

1.0 Introduction

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1.1 Background and Objectives

This document presents the results of feasibility and economic analyses for methyl tertiary butyl ether (MTBE) removal from drinking water. The study was conducted using the most promising and/or widely accepted technologies for removing volatile organic compounds from drinking water — namely, air stripping, advanced oxidation processes (AOPs), granular activated carbon (GAC), and synthetic resin sorbents. These technologies are evaluated as they apply specifically for removal of MTBE.

The first edition of this document was published in December of 1998. This second edition is a significant improvement from the first edition. The most noted changes are the addition of a new chapter on synthetic resin sorbents (Chapter 5), refinement and update of costs for all technologies, significant revisions to the AOPs section, a new introductory chapter (Chapter 1), and a new chapter (Chapter 6) with overall conclusions and recommendations. An executive summary will also be published as a stand-alone summary of this report.

1.1.1 Document Overview

Chapter 1 provides an introductory discussion on the history of the California MTBE Research Partnership (Partnership), background information on MTBE use, discussion of the physical and chemical properties of MTBE, maximum allowable contaminant levels in drinking water, drinking water regulations, and requirements for permitting MTBE treatment systems in California. Although this document is focused on drinking water systems with capacities from 60 to 6,000 gallons per minute (gpm), the information provided in this report should also benefit remediation applications where lower flow rate systems are typically required.

Chapter 2 evaluates air stripping options with and without off-gas treatment for removal of MTBE from drinking water. Air stripping is a proven technology that has successfully removed MTBE in drinking water applications (e.g., La Crosse, Kansas and Rockaway Township, New Jersey). The ability to meet drinking water standards, technical implementability, reliability, flexibility, adaptability, and the potential for modifications are addressed for this technology. Chapter 2 also presents capital and annual operation and maintenance (O&M) costs for various air-stripping and off-gas treatment technologies at flow rates of 60, 600, and 6,000 gpm under influent MTBE concentrations of 20, 200, and 2,000 micrograms per liter ($\mu\text{g/L}$). Please note that these flow rates and influent concentrations were also utilized in the other technology evaluations.

Chapter 3 evaluates advanced oxidation processes, which include use of ozone (O_3), hydrogen peroxide (H_2O_2), ultraviolet (UV) light irradiation, high energy electron beam (E-beam) irradiation, ultrasonic and hydrodynamic cavitation, titanium dioxide (TiO_2) catalysis, and Fenton's Reaction for their ability to remove MTBE from water. While several laboratory and pilot-scale studies have been completed to investigate the ability of AOPs — primarily $\text{H}_2\text{O}_2/\text{O}_3$ and $\text{H}_2\text{O}_2/\text{MP-UV}$ — to destroy organic compounds in drinking water,

there are a limited number of full-scale applications for drinking water treatment. For example, an H₂O₂/MP-UV system was installed in Salt Lake City, Utah for perchloroethylene (also known as tetrachloroethene, or PCE) removal from drinking water. The primary objective of Chapter 3 is to evaluate the feasibility of using AOPs for the removal of MTBE from drinking water. This feasibility evaluation includes a review of the chemical and physical principles behind AOPs, a discussion of the various established and emerging AOPs that have potential for MTBE removal, an analysis of the effect of water quality on the effectiveness of these AOPs, and a cost analysis based on information gathered from manufacturers, vendors, and actual pilot tests. Chapter 3 concludes with overall recommendations for implementation of AOPs for MTBE removal and recommendations for future work.

Chapter 4 presents results of technical evaluations, computer modeling, and cost estimates for the removal of MTBE from drinking water using GAC adsorption. Carbon adsorption is a well understood process that is widely used for the removal of synthetic organic chemicals (SOCs) from water. This chapter provides a detailed feasibility analysis regarding the use of GAC specifically to remove MTBE from drinking water. This feasibility analysis includes determining the conditions (e.g., MTBE influent concentrations, background water quality) under which GAC is most likely to cost-effectively remove MTBE. Chapter 4 also includes a focused literature review and a compilation of vendor information to determine the benefits and limitations of GAC, key variables and design parameters, current usage of GAC for MTBE removal, etc. The detailed evaluation includes computer modeling results and cost estimates prepared to determine the impacts of influent MTBE concentrations, background organic matter, and the presence of other organic compounds upon the removal of MTBE using GAC.

Chapter 5 evaluates the use of synthetic resin sorbents, which had not been addressed in the first edition of this report. Certain developments suggest that synthetic resins may be economically competitive with the treatment technologies previously investigated. First, preliminary findings suggest that synthetic resins may have sufficiently better sorption capacities for tertiary-butyl alcohol (TBA) compared to GAC and, therefore, may present a practical alternative treatment technology for TBA-contaminated sites. Second, improvements in resin regeneration processes may make the life-cycle cost of a resin system competitive or, perhaps, more economical than other options. Third, resins (unlike AOPs) do not produce oxidation by-products. The evaluation of synthetic resin sorbents included a literature review involving published literature and information provided by manufacturers, vendors, and major researchers; an economic analysis using the available literature and AdDesignS (a computer modeling software); and the identification of field sites. Chapter 5 concludes with recommendations for implementation of synthetic resins and recommendations for future work.

Chapter 6 presents a summary of the key findings and conclusions from the evaluations of individual technologies, provides a comparative discussion of the different technologies, and makes overall recommendations for future work.

1.1.2 The California MTBE Research Partnership

In 1996, the City of Santa Monica, California lost 50 percent of its drinking water supply because of MTBE contamination. As a result, the city pursued a cooperative effort with the petrochemical industry and the Association of California Water Agencies (ACWA) to examine MTBE treatment alternatives.

In October 1997, the Western States Petroleum Association (WSPA), the Oxygenated Fuels Association (OFA), and ACWA formed the California MTBE Research Partnership to develop a statewide research program concerned with MTBE treatment technology and source-protection issues. Since then, the Partnership has invested nearly a million dollars to support a comprehensive research program, which is managed by the National Water Research Institute, to address MTBE treatment and protection needs.

The mission of the Partnership is *to identify, prioritize, plan, and sponsor practical research projects to protect, treat, or remove MTBE contamination from drinking-water supplies*. To fulfill this mission, the Partnership has created two focus-area subcommittees to investigate and develop Partnership projects: the Treatability Committee and the Source Water Protection Committee. Each group is comprised of engineers and scientists who represent water utilities, regulatory agencies, the petrochemical industry, academia, and the environmental consulting field.

1.1.3 Preliminary Evaluation or Selection of Treatment Technologies

The purpose of the Treatability Committee is: 1) to evaluate existing and emerging technologies for removal of MTBE and other oxygenates from water; 2) to identify research needs to improve the efficiency of existing technologies; 3) to develop alternative technologies for MTBE removal; and, 4) to coordinate the funding and implementation of identified research projects.

The first meeting of the Treatability Work Group in October 1997 identified research needs for the following five technologies:

- Air Stripping
- AOPs
- Adsorption
- Membranes
- Biological Treatment

Criteria for the selection and evaluation of alternative technologies included the following:

- Ability to consistently meet drinking water criteria (e.g., 5 µg/L)
- Cost-effectiveness
- By-product formation
- Residuals and their impact
- Impact of other constituents in water (e.g., iron, manganese, total organic carbon [TOC]) and feed pretreatment requirements
- Operability (e.g., ability to run unattended)
- Compatibility with existing technologies
- Robustness (e.g., ability to deal with high and low flows and concentrations)
- Simplicity of operation

A second meeting of the Treatability Committee in January 1998 ranked the specific research needs identified during the first meeting and drafted research plan write-ups designed to meet these needs. The time scale for these tasks covered the fiscal years 1998 and 1999. Initially, the Treatability Committee decided that white papers and bench-scale studies would be conducted for each of the technologies. Subsequently, full-scale treatment evaluations may be considered for those technologies that are identified as having the greatest potential for cost competitive and effective removal of MTBE.

At present, the state of knowledge on the treatment of MTBE in drinking water is limited due to the few instances of full-scale drinking water systems where MTBE treatment has been required. However, since the completion of the first edition of this document, numerous pilot and/or field studies have been conducted and/or identified and now provide a significant increase in information that was previously unavailable. The results of this technology evaluation will be of great interest to all water utilities, regulatory agencies, the petrochemical industry, the environmental community, and the public. These evaluations and this report can serve as guidance for federal and state regulators, water utilities, and the petrochemical industry when evaluating the treatment options for MTBE in drinking water.

1.2 History of MTBE Use

1.2.1 MTBE as an Oxygenate

MTBE is an oxygenate compound added to gasoline to enhance octane level and meet the oxygen requirements mandated in the Clean Air Acts Amendments. There are several types of oxygenated fuel — Oxyfuel, Reformulated Gasoline (RFG), and California Air Resources Board (CARB) phase 2 fuel — each with a different specification for oxygen content. Oxyfuel is mandated in carbon monoxide non-attainment areas and requires 2.7 percent by weight oxygen, which corresponds to 15 percent by volume MTBE. RFG is mandated in ozone non-attainment areas and requires 2.0 percent by weight oxygen, corresponding to 11 percent by volume MTBE. Finally, CARB fuel is a California-only fuel based on a predictive model that requires 1.8 to 2.2 percent by weight oxygen. When gasoline is released into the environment, a variety of chemical compounds, including MTBE, can be transferred into the air or water. Because of MTBE's particular physio-chemical properties (such as high solubility, low soil-to-water partition coefficient, and low Henry's constant), it is somewhat difficult to remove from water.

Overall, MTBE treatment presents specific challenges, including the need to implement a readily available removal technology in a timely manner. Because of this, the Partnership's Treatability Committee investigated only the most promising and widely accepted technologies. The group chose to evaluate air stripping, advanced oxidation, carbon adsorption, and synthetic resin sorbents for two reasons: these technologies are proven effective in removing organic compounds; and, California regulators find these technologies generally acceptable for treating drinking water. Membranes, biological treatment, and other alternative technologies may be considered at a later date.

Treatment costs depend on existing system conditions: specifically, system flow rates, MTBE influent concentrations, and the level of treatment needed for MTBE to reach the desired effluent goal. Based on these variables, the Treatability Committee chose specific conditions to evaluate priority technologies. The water-supply flow rates were considered at 6,000, 600, and 60 gallons per minute. At each of these flow rates, the technologies were analyzed for MTBE influent concentrations of 2,000, 200, and 20 µg/L. The MTBE effluent levels were considered at 20 µg/L, 5 µg/L, and non-detect (represented by 0.5 mg/L).

1.2.2 Physical and Chemical Characteristics

MTBE is a polar organic compound that has a chemical formula of $\text{CH}_3\text{OC}(\text{CH}_3)_3$. At room temperature, it is a volatile, flammable, colorless liquid with a terpene-like odor (Squillace et al., 1997). The taste and odor thresholds for MTBE in water range from 2.5 µg/L to 680 µg/L, and 2 µg/L to 190 µg/L, respectively, depending on the individual being tested, level of chlorination, temperature of the water, and other factors (API, 1994; ARCO, 1993; Young et al., 1996; Shen et al., 1997; Malcolm Pirnie, 1998; Dale et al., 1998).

It has been suggested that the treatment of MTBE in drinking water using conventional treatment processes (i.e., air stripping and GAC) poses challenges relative to other organic contaminants, particularly benzene, toluene, ethylbenzene, and xylenes (BTEX) compounds, because of its unique physical and chemical properties. A summary of the physical and chemical characteristics of MTBE relative to BTEX compounds is presented in Table 1-1. As this table shows, MTBE's Henry's constant is approximately an order of magnitude lower than those of BTEX compounds. Since the air stripping potential of a compound is primarily determined by its Henry's constant (H), air stripping of MTBE will tend to be more difficult and more costly relative to these other compounds. Furthermore, the relatively low organic carbon partitioning coefficient (K_{OC}) and the high water solubility of MTBE make GAC adsorption less effective for MTBE relative to BTEX compounds.

Table 1-1
Physical and Chemical Characteristics of BTEX Compounds and MTBE

Physical and Chemical Properties	Benzene	Toluene	Ethylbenzene	o-Xylene	MTBE
Molecular weight [g/mole]	78.11	92.14	106.17	106.17	88.15
Vapor Density @ 1 atm; 10°C	3.36	3.97	4.57	4.57	3.80
Specific gravity @ 25°C	0.88 ^a	0.8669 ^a	0.867 ^a	0.8802 ^a	0.744 ^a
Boiling point [°C]	80.1 ^a	110.6 ^a	136.25 ^a	144.4 ^a	53.6 - 55.2 ^a
Water solubility [mg/L]	1730 ^a	534.8 ^a	161 ^a	175 ^a	43,000 - 54,300 50,000 ^a
Vapor pressure [mm Hg] (@25°C) [kPa] (@100°F)	76, 95.19 ^a 1.26 ^b	28.4 ^a 3.79 ^b	9.53 ^a 1.23 ^b	6.6 ^a 0.889 ^b	245 - 276 ^a 3.33 ^a
Henry's Law Constant [-]	0.23 ^b	0.272 ^b	0.336 ^b	0.212 ^b	0.018 @ 20°C ^a
Log K_{OC}	1.18-1.99 1.50-2.16 ^a	1.56-2.25 ^a	2.94 1.98-3.04 ^a	1.68-1.83 ^a	1.091, 1.035, 1.049 ^a
Log K_{OW}	2.36 ^b	2.73 ^b	3.24 ^b	3.10 ^b	1.20 ^a
Diffusivity (m ² /s) Liquid Gas	9.95 x 10 ⁻¹⁰ 9.36 x 10 ⁻⁶ ^b	8.87 x 10 ⁻¹⁰ 8.35 x 10 ⁻⁶ ^b	8.6 x 10 ⁻¹⁰ 7.59 x 10 ⁻⁶ ^b	8.6 x 10 ⁻¹⁰ 7.56 x 10 ⁻⁶ ^b	8.58 x 10 ⁻¹⁰ 8.45 x 10 ⁻⁶ ^b

^a OSTP Report, 1997

^b Crittenden et al., 1997

MTBE has been found to be recalcitrant relative to BTEX compounds; however, its biodegradation is actively being investigated by several researchers (e.g., Hanson et al., 1999; Salanitro et al., 1999).

1.2.3 Impact of MTBE on Water Supplies

The state of California is the third largest gasoline consumer in the world, with more than 13.7 billion gallons of gasoline used per year. Because of air pollution problems, CARB and the United States Environmental Protection Agency (EPA) mandated the use of oxygenated fuels in California to improve vehicle octane ratings and reduce tailpipe emissions. Although MTBE is credited with significantly reducing emission, it has also contaminated water supplies through accidental gasoline releases at dispensing sites, leaking product pipelines, and via leaks from underground storage tanks (USTs).

According to California monitoring data (November 19, 1999), MTBE concentrations greater than the detection level have impacted 62 of the 6,409 drinking-water sources sampled. However, contamination is not limited to California. Nationwide, there are numerous reports of MTBE leaks and spills from petroleum facilities, including refineries, terminals, pipelines, and service stations. Consequently, MTBE has received widespread attention from municipalities and other drinking water providers, particularly in California where two major drinking water supplies have been significantly impacted by MTBE releases into the environment.

1.3 Drinking Water Regulations

Drinking water quality requirements in California are governed by both the EPA and the California Department of Health Services (DHS) Office of Drinking Water Regulations. Suppliers of domestic water to the public must comply with the regulations adopted by the EPA under the United States Safe Drinking Water Act and with the DHS under the California Safe Drinking Water Act (SDWA). Because California has been granted primacy for enforcement of federal regulations, California must promulgate regulations that are no less stringent than the federal regulations. Historically, California drinking water regulations have been more stringent than the federal regulations.

Since SDWA was passed in 1974 by the United States Congress, it has been amended several times — with significant changes in the water quality regulations — in the last 10 years. The passage of the SDWA authorized the EPA to develop national standards and regulations for drinking water. The regulations controlled the contaminants in drinking water that may adversely affect the overall aesthetics (taste, color, odor, or other conditions) of drinking water and those which would have an adverse effect on health. Historically, the primacy of drinking water regulations on both the state and federal level has been to mandate drinking water standards on health-related contaminants and recommend goals on aesthetic-related parameters. The health-based standards are referred to as Primary Maximum Contaminant Levels (MCLs) and aesthetic-based standards are referred to as Secondary Maximum Contaminant Levels (SMCLs).

Public awareness has increased significantly due to extensive pesticide and organic solvent groundwater contamination throughout the United States and, more recently, due to the detections of MTBE in a limited number of drinking water supplies. As the knowledge of health effects of groundwater contaminants increases, and the analytical detection limits of contaminants decreases, new or amended regulations are promulgated. The SDWA amendments of 1986 and 1996 have enacted numerous revisions, including new drinking water standards and monitoring requirements for existing and new contaminants. California has adopted more stringent standards for a number of inorganic and volatile organic compounds than federal requirements. Furthermore, California has regulations where the California Office of Environmental Health Hazard Assessment (OEHHA) has established Public Health Goals (PHGs) that, in some cases, are more stringent than the Primary and Secondary Drinking Water Standards under federal drinking water standards.

MTBE drinking water standards throughout the United States vary considerably. The concentrations range from 5 µg/L in California to over 240 µg/L in Michigan. In addition, approximately 17 states have not adopted standards and are relying on the EPA Drinking Water Advisory or waiting for the EPA to adopt an MCL. There is also a diversity of MTBE standards that have been developed for cleanup levels for contaminated sites. These standards vary significantly and many are adjusted based on the intended use of the type of water impacted.

1.3.1 Federal Standards

In December of 1996, the EPA issued a draft health advisory of 70 µg/L based on the presumed health effects of MTBE. The advisory level was based on kidney and liver effects observed in laboratory animal experiments (Office of Science and Technology, Office of the EPA). In December 1997, the EPA Office of Water issued a Drinking Water Advisory on MTBE (Drinking Water Advisory: Consumer Acceptability Advice and Health Effects on Methyl Tertiary-Butyl Ether). The advisory is not a mandatory standard for action, but discusses the limitations of estimating a risk level for MTBE in drinking water and characterizes the hazards associated with this route of exposure. The Advisory provides guidance to communities that have been exposed to water contaminated with MTBE. The Drinking Water Advisory concluded that “keeping the concentrations in the range of 20 µg/L to 40 µg/L or below will likely avert unpleasant taste and odor effects.”

1.3.2 California Drinking Water Standards

In 1997, two California bills (SB1189 by Hayden and AB592 by Kuehl) were signed into law requiring the DHS to develop Primary and Secondary Drinking Water Standards for MTBE. The bills required that the DHS establish the secondary drinking water standard by July 1, 1998 and the primary drinking water standard by July 1, 1999. At the time the bills were signed by the Governor, an action level had already been established in California in 1991 along with a draft federal health advisory level.

Action Levels

In 1991, the Pesticide and Environmental Toxicology Section — which is now OEHHA — developed an action level of 35 µg/L for MTBE. Action levels provide drinking water guidance for chemicals without drinking water standards. The 35 µg/L is based on non-carcinogenic effects with a large uncertainty factor to provide a margin of safety to exposure in drinking water.

In February 1997, DHS added MTBE to the unregulated (i.e., without an MCL or SMCL) chemical list for which monitoring is required. This monitoring requirement has created documentation on the extent of MTBE occurrences in groundwater and surface water sources. One important aspect in regards to monitoring for MTBE is the requirement that laboratories report MTBE analytical results at or above the detection limit for the purpose of reporting (DLR). The DLR established in August 1998 is 3 µg/L.

Public Health Goals

In March 1999, OEHHA adopted a PHG of 13 µg/L for MTBE. PHGs are developed for chemical contaminants based on the best available toxicological data in the scientific literature. PHGs provide estimates on the levels of contaminants in drinking water that would

pose no significant health risk to individuals consuming the water on a daily basis over a lifetime of exposure. The PHG for MTBE is based on carcinogenic effects observed in animals. They are strictly health-based standards set at levels that OEHHA has determined do not pose any significant risk to health.

The PHG of 13 µg/L will be used as an advisory action level by DHS until a primary drinking water standard is established for MTBE. The action level will be used to protect against health risks associated with exposures to MTBE in drinking water.

Secondary Drinking Water Standards

On January 7, 1999, DHS adopted a secondary drinking water standard of 5 µg/L for MTBE. This enforceable SMCL was based on the aesthetic concerns associated with taste and odor detections at low concentrations. This level was established to protect the public from exposure to MTBE in drinking water at levels that can be smelled or tasted. If a drinking water source for a public water system is discovered to contain MTBE in excess of 5 µg/L, the water system is required to notify the governing body of the local agency in which users of the drinking water reside within 30 days of the discovery. The DHS will advise the utility to remove the contaminated source from service, but the utility may elect to continue using the contaminated water. The utility may choose to continue to deliver water above the secondary standard if it has no other sources to meet water system demands. However, the utility will have to provide public notification to each of its customers.

Primary Drinking Water Standards

A primary drinking water standard of 13 µg/L has been proposed by DHS and is expected to be adopted in early to mid-2000. Primary standards include consideration of health risks, technical feasibility of meeting the proposed level, and costs associated with compliance monitoring. Primary drinking water standards are not to be exceeded in water supplied to the public.

Best Available Technology (BAT)

In California, as part of the establishment of a primary drinking water standard, a BAT for treating drinking water contaminated with MTBE must be identified. Selection of the BAT has to take into consideration the costs and benefits of the best available technology that has proven effective under full-scale field applications (California Health and Safety Code, Section 116730). The September 7, 1999 proposed rulemaking for establishment of the Primary Drinking Water Standard, identified air stripping as the BAT for treating water contaminated with MTBE. Because there were only a limited number of sites which had “full-scale field applications” and because those sites identified were only air stripping systems, the proposal of air stripping as the BAT relied on these field applications. There was

not sufficient data in regards to other technologies, including AOPs, GAC, biological treatment, resins, and membrane separation.

Air stripping is expected to be approved as the BAT by DHS for MTBE. However, it is also likely that, due to the significant amount of data compiled on the use of GAC for removal of MTBE, GAC may also be included as a BAT.

Permitting Requirements in California

In California, domestic water supply permits are issued by the DHS Office of Drinking Water. The Field Operations District Offices are responsible for the inspection and regulatory oversight of approximately 8,500 public water systems to assure delivery of safe drinking water to all California consumers. The oversight includes issuing permits, performing inspections of existing systems, reviewing and approving plans for new facilities, issuing administrative orders and citations for violations against systems in non-compliance with laws and regulations, and ensuring that water quality monitoring is conducted in accordance with the law.

The installation of a treatment system to treat municipal wells impacted by groundwater contamination requires the approval of DHS. Water systems considering the installation of a treatment system to remove contaminants from groundwater have to undergo a formal process to obtain a permit or amend an existing water supply permit to permit the installation of the treatment system. Typically, the permit would require the applicant to complete an application and prepare a technical report providing sufficient detail to show that the proposed treatment system can produce a continuous supply of pure, wholesome, healthy, and potable water. The technical report must provide sufficient detail to allow DHS to prepare an engineering report that documents the findings of the DHS investigation and provides recommendations for issuance of a domestic water supply permit to operate the proposed treatment system.

The DHS engineering report will provide information as to the source of the groundwater, historical and current extent of the contamination, potential impacts of the hydrogeology, potential contaminant migration, and effects of the underlying aquifers. The report will also address the sanitary hazards and safeguards that protect the well. Recommendations are then developed for the issuance of the water supply permit to include a detailed description of the treatment train, design flow rates, and operational constraints. Specific monitoring is defined in accordance with the DHS *Vulnerability Assessment and Monitoring Frequency Guidelines* and a monitoring plan is established along with the effluent standards that must meet all MCLs and Action Levels established by DHS. Daily operational records, such as flow rate, volumes treated, chlorine residual measurements, bacteriological sample testing, and operation changes, must be maintained. A specific operations plan must also be developed by the permittee.

Policy Memo 97-005 Policy Guidance for Direct Domestic Use of Extremely Impaired Sources

In November 1997, DHS prepared policy guidance Memorandum No. 97-005 for the direct domestic use of extremely impaired sources. The document provides the philosophy behind the policy, its purpose, and the specific elements of the evaluation process by which DHS approves the use of extremely impaired sources. The document sets forth the guidelines by which DHS approves the use of extremely impaired sources for drinking water use and the establishment of permit conditions. The drinking water “source” is considered the production well(s) and the aquifers(s) from which they draw. This guidance document outlines the elements of the evaluation process, including the 12-step process that would have to be conducted to receive a permit to use an extremely impaired drinking water source for domestic supply. Because the requirements would impact the selection of treatment for MTBE, relevant requirements of the policy are discussed in this document.

As stated in Memorandum 97-005, DHS subscribes “to the basic principle that only the best quality sources of water...should be used for drinking.” The memorandum goes on to say that “these sources should be protected against contamination.” DHS recognizes that “the use of contaminated water as a drinking water source always poses a greater health risk and ... the use of an extremely impaired source should not be approved unless the additional health risks...are known, minimized, and considered acceptable.” In addition, DHS clearly states in the memorandum that “drinking water quality and public health shall be given greater consideration than costs.”

This process requires the completion of 12 tasks in order to restore the use of water from the contaminated well field for domestic drinking water purposes. The permit application requires completion of the first eight tasks by the applicant.

The 12 tasks identified in DHS Policy 97-005 are as follows:

1. Perform Source Water Assessment
2. Perform Raw Water Quality Characterization
3. Develop Source Protection Program
4. Develop Effective Monitoring and Treatment
5. Develop Human Health Risks Associated with Failure of Proposed Treatment
6. Identification of Alternative Sources and Comparison of the Potential Health Risks to those of the Project Potential Health Risk
7. Completion of California Environmental Quality Act (CEQA) Review
8. Complete Permit Application
9. Public Hearing

10. DHS Evaluation
11. Requirements for DHS Approval
12. Issuance or denial of Permit

After DHS reviews the permit application packet (Task 10) and other relevant information submitted, DHS will then request additional information or proceed to the Public Hearing (Task 9). Following the public hearing, DHS will either issue the permit with requirements, deny the permit (Tasks 11 and 12), or request additional information.

Task 4 of the DHS Policy 97-005 will be discussed here due to its importance for understanding these requirements when selecting treatment for water contaminated with MTBE. The treatment process for the use of extremely impaired sources must be at a minimum, the best available treatment technology as defined for the contaminant by the EPA or established by DHS. The treatment process must also be sufficiently reliable to the type and degree of contamination and must address all contaminants. Because the treatment process must also be commensurate to the degree of risk associated with the contaminants present and since a BAT for MTBE has not been established, the treatment process would have to be able to reliably produce water that meets drinking water standards. The use of multi-barrier or independent treatment systems operated in series could provide effective treatment as long as each treatment system is designed to treat all contaminants to meet drinking water standards.

In accordance with Policy 97-005, it can be construed that the use of multi-barrier treatment applications are expected to be required for sources containing MTBE that are extremely impaired under the following conditions:

- The Primary Treatment is not sufficiently reliable.
- The Primary Treatment is of uncertain effectiveness.
- There is no direct way to measure the contaminant.
- The health effect of the contaminant is acute.
- Very large reductions in contaminant concentration are required.

The treatment processes employed to treat sources contaminated with MTBE must protect the public from exposure to water-borne contaminants and must comply with all MCLs and action levels. The treatment processes must demonstrate the ability to meet varying source water quality while maintaining acceptable discharge criteria. The treatment process employed must include multiple levels of redundancy, must accommodate fluctuations in influent contaminant concentrations, and must be reliable to produce the purest wholesome water.

Multi-barrier treatment systems are expected to be required under most sites impacted by MTBE in California. As such, these sites would require the installation of a redundant

treatment system. In most cases, this redundant system will be GAC, due to its proven ability to remove MTBE to levels lower than the secondary MCL of 5 ug/L. In addition, GAC is the least expensive treatment process to install as a redundant process.

1.3.3 Analytical Methods

For drinking water, there are two most commonly used EPA analytical methods under existing regulations for detection of MTBE: EPA methods 502.2 and 524.2. These methods are used to quantify a significant number of regulated contaminants by most drinking water systems. Analogous to these two methods are EPA methods 8020 and 8260, which are used for nearly all types of water samples, but are most commonly used for water samples collected from contaminated groundwater sites. EPA method 8020 and EPA method 502 both use a Purge and Trap Capillary Column Gas Chromatography with Photoionization. EPA method 8260 is similar to EPA method 524.2 in that they both use Capillary Column Gas Chromatography with Mass Spectrometry Data System. A discussion on the two drinking water methods and their applicability is presented below.

EPA Method 502: Volatile Organic Compounds in Water by Purge and Trap Capillary Column Gas Chromatography with Photoionization and Electrolytic Conductivity Detector in Series

This method covers over 60 volatile organic compounds that contain halogen atoms and/or that are aromatic. It is primarily used for detection and quantification of contaminants in drinking water and other source waters. In this method, inert gas is bubbled through a 25 ml or 5 ml water sample. The quantity is dependent on the expected concentrations of analytes in the water sample. Purged sample components are trapped in a tube of sorbent material, which is then heated and backflushed with helium to desorb the trapped sample onto a capillary gas chromatography column. The analytes are then detected using a photoionization detector and a hall electrolytic conductivity placed in series. The photoionization detector is used for the aromatic compounds and the hall electrolytic conductivity is used for the halogenated compounds.

The method detection limits are dependent on the characteristics of the gas chromatographic equipment used, but can be as low as 0.1 µg/L for MTBE.

EPA Method 524.2: Measurement of Purgeable Organic Compounds in Water by Capillary Column Gas Chromatography with Mass Spectrometry Data System

This method covers over 60 volatile organic compounds. It is primarily used for detection and quantification of contaminants in drinking water. In this method, inert gas is bubbled through a 25 ml or 5 ml water sample. The quantity is dependent on the expected concentrations and analytes in the water sample. Purged sample components are trapped in a tube of sorbent material, which is then heated and backflushed with helium to desorb the trapped sample

onto a capillary gas chromatography column. The analytes are then detected using the mass spectrometry data system.

The method detection limits are dependent on the characteristics of the gas chromatographic mass spectrometry data system equipment used, but are commonly as low as 0.1 µg/L for MTBE.

EPA methods 502 and 524.2 are both methods acceptable for determining MTBE concentrations in groundwater; however, a significant number of false positive detections are suspected and have been reported using method 502. False positive detections occur when EPA method 502 detects MTBE while a confirmation analysis using EPA method 524.2 does not detect MTBE. The misidentification using EPA method 502 may be attributed to the presence of other contaminants (hydrocarbons) that may coelute with MTBE and then are incorrectly identified by the photoionization detector. False positive detections may be expected in other EPA methods (such as 8020), which also use Purge and Trap Capillary Column Gas Chromatography with Photoionization. As laboratories gain further experience analyzing MTBE, it is less likely that false positive results will be obtained. However, detections of MTBE using EPA method 502 should always be confirmed using EPA method 524.2.

1.4 Integration of Technologies

This report presents an evaluation of air stripping, AOPs, GAC, and synthetic resin sorbents for removal of MTBE from drinking water. During the formation of the Partnership's Treatability Subcommittee, it was recognized that other emerging technologies are also applicable for MTBE drinking water treatment, including membranes and biological processes. The Research Partnership continues to recognize these and other alternative treatment processes as representing significant potential; however, they were not reviewed in this report due to their limited pilot and field testing and emerging nature. As additional field and pilot-scale research is completed by other entities, the Research Partnership or other MTBE research organizations may choose to pursue these alternative treatment options in the future.

Despite the relatively proven nature of the treatment processes selected for review in this report, many treatment and remediation scenarios may require a combination of treatment processes to meet effluent criteria. For example, as noted above, all drinking water treatment process in California will likely require redundant treatment (i.e., a treatment process that serves as a barrier between the consumer and the contamination). In many cases, GAC will be used as the redundant process. Similarly, AOPs will often employ additional treatment processes to remove oxidation by-products or residual oxidants, as discussed in Chapter 3.

Alternatively, some treatment processes may not be able to reach drinking-water effluent criteria alone, especially in cases where the influent concentrations are high (e.g., 2,000 µg/L) and the effluent criteria is non-detect (e.g., 0.5 µg/L). In these circumstances, two treatment processes may be required — the first process would be used to lower concentrations by 90 to 99 percent and the second process would be used as a polishing step to remove the remaining 1 to 10 percent. Throughout this report, the economic evaluations for each treatment process were completed such that this process integration analysis is possible. For example, it is possible to estimate air stripping or AOP costs for removal of MTBE from 2,000 µg/L to 200 or 20 µg/L and GAC costs for removal of MTBE from 200 or 20 µg/L to 0.5 µg/L. The costs presented in this report have relied on similar assumptions for mark-up and water quality and, thus, the accuracy of the cost estimate for MTBE removal should not be affected by combining individual process costs.

1.4.1 Conclusion

In summary, this report presents a detailed literature review of the state-of-knowledge regarding the use of air stripping, AOPs, GAC, and synthetic resin sorbents for removal of MTBE from drinking water. In addition, each chapter presents a cost analysis, which can be used to estimate drinking water treatment costs as a function of flow rate, influent concentration, and removal efficiency. However, this cost analysis does not present costs as a function of water quality and should not be used in place of a site-specific engineering cost estimates. The Partnership is currently developing scopes of work or implementing projects to fill some of the research gaps identified within this document for each technology.

1.5 References

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