion efficiency (Kittrell et al., 1991). The performance of this catalyst should be confirmed by independent tests. As with incineration, further treatment of the off-streams from the catalytic process may be needed to remove or neutralize hydrochloric acid. Additionally, this technology requires a fuel or electrical heat source. Costs for the reduction of CVOCs with catalytic process are comparable to incineration.

EMERGING TECHNOLOGIES

Because of the anticipated wide-spread need for the abatement of CVOC emissions, a small reduction in the cost of CVOC removal would result in a tremendous savings for the Department of Energy and United States industry. The greatest overall cost savings would be in reduced operating costs, but simplification of the CVOC treatment process could result in reduced capital and start-up costs. As a result, improved technologies for CVOC removal are being aggressively developed and pursued. A description of technologies that are being considered for Phase I of the off-gas treatment demonstration is provided below.

Gas-Phase Membrane Separation

Gas-phase membrane separation is a mature technology where gas-phase components are selectively separated as they flow through a specially designed proprietary membrane (Wijmans et al., 1990). The estimated operating costs for this technology are about \$6 per kg of CVOC recovered. One of the advantages of the process is that the removed TCE and PCE can be recycled. A company that will take the

TCE/PCE from the demonstration of this technology has been identified. The disadvantage is that the current technology is more expensive than existing technologies. The main reason for the relatively high cost is that currently available membranes can only remove a portion of the TCE or PCE from the waste stream per cycle thereby requiring multiple cycles.

The principal investigators for this project are Craig King and Mike Schleibe of Westinghouse Hanford Company, and the industrial partner and developer of the process is J.G. Wijmans of Membrane Technology & Research Inc. Safety-Kleen will recycle the solvent.

Gas-Phase Bioreaction

A gas-phase bioreactor will be used to aerobically break down CVOCs to carbon dioxide, water and chloride ions. The reactor will use a packed bed consisting of ceramic beads on which a biofilm will be maintained. Indigenous organisms capable of co-metabolizing TCE will be developed. The advantage of this system is that the operating costs are minimal and no hazardous byproducts are produced. The disadvantages include maintaining a viable biofilm and the requirement of long residence times. Work on similar technology has been done in the treatment of groundwater contaminated with TCE (Strandberg et al., 1989). Envirogen Corporation has successfully treated vapor phase concentrations of TCE in the laboratory with 90% destruction efficiency.

The principal investigator for this project is Christopher Berry of the Savannah River Technology Center and the industrial partners are Envirogen Corporation and ECOVA Corporation.

Carbon Regeneration by Steam Reforming

TCE and PCE are removed from a gas stream by adsorption on granular activated carbon and are later desorbed by passing 260°C steam over the activated carbon. The CVOC-laden steam is passed through a moving-bed reactor, that is packed with ceramic spheres that are coated with a slurried base. In the reactor, which operates at 700°C, the CVOCs are dechlorinated. The reactor creates hydrochloric acid that is neutralized by the slurry base. The HCl depleted stream from the reactor is sent to a steam reforming reactor, which operates at 1500°C, where all the undestroyed organic materials are completely mineralized to CO₂ and H₂O. The advantages of this technology are: 1) the system is portable, 2) the system is suited for 55 gallon drums of carbon, 3) operating costs are estimated to be about \$1 per kg of CVOC, 4) 99.99 percent destruction efficiencies have been achieved, and 5) all emissions from the system meet air quality standards. Disadvantages are that all of the HCl generated may not be reacted.

The principal investigator for this project is Jerry Sprung of Sandia National Laboratories and the industrial partner is Synthetica Technologies, Incorporated. This technology will also be tested at the Hanford Site on a carbon tetrachloride CCl₄ as part of the Arid Site Integrated Demonstration.

High-Energy Corona or Low-Energy Plasma

This technology uses several nonconductive electrodes within a reactor to create a low-temperature plasma. The plasma is created as the electrodes discharge causing the gas within the reactor to partially ionize. In other words, the electrical field will force current to flow by stripping electrons off neutral gas molecules. The electrons discharged are highly reactive and catalyze the reaction of TCE and PCE. The advantages of this technology are that no heating, additives, or catalysts are required and the energy consumption is relatively low. The disadvantage is that it is unproven for treatment of high-flow rate streams required for field demonstration.

The principal investigator for this project is William Heath of Battelle Pacific Northwest Laboratory. There is currently no industrial partner.

Photocatalytic Oxidation

Photocatalytic oxidation usually refers to the process in which a contaminant is oxidized by free radicals formed from the interaction of light and a catalyst such as ozone, hydrogen peroxide, or titanium dioxide. The photocatalytic oxidation process typically uses an ultraviolet (UV) light source and one or a combination of the oxidizing agents listed above. For organic compounds such as TCE or PCE, the oxidation process is actually multifaceted. The contaminant can be destroyed by direct photolysis through the molecular absorption of UV light, interaction of the contaminant with the oxidant, the oxidation of the contaminant by free radicals formed from direct photolysis of the oxidant, or interaction of the two oxidants such as ozone and hydrogen peroxide (Glaze et al., 1987; Ollis et al., 1991). The production of free radicals has been found to be the most significant mechanism in these systems (Glaze et al., 1987; Peyton and Glaze, 1988; Glaze and Kang, 1989a; Glaze and Kang, 1989b). Most work in this area has been done using an aqueous waste stream; however, for surface site interactions such as titanium-dioxide mediated processes, a vapor phase waste stream should be mitigated at similar if not increased rates due to a lower concentration of radical scavengers. Some common scavengers in natural waters are inorganic carbon species and natural humic substances (Zafiriou, 1977; Fischer et al., 1987; Glaze and Kang, 1989b). The principal off-gas products are carbon dioxide, water, and hydrochloric acid. Complete mineralization has been achieved (Ollis et al., 1991) and is possible in practice dependent on the concentration of radical scavengers in the waste stream. Two advantages of this process are low capital costs and low operating costs while maintaining high destruction efficiencies. It is currently unproven technology at the field scale.

The principal investigator is Carol Eddy of Savannah River Technology Center and University of Wisconsin is the academic partner.

EVOLVING AND EMERGING TECHNOLOGIES FOR FUTURE DEMONSTRATION

Other technologies that are emerging or evolving for abatement of CVOC emissions are briefly described below. These technologies were not selected for this phase of the program, but may be tested as part of another phase of Off-Gas Treatment technology demonstrations under the SRS Integrated Demonstration.

Carbon Regeneration by Bioreaction

Activated carbon adsorption in conjunction with bioreaction is used to destroy CVOCs. This technology has had its seminal work accomplished in the water treatment field to eliminate bacteria and organic carbon (DeWaters and DiGiano, 1990; Servais et al., 1991; Chozick and Irvine, 1991). The process involves a surfacial biomass growth which can degrade organics on granular activated carbon. The large available surface area on the carbon ensures a high biomass to organic carbon ratio allowing for efficient degradation. This technology is similar to the gas-phase bioreaction described above but may incorporate the added benefits of carbon adsorption and increased surface area to support growth. This process is in the research and development stage.

Current known principal investigators are Daniel Smith at Iowa State University and Colin Felton at the University of Cincinnati.

Bremsstrahlung Treatment

The process uses high-energy electromagnetic waves (x-rays) to destroy CVOCs. Limited bench-scale experiments indicate that TCE and PCE dissolved in water are completely mineralized by this process. The mechanism for the oxidation of the organics in this process is believed to be related to the production of free radicals. Results from tests performed at Lawrence Livermore National Laboratory indicate an exponential decay of TCE in the aqueous and vapor phases as a function of radiation dose. For example a 100 kR dose reduced a vapor phase concentration from 480 ppmv to 177 ppmv and a 300 kR dose reduced the

concentration to below 1 ppmv (Matthews, 1991). John Bayless of Pulse Sciences Inc. has recently completed a final report on the technology, available through the N.S.F. 1991 SBIR program.

The current principal investigators for this technology are Stephen Matthews of Lawrence Livermore National Laboratory and Donald T. Reed and James C. Cunnane of Argonne National Laboratory. John Bayless of Pulse Science Inc. is the industrial partner with Argonne National Laboratory.

Electron Beam Technology

Electron beams are used to produce highly reactive hydroxyl and superoxide radical species. This mechanism of this technology is similar to the photocatalytic and Bremsstrahlung processes described above, using water as the free radical forming catalyst. The technology has been demonstrated to be effective in aqueous solutions and is under development for wet vapor phase CVOCs.

The principal investigator is Lou Rosocha of Los Alamos National Laboratory, and academic partners are University of Illinois, Florida International University and Auburn University.

Microwave-Induced Plasma Incineration

Microwave heating is used to create a uniform temperature distribution and generate reactive species and destroy CVOCs. Argon is used as a carrier gas to eliminate the production of NO_x, and O₂ is used as the oxygen source. To be practical, the process must be able to use air as the carrier gas. As a result, this project is currently in the research phase and is being funded by the Office of Technology Development.

The current principal investigators are Donald Reed and James Cunnane at Argonne National Laboratory.

Microwave Carbon Regeneration

Activated Carbon is used to strip CVOCs from air streams. Microwave energy in the frequency range of 0.9 to 4.5 GHz converts the adsorbed CVOCs to carbon dioxide, water, and hydrochloric acid regenerating the carbon. Operating temperatures for this process are approximately 400° C and destruction efficiencies greater than 90% have been achieved (Varma and Nandi, 1991). One of the byproducts of this process in dry air is free chlorine, which is more difficult to remove from carbon than the other byproducts produced. To successfully regenerate carbon using this procedure it is necessary to convert this free chlorine to a more mobile species such as HCl. This can be achieved by providing sufficient hydrogen to the waste stream (Varma and Nandi, 1991). This process is in the R&D stage and has been funded by the Office of Technology Development.

The principal investigator is Ravi Varma of Los Alamos National Laboratory.

Microwave Fluidized Bed Detoxification

CVOC gas streams pass through a series of microwave heated activated silicon carbide fluidized-bed reactors where they are converted to carbon dioxide and hydrochloric acid (Varma et al., 1990). Operating temperatures are about 600° C and conversion efficiencies of 98% have been achieved compared with 26% conversion by conventional thermal methods under similar operating conditions (Varma et al., 1990). The process is in the research and development stage.

The principal investigator is Ravi Varma of Los Alamos National Laboratory.

Tunable Hybrid Plasma

A gas-phase CVOC plasma is heated by electron beams and radio frequency power (e.g. microwaves) to create highly reactive hydroxyl and elemental oxygen radicals. These radicals are known to oxidize chlorinated organics such as TCE and PCE. The process is tunable because the amount of heating can be controlled by adjusting the microwave power. The process is relatively untested, and requires significant research and development.

Principal Investigator is Daniel Cohn of the Massachusetts Institute of Technology. This technology will be tested under the Arid Site Integrated Demonstration.

Vapor-phase Photolytic Destruction

CVOCs undergo photolysis when exposed to the proper electromagnetic frequency corresponding to the intramolecular bonding energy of the CVOC. The electromagnetic energy in this process can be supplied by any source that emits within the absorption band of the target contaminant. TCE has an absorption band that centers around 230nm while benzene has two relatively strong absorption bands at 184 nm and 202 nm. Traditionally used sources have been mercury vapor lamps (Wekhof, 1991) which have a strong but relatively narrow banded output at 254 nm. These sources were used in water treatment advanced oxidation processes with hydrogen peroxide or ozone, which have absorption bands in the vicinity of 254 nm leading to the formation of free radicals. The target contaminant would therefore be predominantly oxidized by the free radicals formed rather than by direct photolysis since the 254 nm line is on the fringe of the TCE absorption band. The oxidation of the contaminant in this situation would depend on its refractivity and the refractivity of its intermediate breakdown byproducts to free radical attack. In contrast, a broad band UV source would have the advantage of supplying energy in the absorption bands of several contaminants as well as their intermediate photolytic byproducts (Wekhof, 1991). This would ensure a complete mineralization of the contaminant by successive photolytic reactions.

Promising sources for broad band UV output are currently commercially available and custom built, pulsed xenon sources are becoming established technology. Bench scale tests of this technology have been successful in removing TCE, benzene, and polychlorinated biphenyl compounds (Wekhof, 1991).

The principal investigators are P. Daley and A. Boegel of Lawrence Livermore National Laboratory and Hann Hwang of Argonne National Laboratory. The industrial partner is PURUS, Incorporated. In addition, Alex Wekhof of Ultraviolet Energy Generators, Inc. has successfully completed bench scale tests on contaminated water, air, and soil.

Concentrated Solar Energy

This is a technology that uses concentrated solar energy to destroy TCE by UV photolysis. The technology has been applied to liquid-phase TCE and aqueous phase TCE in which oxidation is by direct photolysis and photocatalytic processes. The Solar Energy Research Institute (SERI) has been developing processes for detoxification of waste streams using solar energy. The processes have included photolytic/photocatalytic systems as well as solar thermal systems. The photolytic/photocatalytic system used an array of parabolic reflectors focused on a glass tube carrying the waste stream (Alpert et al., 1990). The thermal process involved solar-driven steam reforming performed in a solar furnace. The goal of both of these processes is a 99.99 to 99.9999% destruction efficiency at a few kg/hr. One disadvantage with these systems is that solar energy is not subject to operator control, although alternate energy sources can be used when solar is not available.

The principal investigator is B. Gupta of the Solar Energy Research Institute (SERI).

Ultrasonic Decontamination

Ultrasound is used to create free radicals either in a solution, or on a surface. The free radicals then oxidize the contaminant. Work with this technology has been done with aqueous and other solutions (Cheung et al., 1991; Koszalka et al., 1992) but much more experimentation is needed to determine the mechanistic pathways in the creation of free radicals using ultrasound.

This technology is being advanced by Duane P. Koszalka of Trinity Environmental Technologies, Inc.

Pulse Combustion

This process uses a two-stage thermal destruction method involving rapid fluid dynamic mixing in the combustion chamber and acoustic resonance to increase mass transport to the catalyst material (Keller et al., 1990). The two stages are high combustion intensity in the pulse combustor's combustion chamber and acoustic resonance in its tailpipe. Destruction efficiencies in excess of 99% have been achieved with methyl ethyl ketone in laboratory experiments.

The principal investigator is T. Tazwell Bramlette of Sandia National Laboratory.

Adsorption-Molten Salt Oxidation

This is a three step process involving activated carbon adsorption followed by regeneration using heated nitrogen to desorb the CVOCs. The CVOC laden nitrogen is then cooled, condensing the CVOCs to the liquid phase. The final step involves thermal destruction of the liquid CVOC in a molten salt bed at temperatures between 800 and 1050 C. The CVOC waste stream is completely mineralized in this process (Yosim et al., 1984).

Zeolite Adsorption with Ozone Oxidation

CVOCs are adsorbed to zeolite and then readily oxidized with ozone. This system has advantages of reduced fuel costs, but has the disadvantage of requiring ozone. The process is in the research and development stage.

The principal investigator is Jim Wilson of Oak Ridge National Laboratory. Vanderbilt University is an academic partner.

TECHNOLOGY PROGRAMMATIC REQUIREMENTS:

The role of the technologies selected for Development, Testing and Evaluation (DT&E) is to effectively abate CVOC emissions at reduced costs. The regulations promulgated pursuant to the Clean Air Act of 1990 mandate maximum achievable control technology for listed air toxics (some CVOCs). This should require air abatement systems to eliminate greater than 95 percent of the CVOC from an emission. To be economically competitive, emerging technologies should be capable of abating CVOC emissions at less than approximately \$1 per kilogram.

TECHNOLOGY DEVELOPMENT AND EVALUATION REQUIREMENTS:

Cost Benefit

The current target cost for destruction of CVOC air emissions is \$1 per kilogram (2.2 pounds). However, this number should be used with caution because there are several important considerations. For instance, if a relatively small amount of CVOC is to be removed, carbon adsorption may be the technology of choice

because of low capital cost even though operating costs are about \$10 per kilogram of CVOC. If a catalytic system is used, the operating cost per kilogram would be about \$1 per kilogram. This is the current technology of choice for high concentrations of CVOC because the benefits of low operating costs outweigh the capital equipment costs and the installation cost (power resource, etc.). Therefore, to be cost competitive an emerging technology would have to have a process that would destroy significant amounts of CVOC for a price of about \$1 per kilogram. Any reductions in capital equipment expenditures or operating costs over current technologies would also be extremely beneficial.

Risk Reduction

The greatest health and environmental risk associated with CVOC emissions is direct untreated discharges. This risk can be negligible, however, because of atmospheric dispersion and natural ultraviolet degradation by direct photolysis and photocatalytic processes. A significant level of risk reduction via the atmospheric exposure pathway is provided through adsorption onto activated carbon. However, if the activated carbon is disposed of at a landfill, this process has generated a secondary waste and a separate exposure pathway. If the activated carbon is regenerated, then there is minimal risk, as long as the desorbed material is destroyed. Catalytic oxidation and incineration provide direct destruction of the CVOC, so there is little risk from CVOCs. It is necessary to insure that the CVOC is completely mineralized in this process and that no products of incomplete oxidation that are dangerous are produced. In addition, hydrochloric acid is usually a secondary waste product from these processes and must be dealt with therein.

Schedule Acceleration

Because the air abatement technology is not the rate-limiting step towards achieving a ground water or soil remediation, we do not anticipate that an acceleration in the schedule will be achieved through improved air abatement technologies. However, treatment of vadose zone sources will reduce the time for groundwater cleanup.

TECHNOLOGY INTEGRATION REQUIREMENTS

Regulatory Compliance

Regulatory compliance will be achieved for the testing of the technologies under this program through formal approval with the State of South Carolina Department of Health and Environmental Control (SCDHEC). A detailed program plan containing a description of the technologies for testing, anticipated atmospheric discharges, and conditions for stop-testing has been sent to the SCDHEC in order to obtain an air permit.

Societal Acceptance

Societal acceptance of the technologies proposed for testing under this program is anticipated. The technologies are easily demonstrable and represent a solid commitment to sound environmental restoration. In addition, these technologies ultimately destroy the contaminants. This eliminates the problem of dealing with the waste in another form as is currently done with most adsorbent based remediation methods.

Contribution

The unique contribution envisioned for this technology development is a better and more cost effective method for treating VOC-laden emissions. Another contribution is that a single systematic effort is made towards testing the emerging technologies for air emissions control. As a result, industry will not have to complete repetitive research. Technologies will be comparatively tested and evaluated for technical performance and cost effectiveness.

Technology Transfer

The projected technology transfer opportunities for a competitive technology under this program are enormous. Indeed, many of the systems to be demonstrated already have an industrial partner. Not only would the technology be applicable for remediation of ground water, but similar technology needs exist for many industrial processes that have similar discharges.

TECHNOLOGY EVALUATION REQUIREMENTS

All of the technologies selected for the first phase of testing under this program have the capability to meet the anticipated regulatory requirements with public acceptance. The lowest probability of success of the technologies is with the High-Energy Corona, because it has not been tested as completely as other technologies. The membrane separation technology is a suitable method for recovering CVOCs, but improvements must be made in the membranes for separating CVOCs. Because the technologies selected for DT&E under this program have not been tested at the field scale, it is unknown whether they will be able to meet the current benchmark cost of \$1 per kilogram of CVOC abated. Thus it will be necessary as part of this program to evaluate the cost-effectiveness of technologies field-tested.

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11 / 09 / 92