ALTERNATIVES TO METHYL BROMIDE

Prepared by

ICF Incorporated

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1. INTRODUCTION

Methyl bromide is used around the world as a fumigant to kill insects, nematodes, fungi, weeds, bacteria, and other pests that can damage agricultural commodities and other goods. Unfortunately, when methyl bromide is emitted during these applications, it can rise to the stratosphere and, through a series of chemical reactions, destroy ozone molecules that prevent harmful ultraviolet radiation from reaching the Earth's surface. Because of this, the United States Environmental Protection Agency (EPA) has proposed to list methyl bromide as a class I substance under the authority granted to it by Section 602 of the Clean Air Act Amendments of 1990. If promulgated, this action would require that methyl bromide production in the United States cease by the year 2000. In addition, manufacturers would be required to freeze production at 1991 levels by January 1, 1994.

This report examines the alternatives that have been discussed as substitutes for current methyl bromide uses if methyl bromide is no longer available and discusses the economic implications of the proposed phaseout. In particular, the report provides an up-to-date "snapshot" of the alternatives so that policy makers and others can understand the state of their development and their key characteristics.

To some extent the report has simplified the issues regarding methyl bromide and its alternatives in order that they could be presented in an accessible fashion. As a result, the report has several limitations. The primary limitation is that the report only examines broad general end uses, when in fact, most decisions regarding alternatives must be made with knowledge of the specific crop or commodity to be treated. The report also does not address regional differences although weather patterns, soil conditions, consumer markets, and regulatory requirements all depend upon the location of treatment.

The remainder of the report is divided into the following three parts:

- Part 1 provides an overview of the current uses of methyl bromide and its historical consumption, lists the major types of alternatives to methyl bromide, discusses several criteria that can be used to evaluate these alternatives, and provides an overview of the likely alternatives users would employ in the absence of methyl bromide;

- Part 2 quantitatively analyzes the cost and cost-effectiveness of the proposed phaseout and explains the key factors that influence estimates of costs and cost-effectiveness;

- Part 3 contains a series of "fact sheets" on the most promising alternatives, each of which includes basic information with regards to a particular alternative on each of the criteria introduced in Part 1.

PART 1

METHYL BROMIDE AND ITS ALTERNATIVES

This part of the report contains Sections 2 through 4. Section 2 reviews the current uses of methyl bromide and its historical consumption. Section 3 surveys the most often discussed and/or promising alternatives to methyl bromide. Section 4 discusses several criteria that can be used to evaluate these alternatives. Section 5 provides a general perspective on the likely alternatives users would choose if the proposed rule were promulgated.

2. CURRENT USES OF METHYL BROMIDE AND HISTORICAL CONSUMPTION

This section discusses the end uses of methyl bromide and presents data on the consumption in these end uses and aggregate consumption over time. The general methyl bromide end uses are (1) soil fumigation (80%), (2) commodity fumigation (8%), and (3) structural fumigation (11%). Methyl bromide is also used as a chemical intermediate in some industrial processes, but because it is not released to the atmosphere during these processes, this end use is not considered in this report.

Each of the end uses can be further divided into smaller end uses. It could be argued that the most appropriate classification would identify each crop or commodity treated in each region of the country, but this would lead to a considerably more detailed discussion than was intended for this report. Accordingly, sub-end uses were chosen that capture the most significant differences in application parameters and requirements that affect the feasibility of alternatives within each of the major end uses.

2.1 Soil Fumigation

The main use of methyl bromide in the United States is as a pre-plant soil fumigant to control nematodes[1] and to a lesser extent soil borne diseases and weeds. The chemical is typically applied as a liquid and then covered with a polyethylene tarpaulin. The liquid quickly vaporizes and the tarpaulin contains the gas in the soil. If the liquid is injected deep enough into the soil (i.e., approximately two feet or more), tarpaulins are not necessary.

Methyl bromide is seldom applied in its pure form, but rather is mixed with chloropicrin, an excellent fungicide that can also kill some other pests. A common mixture is two parts methyl bromide, to one part chloropicrin. Some formulations, however, only contain one half of one percent of chloropicrin. In these cases, the chloropicrin is not used for its active ingredient, but for its distinct smell. Methyl bromide is odorless and, therefore, at a minimum must be mixed with a chemical that has a noticeable odor so that people can know when it is present to protect their health and safety.

The soil fumigation end use can be divided into three smaller end uses: (1) small fruits and vegetables (57% of end use), (2) nursery production (15% of end use), and (3) orchards and vineyards (28% of end use).

2.1.1 Small Fruits and Vegetables

Because methyl bromide is more expensive than many other pesticides, it is most commonly used in the production of high value[2] crops such as small fruits and vegetables. The chemical is applied to the soil each year before the crops are planted. The majority of methyl bromide use in this end use is devoted to tomatoes and strawberries. Significant amounts of methyl bromide are also used in the production of peppers and melons.

Growers in California and Florida are by far the biggest users of methyl bromide in this end use. These states rely more heavily than others on chemical treatments to control some types of pests because they do not experience the cold winters that will usually kill these pests.

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[1] Nematodes are worm-like creatures characterized by unsegmented bodies (unlike insects which have three segments) and a single continuous digestive system. They range in size from microscopic to over two feet long.

[2] Although there is no precise threshold between low and high value crops, high value crops are typically those sold in produce markets directly to consumers. These items earn much higher revenues than low value crops such as grains, which are often fed to animals.

2.1.2 Orchards and Vineyards

The major crops in this end use are almonds, grapes, peaches, and citrus fruit such as oranges and grapefruit. Orchards and vineyards are planted in ten to fifteen year cycles as opposed to annual cycles. Accordingly, methyl bromide is only used as a pre-plant soil fumigant for these crops every ten to fifteen years. The exception is when a significant number of trees or vines in a particular area die due to severe pest infestation. In these cases, the dead trees are removed and the soil is fumigated before new trees or vines are planted.

2.1.3 Nursery Production

Nursery production includes forest tree production and growing plants from seeds to be transplanted later (e.g., tobacco and tomato seedlings). Fumigation in the nursery production end use is similar to other types of soil fumigation, but much higher efficacy levels are usually required in this end use. This is because seedlings and young plants are much more susceptible to pests than mature plants. In addition, plants that grow in a pest-free environment early in their life are often better able to withstand pests later in life. Because of this, many growers will only purchase plants that are certified to be pest-free. The certification process precludes the use of pest control methods that are not fully efficacious.

2.2 Commodity Fumigation

Commodity fumigation involves exposing a commodity to a lethal gas for a period lasting from a few hours to several days to kill pests that could damage the commodity or cross geographical barriers and infect susceptible crops or commodities. Most treatments involve the use of a sealed fumigation chamber, but methyl bromide only requires that a tarpaulin be placed over the items to be fumigated. Although the technology is similar in all commodity applications, commodity fumigation can be divided into three end uses: (1) perishable commodity fumigation (62% of end use), (2) non-perishable commodity fumigation (30% of end use), and (3) quarantine fumigation (8% of end use).

2.2.1 Perishable Commodities

Examples of perishable commodities include dried fruits and nuts, citrus fruits, and blueberries. These commodities are particularly prone to pest infestation after they are harvested. Treatments need to be as short as possible because these commodities will spoil after a period of time.

Commodities in this end use also can be easily damaged by unusually high or low temperatures. High temperatures can cause the commodities to rot. Low temperatures can cause food to lose its flavor or to fail to ripen properly. For this reason, pest-control treatments that rely on the use of heat or cold will not be an option in many cases.

2.2.2 Non-Perishable Commodities

Grain is the predominant commodity in this end use. Because it does not easily spoil, the duration of the treatment is not a key constraint. Treatments are sometimes repeated regularly if the commodities are stored for long periods of time. In some cases, commodities can be stored for several years (e.g., wheat).

2.2.3 Quarantine Treatments

Quarantine treatments employ the same basic technology as other commodity end uses, but are distinct in that they are governed by strict regulations that require very high efficacy levels. For example, the United States Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS) requires efficacy levels of 99.9968 percent for most treatments.

The primary objective of quarantine treatments is to prevent particular pests from establishing themselves in an area where they are not present, not just to control existing pest populations so that they do not cause economic damage. The treatments are usually conducted at international borders, but can also be required for movements of commodities from one state to another. For example, California requires that citrus products from Florida undergo quarantine treatments entering the State to prevent certain species of fruit flies from establishing themselves in that part of the country.

In general the only difference between quarantine treatments and other commodity treatments is the level of efficacy required. Therefore, most of the discussion applicable to perishable and non-perishable commodity treatments also applies to quarantine treatments. Alternatives are more restricted for quarantine treatments than for other commodity treatments, due to efficacy requirements, but otherwise are very similar.

2.3 Structural Fumigation

Structures fumigated in this end use include crop storage areas, food processing plants, warehouses, mills, and grain elevators. In general, the objective of the fumigation treatment is to kill pests that might damage agricultural commodities that are stored in these buildings. The treatment usually involves sealing all windows and doors with polyethylene sheets and last several days.

The length of the treatment is critical in this end use because many facilities cannot afford to suspend operations for a significant period of time. Until recently, methyl bromide treatments could be completed within 48 hours. This allowed building owners to fumigate over a weekend when no one would have been in the building in any case.

However, due to concern for the safety of building occupants, California has set new requirements regarding acceptable concentration levels that have effectively increased the reentry time to seven days. Therefore, in California, methyl bromide no longer has as significant an advantage relative to alternatives as it once had.

Although not common, apartment buildings and residential homes are sometimes fumigated with methyl bromide in cases of extreme insect infestation. Methyl bromide use is limited in residential applications, however, because it can damage household furnishings such as carpet foam and furniture padding.

2.4 Historical Consumption

According to USDA's National Agricultural Pesticide Impact Assessment Program (NAPIAP), approximately 64 million pounds of methyl bromide were used in the United States in 1990. This production was divided as follows:

- Approximately six million pounds were used as a chemical intermediate (but none of this methyl bromide is emitted because it is destroyed during chemical manufacturing processes);
- Of the remaining 58 million pounds, approximately 46.5 million pounds (80%) were used for soil fumigation, 5 million for commodity fumigations (8%), and 6.5 million in structural fumigation (11%);
- Of the 46.5 million pounds used in the soil fumigation end use, approximately 26.5 million pounds (57%) were used for small fruits and vegetables, 13 million pounds

(28%) were used for orchards and vineyards, and 7 million pounds (15%) were used for nursery treatments; and

- Of the 5 million pounds used for commodity fumigation, approximately 3.1 million pounds (62%) were used for perishables, 1.5 million (30%) for non-perishables, and 0.4 million (8%) for quarantine treatments.

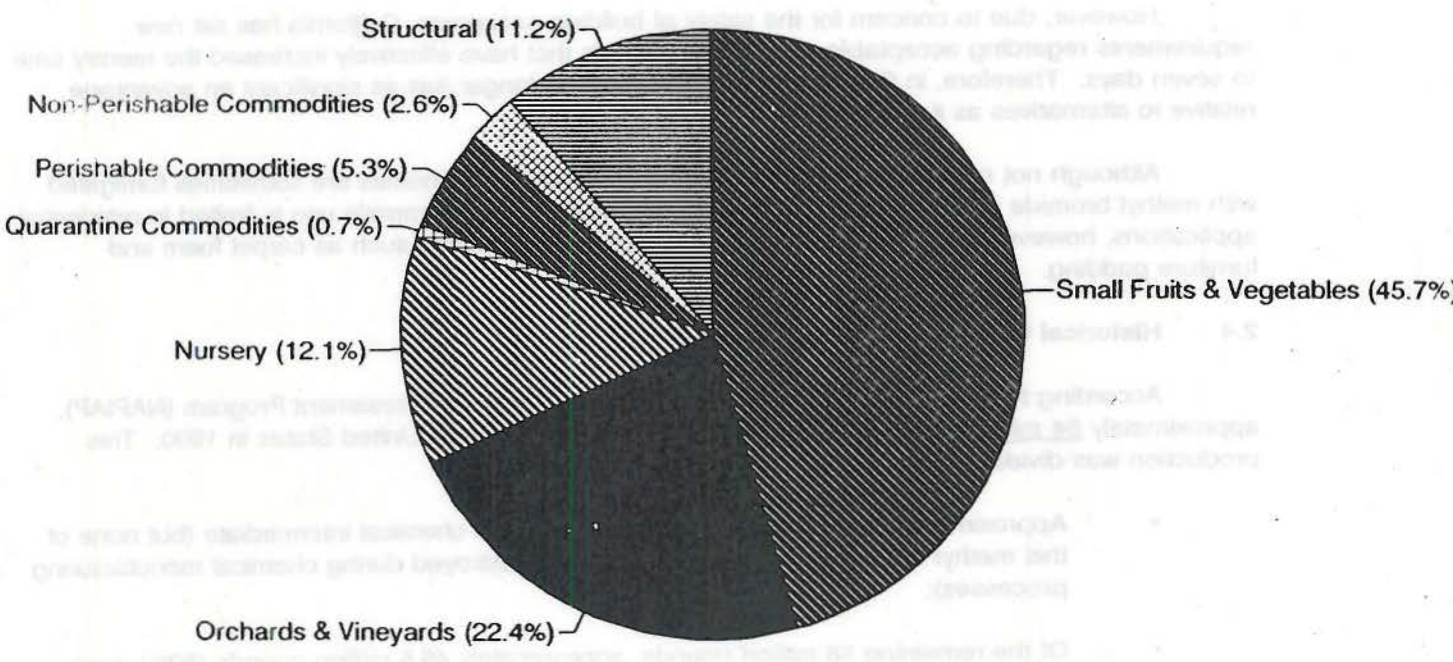
Exhibit 2-1 graphically displays U.S. consumption in each end use.

From a global perspective, U.S. consumption is approximately 40 percent of global consumption. Exhibit 2-2 shows 1990 global methyl bromide sales by world region. Although this chart does not provide an estimate specifically for the United States, the overwhelming majority of North American consumption occurs in this country. As the exhibit shows, regional proportions have remained roughly constant over the past decade.

Exhibit 2-3 displays how global methyl bromide sales have grown over time. Global methyl bromide production has growth at a rate of approximately 5.5 percent during the 1980s. Future U.S. consumption is expected to grow at a rate of approximately 2 percent.

Exhibit 2-1

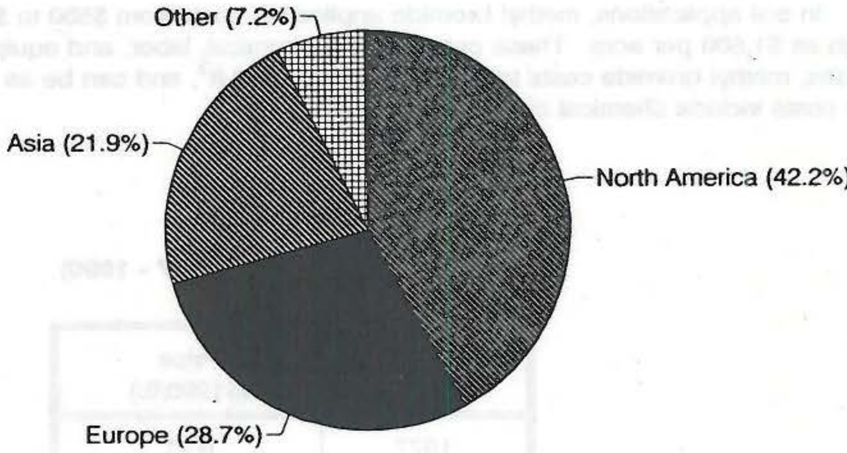
1990 U.S. Methyl Bromide Consumption by End Use (not including chemical intermediate use)



Total U.S. Sales: 58 Million Pounds

Exhibit 2-2

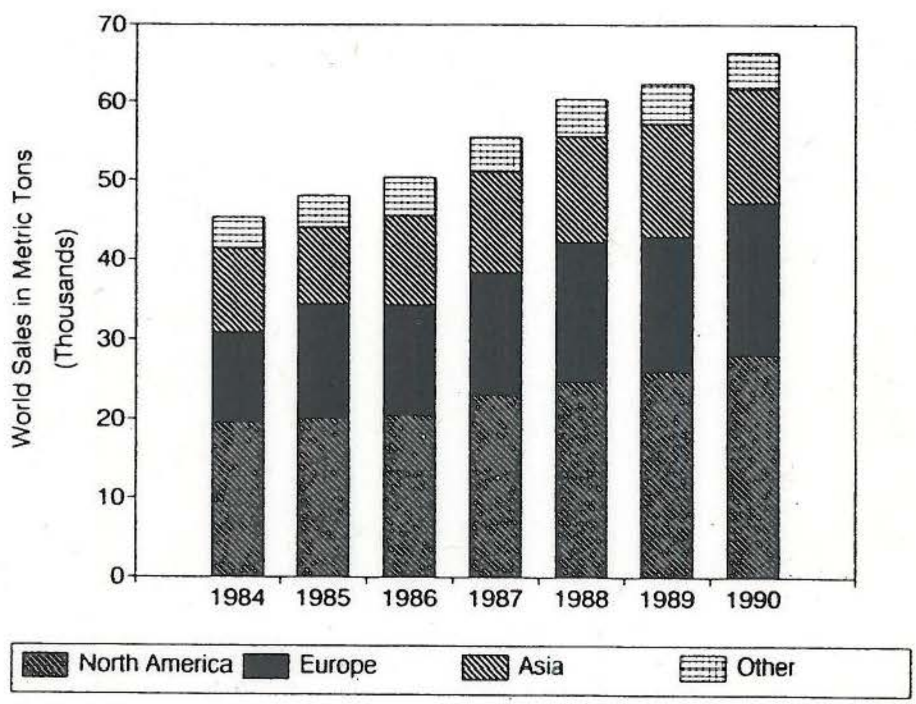
1990 Global Methyl Bromide Sales



Total 1990 Sales: 66.4 million lbs

Exhibit 2-3

Global Methyl Bromide Sales By Region Over Time



2.5 Methyl Bromide Costs

Exhibit 2-4 presents the price of methyl bromide per pound from 1977 to 1990 as reported by the *Chemical Marketing Reporter*. These prices reflect the prices manufacturers charge for bulk deliveries to distributors. Retail prices paid by users can be twice as high.

In soil applications, methyl bromide application costs from $500 to $1000 per acre, and can be as high as $1,500 per acre. These costs include chemical, labor, and equipment costs. In non-soil end uses, methyl bromide costs from $1 to $4 per 1,000 ft^3, and can be as high as $17 per 1,000 ft^3. These costs include chemical costs only.

Exhibit 2-4

Methyl Bromide Prices (1977 - 1990)

Year	Price ($1990/lb)
1977	0.71
1980	0.78
1986	0.64
1987	0.65
1988	0.92
1990	0.88

3. ALTERNATIVES TO METHYL BROMIDE

This section provides an overview of the different types of alternatives to methyl bromide. In general, there are two types of alternatives: chemical alternatives and non-chemical alternatives. In many cases, users can combine alternatives to meet their specific needs. Combination treatments can involve the use of two or more chemical alternatives, a mix of chemical and non-chemical treatments, or a combination of non-chemical alternatives. These replacement materials often do not duplicate the biocidal activity of methyl bromide, but rather control those pests which are currently being controlled by methyl bromide.

There are essentially three ways to prevent pests from destroying agricultural commodities: (1) control pest populations; (2) remove the plants or commodities from places where the pests are present; and (3) alter the plants or commodities themselves so that the pests no longer harm them. Chemical alternatives are exclusively of the first type. Non-chemical treatment can involve any one of these three methods.

Sections 3.1 and 3.2 discuss chemical and non-chemical alternatives respectively. Section 3.3 presents the leading alternatives for each of the major methyl bromide end uses. For more detailed information on specific alternatives, see Part Three of the report.

3.1 Chemical Alternatives

There are a wide variety of chemical alternatives in each of the end uses that currently use methyl bromide. They can be classified using three parameters: (1) the spectrum of activity; (2) the mode of action; and (3) the application method. To a great extent, all of these are determined by the chemical properties of the active ingredients in the alternative's formulation.

3.1.1 Spectrum of Activity

The spectrum of activity is the range of pests that the alternative is capable of killing. Depending upon its spectrum of activity, an alternative might be referred to as an insecticide, nematicide, fungicide, bactericide, or herbicide. An alternative might be able to be classified across several of these categories, or it may have an even narrower spectrum of activity. For example, one pesticide might kill a wide range of both nematodes and insects, while another might only be able to control a particular kind of beetle. The spectrum of activity can also be limited to a particular life stage of a pest (e.g., adult, pupae, larvae, or egg) or growth stage (e.g., weeds before emergence, weeds after emergence).

Methyl bromide is a general biocide, meaning that it can kill most life forms with which it comes into contact. Many alternatives, however, are considered narrow-spectrum pesticides, meaning that they are only capable of controlling a single pest species or a small related group of species. In some cases, if an alternative has a narrower spectrum than methyl bromide, then the user may suffer economic damage due to the lack of full pest control. In other cases, the user may be able to combine pesticides to achieve the spectrum of activity desired in the given application.

Utilizing the principles of Integrated Pest Management (IPM), pest levels and potential economic injury can be quantified, thereby allowing the narrowest spectrum pesticide possible to be utilized. This has the effect of killing only the pests which are causing problems and no others (See section 4.1.2 Determining Efficacy Requirements for a further discussion on the spectrum of activity required for a particular application.)

3.1.2 Mode of Action

The mode of action of a pesticide refers to the way in which the alternative kills the pest being targeted, and often determines the pesticides spectrum of activity.

Pesticides that are applied to plants are either systemic or non-systemic. Systemic chemicals are carried through the plant (e.g., from leaves to roots) while non-systemic pesticides are not absorbed by plant tissue. Pesticides that are applied to plants can kill the plant itself (e.g., herbicides) or other pests that feed on the plant. In general, systemic pesticides are more effective because they provide control throughout the plant, but because of this, chemical residues are a greater problem with systemics than with non-systemics.

If a pesticide is designed to kill pests when they feed on a plant, whether systemic or non-systemic, it will only affect pests that are in the life stage in which plant feeding occurs. Eggs and larvae may still survive. Thus these types of pesticides often have a limited spectrum of activity.

Other modes of action include stomach and contact action. In the case of stomach action, the pesticide affects the digestive system and therefore must be eaten to be effective. Contact pesticides affect the circulatory or respiratory systems of the pest, but the pest must come into direct contact with the chemical in order for it to be effective.

Fumigants such as methyl bromide are especially effective because fumigant vapors can easily penetrate surfaces with which they come into contact. Thus they can move through the soils or the commodities to which they are applied and into the pests they are designed to kill.

3.1.3 Application Method

Application methods vary depending upon the end use in which the pesticide is being applied. The prevalent methods in the soil fumigation end use are as follows:

- Shank or chisel application, in which liquids or gases are injected into the ground at the required depth;
- Granular incorporation, in which the chemical formulation is spread over the soil and then tilled into it so that it is evenly distributed;
- Chemigation, in which the chemical is put into the irrigation system and distributed through the soil by the irrigation process; and
- Spray applications, in which booms, cones, or other types of equipment are used to apply liquid mixtures containing the pesticide.

In the quarantine, commodity, and structures end uses, there are two common treatment methods:

- Heat transformation, in which a heat transformer changes the fumigant from a liquid to a gas form and injects it into the treatment area; and
- Canister and pellet release, in which a fumigant is applied as a liquid or solid but evaporates without the use of a heat transformer.

Canisters are also used to a limited extent for small applications of soil treatments.

3.2 Non-Chemical Alternatives

Non-chemical alternatives include a variety of management techniques that either exclude the pest from the area, make the crop resistant to the pest, or alter the environment, without using chemicals, so that pest life can not be sustained.

3.2.1 Direct Pest Control

Methods by which one can kill pests without chemicals include exposing them to severe heat, exposing them to radiation, or asphyxiating them. Heat can be used in most end uses. In the soil fumigation end use, growers can inject steam into the soil to kill pests. A possible future approach, in which growers would use tarpaulins to trap the heat from the sun, is a technique called solarization. In the quarantine and commodity end uses, heat treatments are referred to as thermotherapy and can last from 50 minutes to 30 hours.

In the quarantine and commodity end uses, facilities can also kill pests using low levels of gamma radiation. This procedure involves placing commodities on a conveyor belt that moves through a radiation chamber. Another method involves putting the commodities into a sealed chamber that does not contain sufficient oxygen to support life. This is typically achieved by significantly increasing the amount of carbon dioxide or nitrogen in the chamber, referred to as controlled atmosphere. The treatment can last from 4 to 30 hours.

3.2.2 Pest-free Environments

For the most part, it is extremely difficult to create environments without pests. One way to eradicate soil pests, however, is to eliminate the soil. With an emerging technology called hydroponics, plant roots are placed in a tray of sand (or some other water-retaining substrate) and water containing the necessary nutrients is circulated through the trays. Fungi can still grow in this environment but they can be removed easily with a disinfectant. Although hydroponics is more expensive initially than traditional agricultural methods, it is promising because growers can greatly increase their output on a per acre basis using this new technology.

In the structural end use, more thorough sealing of facilities can greatly decrease the probability that pests will enter the facility, and will improve the efficacy of pest control methods treatments if the facility does become infested.

3.2.3 Pest-Resistant Commodities

The final non-chemical means of avoiding pest damage is to alter the commodities so that they are no longer as susceptible to damage. This can be accomplished by finding plant varieties that are resistant to the most prevalent pests in a particular area. Genetic engineering is another way of increasing plants' resistance to pests, although this technology is still in its earliest stages of development. Importantly, pest resistance is not limited to agricultural products. For example, the surface of wood structures or furniture can be treated so that pests will not bore into them.

3.3 Alternatives by End Use

Exhibit 3-1 presents a list of the leading chemical and non-chemical alternatives to methyl bromide and the end uses in which they are applicable. For more specific information on each of these alternatives, see the fact sheets in Part Three of the report.

Exhibit 3-1. Potential/Candidate Alternatives and Their End Uses

ALTERNATIVES	SOIL USE AREAS			NON-SOIL USE AREAS			
	Small Fruits and Vegetables	Nursery Production	Orchards and Vineyards	Perishable Commodities	Non-Perishable Commodities	Quarantine	Structures
Vorlex®	X	X	X				
Telone C-17®	X	X	X				
Dazomet	X	X	X				
Metam-sodium	X	X	X				
Enzone®	X		X				
Formalin/Formaldehyde	X	X	X				
Steam	X	X					
Solarization	X	X	X				
Hydroponics	X						
Non-fumigant Pesticides	X	X	X				
Organic Matter	X	X	X				
Plant Modification	X	X	X				
Integrated Pest Management	X	X	X				
Future and Preliminary Research Alternatives	X	X	X				
Irradiation				X	X	X	
Phosphine					X	X	X
Sulfuryl Fluoride						X	X
Previously Used/ Limited Use Alternatives						X	
Controlled/Modified Atmosphere					X	X	X
Thermotherapy				X	X	X	X
Combination Treatments	X	X	X	X	X	X	X

4. CRITERIA FOR EVALUATING ALTERNATIVES

This section discusses some of the key criteria one should use to make judgements about the feasibility of an alternative to methyl bromide and whether users are likely to implement the alternative if EPA phases out production of the compound. These criteria are: (1) the efficacy of the alternative relative to methyl bromide and to that required for the particular application; (2) the current or expected regulatory status of the alternative; (3) the development of the market infrastructure that would be needed in order for the alternative to be widely commercially available; and (4) the cost of the alternative.

Health and safety concerns are also very important determinants of the feasibility of an alternative but they are, for the most part, covered by EPA's pesticide registration process. EPA's program is designed to prevent uses of pesticides that pose unacceptable risks to human health or the environment. A detailed assessment of health and safety factors is beyond the scope of this report, but a summary of toxicity data for methyl bromide and some alternatives is contained in Part 3.

4.1 Efficacy

The relative efficacy of an alternative to methyl bromide is the proportion of the given pest population that is killed as result of the application of the pesticide relative to the proportion that would have been killed by methyl bromide. Relative efficacy is a measure of how well an alternative works, and therefore, is an indicator of whether or not an alternative is feasible. The relative efficacy of an alternative must also be stated in terms of its spectrum of activity. In many cases, the relative efficacy of an alternative may vary depending upon the spectrum of activity in question.

It is important to consider that the ultimate goal of any pest control program, whether utilizing methyl bromide or another control agent, is to keep population numbers of economically injurious pests below damaging levels. Users' primary goal is to insure that the crop, commodity, or facility is not damaged by pests. Therefore, efficacy must be measured not only in relation to methyl bromide, but also as a function of direct pest control.

Importantly, low efficacy rates are only an issue from the perspective of the user if they lead to economic damage. In the case of soil fumigation, economic damage would result from lower crop yields. In the commodity and structural end uses, economic damage would result from the loss of commodities or products ruined by pests. In many cases, however, pest populations are not high enough to cause economic damage. Determining the feasibility of an alternative in a given application involves an assessment of both the efficacy of the alternative and the efficacy level required in that application.

The remainder of this section is divided into two subsections. Section 4.1.1 discusses the chemical and application factors that determine the efficacy of an alternative. Section 4.1.2 introduces the reasoning process by which one can determine if a given efficacy level is sufficient for a particular end use.

4.1.1 Factors that Influence the Efficacy of an Alternative

Although the efficacy of an alternative within a given spectrum of activity can be measured quantitatively in experiments, in practice the efficacy of an alternative may vary depending upon the context in which it is used. The factors that drive the performance of an alternative include:

- application parameters such as the application method and the rate of application;
-

- the chemical characteristics of the active ingredients[3] such as the chemical's mobility and penetration ability, and the duration of chemical activity; and

- climate and soil conditions.

Application Method

Improper application is perhaps the most important reason why the efficacy of an alternative might differ from its reported level. Even if a chemical alternative had the identical characteristics and spectrum of activity as methyl bromide, users might still experience greater pest populations because they would be unfamiliar with its use and, therefore, might apply it incorrectly. To some extent, the potential for lower yields explains why methyl bromide users resist a methyl bromide phaseout even for applications where there are promising alternatives.

The most common reason why a chemical treatment would fail to work as expected is if the chemical were not distributed evenly enough, and thus did not come into contact with the pests targeted for elimination. Granular soil fumigants are particularly susceptible to this problem if growers do not adequately till or irrigate the soil after application. Liquid soil fumigants can also fail if they are not contained in soil. Therefore, as with methyl bromide, the proper use of tarpaulins is often critical to the performance of such treatments.

Application Rate

EPA specifies maximum application rates for all pesticides based on health and safety considerations. At the same time, minimum application rates are needed to ensure the effectiveness of the treatment. If the minimum rate is relatively close to the maximum rate for a given alternative, then it is more likely that the treatment will fail due to uneven application or incomplete breakdown of the pesticide. Thus even if an alternative has the potential to be as efficacious as methyl bromide, it may not be because regulatory limits make it more likely that the quantity of chemical used in practice will be insufficient to kill the targeted pests.

Mobility and Penetration Ability

Some chemicals have a greater ability than others to move through soil or other media. If the active ingredients of a pesticide have only limited mobility, then it is more likely that uneven application will leave some areas inadequately treated. Even when the pesticide is applied correctly, weak penetration could mean that the chemical does not reach pests that reside within the item undergoing treatment (e.g., a type of fruit in the case of commodity fumigation, or wood furniture in the case of residential structure fumigation).

Duration of Chemical Activity

The length of time an active ingredient remains in the treated area before it breaks down affects the number of pests that may come into contact with the chemical. If some pests remain after application, chemicals with a significant duration period will be able to stop pests from repopulating the treatment area. On the other hand, if the treatment is consistently less than fully effective and the duration period is especially long, then some pests may develop a resistance to the treatment, thereby substantially reducing its efficacy.

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[3] Active ingredients of a pesticide refer to the part of the pesticide that actually kills the pests. There are often other chemicals in a formulation that are important to the application such as dispersers and warning agents.

In some cases, microbes and fungi can adapt to the pesticide and digest it before it can release its active ingredients. When this happens the treatment is rendered ineffective against all pests because the treatment is never in an active phase. For instance, granular formulations are susceptible to this problem because they take longer to release active ingredients than liquid formulations, and, therefore, give the microbes and fungi a longer period to digest them.

Duration can often be directly related to the formulation of the pesticide and the application method. In many cases, either of these characteristics can be modified to change the coverage and duration of a material in soil.

Climate

Weather conditions affect the rate at which pests populations can grow and therefore the time needed for them to reach dangerous levels. In Northern climates, winter freezes kill most pests, thereby providing a natural means of control. Cold climates can also slow the growth of pests in storage areas. If weather conditions are conducive to rapid pest growth, then users will be less likely to be able to tolerate lower efficacy rates than those achieved with methyl bromide.

Soil Conditions (soil fumigation only)

Soil conditions affect the ability of treatments to move through the soil and, in large part, determine the types of pests that will be present and their growth patterns. In addition, some pesticide treatments need certain soil conditions in order to work effectively and thus may only be able to be used in certain areas. For example, granular formulations rely on moisture in the soil to change them to their vapor state. Some pesticides injected into irrigation systems also rely on moisture to release their active ingredients.

4.1.2 Determining Efficacy Requirements

The easiest way to control pests in agricultural production or in another environment is to achieve a "total kill" of all life in the area in which one desires the control. Methyl bromide is a popular pesticide because it achieves as close to a "total kill" as one is likely to get with the use of a legal substance. Yet if "total kill" is held as the standard, then there is no known alternative that meets the same level of efficacy as methyl bromide in the applications in which it is currently used.

A "total kill," however, is almost never necessary to get a desirable outcome from the perspective of the user, and reductions in pesticide use are increasingly being viewed as necessary environmentally. Also, many soil organisms are considered beneficial, and will often aid in pest control efforts, making the "total kill" effect more costly than previously thought. For this reason, the future in pest control lies in "managing" pests with fewer environmentally-harmful substances rather than striving for the elimination of all life in the treatment area. This trend is likely to take place regardless of whether methyl bromide is phased out or not. Accordingly, statements about the efficacy of alternatives must be put in context regarding what level of pest control is actually needed in the given application.

In an integrated pest management regime, the user (possibly advised by the applicator) must go through a planning process to determine which pest control method to use. The planning process involves much more complex notions of acceptable efficacy levels than a simple comparison with methyl bromide, but it can lead to desirable results for the user. The process involves the following steps:

(1) For each potential pest, determine the population threshold at which the pest causes economic damage to the user (often referred to as the economic threshold limit);

(2) Determine ways in which the plant or commodity in question can be altered to change its resistance level to different types of pests, thereby changing the economic threshold limits for that commodity;

(3) For each potential alternative, review the efficacy of the treatment for each type of pest, not just all pests taken together;

(4) Identify the alternatives, or combination of alternatives, that will reduce each type of pest below the economic threshold limit for that pest; and

(5) Choose among the identified treatments and implement it when pest populations are near or are anticipated to rise above the economic threshold.

The first step is critical in the soil fumigation end use because many plants can still be fully productive in the presence of moderate pest populations. Thus, even a 20 percent efficacy decline relative to methyl bromide for a particular pest (e.g., insects) may not result in any yield loss in the final harvest. That same plant, however, may be susceptible to a particular fungus prevalent in the region in which the plant is grown. As a result, it may only be able to tolerate a 5 percent efficacy reduction before disease begins to destroy the crop. In the case of any crop, the key is to profile that crop's weaknesses.

The second step involves searching for ways in which these weaknesses can be overcome before initiating the pesticide treatment. For instance, in the example above, a another breed of the plant that is susceptible to the prevalent fungus may exist that is resistant to the fungus. Switching to the resistant plant could allow the grower to use a pesticide alternative that is a weak fungicide, but which can achieve the economic threshold limits for other pests. In many cases, plant varieties with different resistance characteristics are currently available. In the future, these different varieties may be created through genetic engineering.

Another step in the IPM process is to survey the soil and plants for pests and signs of pest damage. This should be done near the end of each cropping season, between seasons, before planting, and during the growing season. These surveys enable the grower to determine which pests are present and their population levels. Also, by closely following the pest populations, treatments can be applied at the most critical points. Surveying is also important for structural and commodity treatments. Food processing facilities, warehouses, and commodities in storage should be checked regularly for pests. Traps, pheromones and other techniques are used to determine pest population levels in these situations.

Once the user catalogs the various economic threshold limits and possible remedies, the user is then prepared to critically evaluate the alternatives. The consideration of combination treatments is very important at this stage. For example, many of the crops for which methyl bromide is used as a soil fumigant are susceptible to nematodes, but MITC, the active ingredient in several of the leading chemical substitutes, is a weak nematicide. The lower relative efficacy of MITC-based alternatives, however, is not necessarily a problem because they can be used in combination with a nematicide.

When evaluating the efficacy of alternatives or combination treatments in the soil fumigation end use, the grower must also be cognizant of the soil ecology. There are a number of predator-prey relationships that provide checks against the uncontrolled population growth of any one pest. When killing a particular pest, the user should know whether it is also killing its predator and, if so, what the consequences of that might be. Most treatments only last for a period of time, and whatever pests are left may quickly repopulate after the lethal effects of the treatment are over if no predators are present. Given knowledge of the soil conditions (and for given weather conditions), the user must forecast whether the economic threshold limits will be exceeded at any time during the growing process.

Given information about its pest control requirements and the efficacy of the potential alternatives with regard to each of the relevant pests, the user can, in many cases, implement an effective pest control program that, taken as a whole, can meet the same objectives achieved with methyl bromide. On the other hand, it should be recognized that it may take several years for users to develop these programs and that they may be more expensive than current treatments.

4.2 Registration Status

By law, all pesticides must be registered by EPA before they can be entered in to United States commerce. This section discusses (1) the statutes that authorize EPA's regulatory program; (2) the steps that a manufacturer must take to get a pesticide registered; (3) the implications of the registration process for the cost and availability date of alternatives; and (4) health and safety concerns in the context of the registration process.

4.2.1 Statutory Background

Although the use of pesticides is directly and indirectly affected by numerous statutes administered by several Federal agencies, two of the most significant statutes that underlie the registration process are the Federal Food, Drug, and Cosmetic Act (FFDCA) and its Amendments and the Federal Insecticide, Fungicide, and Rodenticide Act of 1947 (FIFRA) and its Amendments.

Federal Food, Drug, and Cosmetic Act (FFDCA)

FFDCA sets requirements regarding pesticide residues in foods and therefore governs what EPA can determine is safe in the registration process. The Act, however, does not directly set requirements regarding the registration process itself.

FFDCA requires the Federal Government to set Acceptable Daily Intake (ADI) levels (often called reference doses) for various pesticide residues. Tolerance levels are based on the active ingredients in a pesticide and also its degradation products. In the registration process, EPA uses the ADIs to determine the maximum quantity of pesticide that can be used in any given application and the maximum quantity that can be used in aggregate across all crops nationwide.

Unfortunately, this aspect of the law may discourage many manufacturers from registering alternatives for some of the minor use crops that currently rely on methyl bromide because doing so would prevent them from entering or retaining the larger markets generated by crops with much higher production volumes. ADI levels, in effect, cap the extent to which firms can expand the use of existing pesticides to replace methyl bromide.

The Delaney Clause of the 1958 Food Additives Amendment to FFDCA also may also affect the availability of many potential alternatives. The Delaney Clause prohibits the use of any carcinogenic substances in processed foods, but de minimis levels are allowed in fresh foods. For many years, EPA interpreted the statute as prohibiting additives that posed a significant cancer risk, but this will almost certainly change as a result of a recent decision by the Ninth Circuit Court of Appeals that ruled that "Congress intended to ban all carcinogenic food additives, regardless of amount or significance of risk."

Unless the law is amended, EPA may be required to suspend or cancel the registration of many pesticides. Fungicides are particularly vulnerable because many of them are potential carcinogens. The ruling could also affect the use of pesticides in the production of fresh foods because many growers often do not know whether their crops will be used for fresh or processed markets.

Federal Insecticide, Fungicide, and Rodenticide Act of 1947 (FIFRA)

FIFRA governs the registration process itself. The original statute requires the manufacturer to determine the safety of a pesticide before marketing it. Amendments to FIFRA prescribe the procedures that a firm shall follow to make the safety determination. The most significant amendment to FIFRA is the Federal Environmental Pesticide Control Act of 1972, which extends Federal pesticide regulations to all pesticides, including those distributed or used within a single state. Together with the FIFRA Amendments of 1975, 1978, and 1980, this statute virtually rewrote the original FIFRA law of 1947, implementing the testing protocols and data requirements that EPA uses currently.

The key provisions of FIFRA are as follows:

- All pesticides in U.S. commerce must be registered with EPA;
- Manufacturers must obtain an Experimental Use Permit before initiating the tests required by the registration process;
- Pesticides must be classified as general use or restricted use based on the products potential harm to human health and the environment (restricted use pesticides must be applied by a certified applicator);
- EPA can exempt a pesticide from registration requirements if it determines that emergency conditions exist (Section 18); and
- If EPA has reason to believe that a registered pesticide is a threat to the environment it can suspend the registration, cancel the registration, or change the classification (e.g., from general to restricted use).[4]

The 1988 Amendments to FIFRA (FIFRA 88)

FIFRA 88 requires that all pesticides registered before November 1, 1984 be reregistered by December 31, 1997. The intent of FIFRA 88 is to ensure that pesticides registered years ago meet current human health and environmental risk standards.

When FIFRA 88 was passed, there were approximately 44,000 registered pesticide products encompassing 611 active ingredients or groups of active ingredients. By October 1991, only 20,000 products encompassing 405 active ingredients remained both because many of the pesticides had become inactive registrations, and because many firms chose to voluntarily withdraw their applications for reregistration. Recently, Nor-Am withdrew Vorlex®, a promising alternative to methyl bromide in soil fumigation applications. Other alternatives may be subject to the same fate in the future.

FIFRA 88 also includes measures to accelerate the registration process, but despite this, only a few pesticides have been reregistered to date. There is some concern that many products will not meet the 1997 deadline. In other cases, manufacturers are withdrawing registration applications for minor use crops because they fear that by spreading their efforts they may not meet the deadline for the major use crops that comprise a larger portion of their market share.

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[4] Suspension is an immediate halt on the production, sale, and manufacture of a pesticide. In practice, suspension can be a stronger measure than cancellation because the manufacturer is allowed to sell a cancelled pesticide throughout the appeals process, which can last several years.

4.2.2 The Registration Process

This section reviews the stages of the FIFRA registration process and discusses additional requirements for treatments in the quarantine end use. With knowledge of the process, one can understand the hurdles that alternatives need to pass before they can replace methyl bromide.

The Stages of the Process

If a manufacturer would like to market a pesticide, the first step is to obtain an Experimental Use Permit (EUP). The permit allows the manufacturer to gather the field data needed to determine the efficacy of the product. To protect human health and the environment at this preliminary stage, EPA may establish a temporary pesticide tolerance level. EPA can also delegate this activity to State governments as long as they implement the program in a manner consistent with FIFRA requirements.

At this point the manufacturer also will have to pay registration fees to EPA. There is a fee paid for each product and each active ingredient. In the case of reregistration, firms pay fees each year until 1997, the final year of the reregistration process. Typically, fees range from approximately $5,000 (which encompasses several product labels) to $200,000 depending upon the products included. In many cases, the fees themselves discourage manufacturers from submitting new products. This is especially true in the case of reregistration, which involves payment of a one-time fee for each active ingredient, plus payment of maintenance fees for years without any certainty that the product will eventually be approved.

The second step involves performance of various tests that depend on the individual characteristics of the pesticide to be registered. All pesticide manufacturers must conduct a required set of tests including product chemistry, residue chemistry, and environmental fate. Furthermore, depending on the end use and the physical nature of the pesticide, additional tests may involve one or more of the following tests (see 40 CFR Part 158):

- Toxicology
- Post-application Exposure Monitoring/Reentry Protection
- Spray Drift
- Wildlife and Aquatic Organisms
- Plant Protection
- Nontarget insects
- Product performance
- Biochemical Pesticides
- Microbial Pesticides.

After collecting the required data, the manufacturer will also prepare a proposed product label describing the application method and rates to be used, and the need for safety devices or other precautions. The manufacturer would then submit the entire package to EPA for review. EPA can register the proposed pesticide, reject it, or work with the manufacturer to change the proposed application parameters if they do not adequately protect human health and the environment.

Finally, EPA has streamlined guidelines for minor use crops because it is realized that the costs of testing may prevent firms from developing low volume products. EPA has also reduced requirements for natural biochemical pesticides to promote their use. Despite these efforts, the cost of testing may cause some manufacturers to forego registration of methyl bromide alternatives for some market segments.

Special Requirements for Quarantine Treatments

In addition to EPA regulation, quarantine treatments are regulated by the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (APHIS). In the certification of a quarantine treatment, APHIS determines all application parameters for the pesticide, including application rate, atmospheric pressure, temperature, and, in some cases, humidity. Unlike EPA, APHIS examines the efficacy of a treatment in addition to its safety (EPA will only register a pesticide that has already proven effective; efficacy data must be kept for submission to EPA upon request). To be approved, a treatment must achieve a 99.9968 percent kill rate in experiments. Treatments are tested by pest species, by pest life stage, and by commodity.

By law, APHIS's standards must be at least as stringent from a health and safety perspective as those set by EPA under FIFRA. APHIS, however, may obtain FIFRA Section 18 exemptions by meeting several criteria, among which is declaring that an emergency exists when no feasible alternatives to the pesticide in a particular application are available.

Many exports are also subject to quarantine treatment. These treatments, however, are regulated by the import regulations of other national governments rather than APHIS. Many of these Governments would have to change their regulations for U.S. exporters to be able to use alternatives to methyl bromide. If they did not, a number of export businesses in the United States could no longer operate.

4.2.3 The Implications of the Registration Process for the Cost and Availability Date of New Pesticides[5]

The EPA registration process requires generation of health and safety data to ensure that a pesticide is safe, a requirement that is expensive and lengthy. Manufacturers can pay up $10 million in fees and testing costs for each pesticide by the time the process is complete. Not only does this add to the eventual price of manufacturing and developing alternative pesticides, in many cases it discourages manufacturers from making the investments necessary to commercialize it.

In addition, the length of the process is the primary determinant of the availability date of many methyl bromide alternatives. EPA estimates that a new active ingredient may take from six to nine years to move from development in the laboratory to commercialization. EPA review alone can take from two to three years, depending on data gaps and findings on the data submitted.

4.2.4 Health and Safety Concerns in the Context of the Registration Process

Evaluating the health and safety effects of alternatives is complicated by two factors: first, all pesticides are inherently dangerous because their function is to kill living things; and second, an extensive regulatory program exists to ensure that the use of pesticides is not harmful to human health and the environment. Thus, in most cases, alternatives will pose serious risks but these risks should be controlled by the current regulatory apparatus. A topic for future study is the quantification of these risks relative to those for methyl bromide.

Nevertheless, there are some risks that may not be adequately addressed by the regulatory process. These include: (1) risks due to non-compliance with current regulations; (2) risks from lack of scientific knowledge about pesticide chemistry; (3) inhalation exposure by people working or living near fumigation sites; and (4) risks to wildlife.

Non-compliance is difficult to control, but it is potentially a serious problem. A number of people have died from the acute toxic effects of methyl bromide because they reentered fumigated buildings too soon after treatment. In California the response has been to lower acceptable reentry

[5] While this section only addresses the registration of chemical control methods, it should be noted that other control methods, such as genetically engineered resistant plant varieties, must also be registered through the FDA.

concentrations from 5 to 3 parts per million. This, however, still does not protect those that unlawfully enter these areas. Indeed, a number of people have died during burglaries of fumigated structures.

In some cases, despite careful screening, not enough is known about chemical processes to be able to assess all potential risks before registering a pesticide. In particular, many of the degradation properties of pesticides are not well understood. In Florida, for example, a registered fungicide called Benlate® unexpectedly killed all the plants is a treatment area as a result of the unforeseen effects of the heat and humidity in the area.

There is also some evidence that tighter oversight of inhalation exposures may be needed. For example, workers at food processing plants have reported headaches, dizziness, and nausea when nearby storage facilities were fumigated even though the users were allegedly within all of the required application parameters. The potential risks of inhalation exposures are likely to increase in states such as California and Florida where rapid population growth is increasingly causing urban development to be contiguous with agricultural production.

Finally, there is some concern that current regulation may not adequately protect wildlife. For example, birds are known to ingest granular formulations of pesticides, mistaking pesticide granules for the small seeds or pebbles that they use as a digestive aid. Ingesting the pesticide is lethal in most cases. Because of this, EPA is considering avian granular protection regulations.

4.3 Market Infrastructure

The market infrastructure for developing an alternative refers to everything other than the regulatory and other legal matters that need to be in place before the alternative can be commercially available. Several of the key items that constitute market infrastructure include the following:

- Manufacturers must develop the capability to produce the alternative in sufficient quantities to supply the market;
- Applicators must acquire the equipment and skills needed to utilize the alternative;
- Users (or those purchasing pest control services) must have knowledge of the alternative and feel confident that it will be effective; and
- Consumers of end products may need to be convinced of the safety of the new chemical or method (EPA registration represents certification as to safety).

In most cases, manufacturers will be able to produce sufficient quantities of an alternative pesticide without much difficulty. For instance, if a chemical is already in use, but simply hasn't been registered for the crops that are currently treated with methyl bromide, then once the product is registered, plants should be able to increase production to needed levels within a matter of weeks or months. On the other hand, it may take firms up to two years to develop the manufacturing capability for newly-developed alternative pesticides.

In many cases, applicators will not face a difficult transition either. Soil fumigators that have had experience with a particular alternative may have little difficulty transferring their skills to crops whose soils are currently treated with methyl bromide. In addition, once application rates are set in commodity and structural treatments, the use of an alternative may involve little more than substituting one product for another.

The ease of the transition for applicators, however, is contingent upon the relative efficacy of the alternatives. If simple substitution does not produce acceptable results, applicators will need to take a much more sophisticated approach to pest control using approaches such as combination treatments and Integrated Pest Management (IPM). If a "total kill" is no longer possible, the focus will turn to ensuring that pests remain below their economic threshold levels. In this environment, applicators (or other agricultural service professionals) will need to test soils more frequently. They will have to have greater knowledge of the plants or trees they treat and of the soil ecology. This will either require training in pest identification and survey techniques, or require the grower to consult with an IPM field advisor. Data with which to evaluate the relative effectiveness of alternatives is not as yet available.

The users of methyl bromide (i.e, growers, importers, and building owners) are likely to resist alternatives because methyl bromide has consistently produced good results from their perspective. The market infrastructure needed to aid in changing their minds includes educational efforts by agricultural extension personnel and marketing efforts by manufacturers and applicators. Even the best substitutes may be difficult to sell. For instance, an alternative that is scientifically tested to be as effective as methyl bromide in the laboratory may not be effective in practice if applicators use it improperly due to lack of experience. One of the reasons users are reluctant to use alternatives is because they know this. Full acceptance of any alternative that is not already in widespread use will probably take at least two years. Information needed to evaluate what users are likely to do (and the associated costs) is not available at this time.

Consumers of the end products such as tomatoes and strawberries may also need to be persuaded of the merits of an alternative before it can be widely implemented. The use of genetic engineering and irradiation are likely to be the among the most controversial and consumers may reject these technologies even if the Federal Government certifies that they are safe. Not only is consumer acceptance difficult to predict, it may be the most subtle and difficult aspect of market infrastructure to establish.

4.4 Cost

The factors that influence the cost of an alternative include: (1) the costs manufacturers must incur to conduct registration tests and develop the alternative for commercial use; (2) the up-front equipment and training costs applicators and users must incur to be able to use the alternative; and (3) the incremental operating costs users will incur on a recurring basis.

4.4.1 Development and Testing Costs

Development costs are the costs required to determine the efficacy of the alternative and build the infrastructure needed to commercialize the product. To determine the efficacy of the alternative, the manufacturer will have to test the alternative to learn the most appropriate application rates and methods in each end use. As discussed in Section 4.3, building infrastructure can involve numerous tasks, such as constructing or expanding production facilities, training applicators and users, and persuading consumers of the merits of the new technology.

Testing costs refer to the cost of registering or reregistering an alternative. As mentioned in Section 4.2, registration tests are numerous and can take years to complete. The cost of registration or reregistration is often prohibitive and therefore prevents many manufacturers from commercializing their products.

In the long run, both development and testing costs will be reflected in the price of the alternative and borne by consumers. The one exception to this is when the Federal Government subsidizes some of these up-front costs. For example, USDA administers the IR4 program, which pays for the registration tests for pesticides that are intended for use on minor use crops. Alternatives that benefit from this program may have lower prices than those that do not. In these cases, the price of the product does not reflect the incremental social cost of the alternative because the it does not account for economic resources expended by the Government to commercialize that alternative.

4.4.2 Up-Front Transition Costs

Up-front transition costs are the costs entities other than manufacturers must incur to be able to use the alternative. These costs include the costs of purchasing new equipment or modifying existing equipment, or – in the case of commodity and quarantine end uses – building new or resealing existing treatment facilities. Applicators and users will also need to learn how to apply or use the new alternative. Even if manufacturers or agricultural extension offices provide instructional materials and general information for free, applicators and users will incur a cost simply by spending time on these matters.

One of the most difficult aspects of a transition to alternatives to quantify is the impact of increased treatment times. In the quarantine, commodity, and structural fumigation end uses, some alternatives need to be applied for much longer periods than methyl bromide (in some cases, several days longer). If a facility chose to switch to one of these alternatives as a result of the proposed methyl bromide phaseout, it might have to build additional fumigation chambers to handle the same volume of business, or it might choose to forego some of its current business. On the other hand, if the facility currently has periods of time in which it is not in operation, then it may be able to handle longer application periods without major modifications to procedures or equipment.

4.4.3 Incremental Operating Costs

Incremental operating costs include incremental chemical costs (if the alternative is a chemical treatment), incremental labor costs, changes in production costs due to changes in treatment efficacy, and costs associated with different treatment times.

Incremental chemical and labor costs are fairly straightforward. The cost of a chemical substitute might be different from methyl bromide, either because its unit cost (e.g., price per pound) is different, because it requires a different application rate, or due to changes in the competitive market structure.[6] Incremental chemical and labor costs may decline over time as manufacturers, applicators, and users gain experience and discover cost-saving technologies and methods.

The cost of the lower relative efficacy of an alternative is measured by the increase in the average production cost that would result from the decline in output. Once it is determined what percentage of a commodity is unable to be sold due to the lower relative efficacy of a treatment, the treatment and planting costs are sunk. These sunk costs increase the average cost of producing and marketing the commodities that remain.

It is important to think of efficacy reductions in terms of average production costs because given the new average cost structure, growers or importers may choose to expand production to make up for lost output. For example, a 10 percent efficacy reduction in an end use does not mean that there will be a 10 percent reduction in the supply of the commodities in that end use.

The economics of efficacy reductions is further complicated by the fact that lower relative efficacy rates will cause users to employ combination treatments and Integrated Pest Management (IPM) techniques. These types of treatments involve more frequent soil testing and more extensive

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[6] Changes in market structure may mean that firms will produce methyl bromide and its alternatives in different quantities and, therefore, may either lose or gain economies of scale. In this occurs, changes in the prices of the various chemicals may reflect changes in production costs. These price changes would result in social costs because real economic resources are involved. On the other hand, changes in the market structure of the industry may cause some firms to gain or lose market power. Price changes as a result of changes in market power would affect the profitability of these firms, but the changes in the prices of the chemicals should not be considered a social cost (or cost-savings). Instead, they should be viewed as transfers from consumers to producers.

training, but the cost of these items is not accounted for in the incremental chemical cost of the alternative.

Time delays associated with alternatives also impose cost on users. Many alternatives require longer application periods or reentry times. As mentioned above, this can increase fixed costs if the delays necessitate the construction or modification of new facilities. It may also increase operating costs because of the need to change the hours of employees or operate additional fumigation chambers.

5. AN OVERVIEW OF LIKELY PEST CONTROL PRACTICES IN THE ABSENCE OF METHYL BROMIDE

This section discusses the likely alternative chemicals and practices that current methyl bromide users may use if the proposed rule is promulgated. Section 5.1 reviews the general implications of the proposed phaseout, including what is likely to happen in the short term (before the year 2000) and in the long term (after the year 2000). Sections 5.2 through 5.8 provide more detailed information for each of the major methyl bromide end uses.

5.1 General Implications of the Proposed Phaseout

There will be no single alternative to methyl bromide for any of the major methyl bromide end uses.The alternatives selected by growers in the soil fumigation end uses will be based on their production systems, the climate, the pests present in the soil, the geographical location, and the crop. Alternatives selected by users in the commodity, quarantine, and structural use areas will be based on the type of facility or commodity, the management system, the geographical location, and time constraints (i.e., how quickly the commodity must be processed to preserve freshness or maintain some other quality).

Before the phaseout date, demand for methyl bromide will still be increasing, but because supply will be fixed, the price of methyl bromide may rise. If methyl bromide becomes more expensive, its price could rise above those of some readily available alternatives. This is likely to encourage many users to switch to alternatives before the phaseout date. For example, non-perishable commodity fumigation users may switch to phosphine during this period because it currently has cost and performance characteristics similar to those of methyl bromide in non-perishable commodity fumigation applications.

As the phaseout nears, most users will begin to experiment with alternatives to determine whether they will be acceptable replacements. During this period of adjustment and experimentation, users could experience yield or commodity losses. Once users become more familiar with the application techniques, the chances of experiencing losses would most likely decrease.

In general the higher the efficacy requirements, the harder it will be for users to find acceptable alternatives. For instance, it will be harder for nursery owners to make a successful transition than it will be for general farmers who grow small fruits and vegetables or manage orchards or vineyards because nursery plants are more vulnerable to pests than mature crops, even when the same plant species is involved. The hardest end use of all in which to find alternatives will undoubtedly be the quarantine end use; currently 99.9968 percent efficacy levels are required by law in this end use.

Thus, in general, most users should be able to find alternatives by the proposed phaseout date, though it may be considerably more difficult for some than others. In addition, some users may experience yield losses because the alternatives may be less effective in controlling target pests. In instances in which users cannot achieve acceptable efficacy levels with any of the alternatives at a reasonable cost, they will have to grow, process, or transport other commodities. Although this may involve some dislocation, it is unlikely that consumers will not have a sufficient supply of the commodities they currently purchase. For example, if it is no longer feasible to grow strawberries in Florida, then growers in Northern states and in other countries will probably expand production to meet the shortfall. These shifts will probably be accompanied by higher production costs and market prices.

5.2 Soil Fumigation – Small Fruits and Vegetables

The most likely short term alternatives to methyl bromide in the small fruit and vegetable production use area are other fumigants, specifically Vorlex®, Telone C-17®, dazomet, and metam-sodium. If Vorlex® is reregistered it may be a viable alternative in areas with nematode, fungi, and weed problems. Telone C-17® may be used in areas with extreme nematode problems and some fungi problems, while the MITC releasers (i.e, dazomet and metam-sodium) may be used in areas with extreme fungi problems and some nematode problems.

Because these alternatives typically do not have as broad a spectrum and are somewhat more expensive to apply relative to methyl bromide, many users may also begin to try combination treatments to raise the efficacy of their treatments. The use of herbicides may increase in areas such as California where farmers do not use tarpaulins throughout the growing season. In addition, soil testing to determine pest population levels may become a more regular practice in all small fruit and vegetable production systems.

In the long term, because there is considerable concern over the toxic effects of the leading pesticide substitutes, especially over their ability to contaminate ground water, alternatives such as hydroponics and comprehensive IPM systems (i.e., ones that use modified plants, organic amendments, narrow-spectrum pesticides, and biological controls) may capture a larger market share. However, if alternatives in the preliminary research stages such as bromonitromethane[7] are successful in their development, then they may replace methyl bromide and other currently used soil fumigants.

5.3 Soil Fumigation – Orchards and Vineyards

Growers in the orchard and vineyard use area will most likely adopt a variety of alternatives for fields currently being replanted. These alternatives will most likely include Vorlex®, Telone C-17®, dazomet, and metam-sodium. Some growers may decide to wait one or more years before replanting so that they can learn from the experience of other users with the potential alternatives. If formalin/formaldehyde is reregistered and new application techniques are perfected, it may be used in orchards with serious replant disease problems, but will most likely not capture a large market share.

Long term alternatives are difficult to predict, but if the development of Enzone®, modified plants, and bromonitromethane are successful, they may either replace or be used in combination with Vorlex®, Telone C-17®, dazomet, and metam-sodium.

5.4 Soil Fumigation – Nursery Production

In nursery production systems, the short term alternatives most likely to be adopted if methyl bromide is phased out will likely parallel those for small fruits and vegetables. Different alternatives, however, are likely to be used in different segments of the end use. The less expensive soil fumigants such as Telone C-17®, metam-sodium, and dazomet are likely to capture most of the market in forest nurseries and tobacco seedling production, while the more expensive alternatives such as Vorlex® and steam may capture most of the transplant production market. In the long term, users may employ IPM systems combined with disinfestation practices to prevent the introduction of pests.

It is more difficult to predict the potential alternatives for pest-free certified transplant production because of the high efficacy requirements in these applications. In the short term, growers may combine a variety of practices using fumigants and narrow-spectrum pesticides, thereby increasing the over-all use of pesticides. On the other hand, they may also forgo pest-free certification and wait to see which of the experimental techniques perform well before making any major changes in their production practices.

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[7] Bromonitromethane has very similar chemical characteristics to methyl bromide and thus has the potential to be an ideal substitute. Because it contains bromine, however, it theoretically has the potential to deplete stratospheric ozone. Current scientific data on the volatility of bromonitromethane suggests that it does not pose a threat to the stratosphere, but this conclusion could be subject to change.

5.5 Commodity Fumigation – Perishable Commodities

In the short term, the management systems (e.g., the processing stages from pre-harvest to market) for perishable commodities may change. More intensive foliar pesticide field applications may be used to decrease the number of pests on the commodities after harvest, and commodities will probably be stored in better sealed and cleaner facilities to prevent pest infestations. Combinations of modified or controlled atmosphere (MA/CA) and thermotherapy will most likely be used to control pest damage during storage and transport. In some cases, when pest infestations are low and the level of potential damage is minimal, post-harvest treatments may no longer be used.

In the long term, these systems will most likely be modified to decrease pesticide use. More field checks before harvest may assist growers in determining when applications are needed. More effective combination treatments will most likely be developed for use during storage and transport, also decreasing the need for pre-harvest treatments. In the treatment of high-cash value perishables that are going directly from harvest to market, users may employ a two-step procedure. First, the commodity would undergo irradiation treatment to weaken any pests that are present. Then, the commodities would be transported in refrigerated or oxygen-deprived containers to ensure that the pests are killed before being sold to consumers.

5.6 Commodity Fumigation – Non-Perishable Commodities

Non-perishable commodities will most likely be treated with repeat applications of phosphine. In the longer term, facilities may be better sealed to prevent pest reinfestation and improve the efficacy of phosphine applications. This could potentially lead to an increase in the use of MA/CA. Storage areas will most likely be kept cleaner with the use of "crack and crevice" sprays. Better pest control methods at the farm level could also decrease the need for a methyl bromide use at exit/entry ports. If a bad pest infestation develops at major exit/entry ports, electron beam radiation may be used as commodities are being loaded on to ships. Irradiation will not be as popular in non-perishable commodity fumigation because it is significantly more expensive than other treatments, and its key advantage (speed) is not usually an important factor for non-perishable goods.

5.7 Commodity Fumigation – Quarantine

Because of the pest-specific nature of quarantine treatments and the extremely high level of efficacy required, numerous alternatives, in both the short and long run will most likely play a role in replacing methyl bromide. In the short term, previously used fumigants may be brought back into use, while other techniques are researched, tested, and certified. Combination treatments may be tested and perfected. Phosphine, sulfuryl fluoride, and thermotherapy will probably be tested and most likely be expanded in their use. In addition, some irradiation facilities may be built as exit/entry ports. If methyl bromide is not banned internationally for quarantine uses, importers may fumigate products before transport to the U.S. and then ship the commodities in well sealed containers to prevent pest reinfestation. More products may also be returned to the exporting countries if they are not able to pass quarantine inspections and if no treatments are available. In the longer term many of these problems will most likely be overcome with the development of combination treatments and the use of irradiation.

5.8 Structural Fumigation

In residential applications, the use of sulfuryl fluoride will most likely expand to replace most current methyl bromide use. In commercial storage applications, combination treatments involving phosphine, thermotherapy, and MA/CA may become more popular. Food processing facilities will most likely install thermotherapy and/or CA/MA equipment. In all of these applications, better house-keeping could decrease the need for pesticides, and "crack and crevice" sprays could potentially decrease the frequency of full facility treatments. The use of pheromone trappings (e.g., Roach Motels®) may also increase in order to better determine which sprays and treatments will be most effective and when they should be applied.

PART 2

THE COST AND COST-EFFECTIVENESS OF THE PROPOSED PHASEOUT OF METHYL BROMIDE

This part of the report contains Sections 6 and 7. Section 6 explains the methodologies used to conduct the cost and cost-effectiveness analyses. Section 7 presents the results of those analyses.

6. METHODOLOGY OF THE COST AND COST-EFFECTIVENESS ANALYSES

This section discusses the procedures used to develop estimates of the social cost and cost-effectiveness of the proposed methyl bromide phaseout.

6.1 Cost Methodology

This section discusses the key economic assumptions used in the analysis, details assumptions regarding other important analytical parameters, presents the substitution scenarios that were modeled, and describes the algorithm used to generate the cost estimates.

6.1.1 Key Economic Assumptions

To make the analysis tractable, a number of simplifying assumptions were made regarding the markets for methyl bromide and various agricultural commodities. To eliminate possible confusion, the market for methyl bromide will hereafter be referred to as the input market because the chemical is an input to the production of the commodity in question. The commodity markets will be referred to as output markets because the commodities are the output of the production process involving methyl bromide. Of course, the two are intimately related; the price and availability of inputs to a firm's production process affect the supply and price of that firm's product.

The key assumptions and the rationale for choosing them are as follows:

- Demand in output markets is perfectly inelastic. The implication is that all cost increases will eventually be passed onto consumers of the outputs, and that they will not change their behavior because of any price increases that might result from the additional costs. This assumption allows us to ignore the effects of a methyl bromide phaseout on output markets.

- Input markets are perfectly competitive. In other words, methyl bromide manufacturers currently do not make any economic profits and produce the chemical at a constant average unit cost. This assumption allows one to ignore changes in producer surplus due to a phaseout, and instead focus exclusively on the consumers in the input markets.

- Input markets are efficient. In other words, cheaper substitutes are always implemented before more expensive ones, and methyl bromide consumers do not use substitutes before it is financially worthwhile for them to do so. This assumption provides a basis for the cost model algorithm discussed in Section 6.1.4.

The general objective of these assumptions is to transform the analysis from a traditional economic welfare analysis – in which the analyst constructs supply and demand curves, shifts them, and then measures the resulting changes in consumer and producer surplus – to an engineering cost analysis – in which the analyst determines the quantity of methyl bromide consumed in each end use, multiplies it by the incremental unit cost of the most likely alternative, and sums across the end uses to calculate the total cost of the rule.

Given the assumptions listed above, the "engineering" approach is still valid in the context of economic welfare analysis. The various incremental costs form a "step" demand function. The total cost of alternatives aggregated across all end uses is the equivalent to the area under this step demand function or, in the language of welfare analysis, the consumer surplus generated by methyl bromide use.

To implement this approach, a spreadsheet has been developed that constructs the step demand curve, determines which steps are needed in each year to meet scheduled phaseout targets, and discounts the resulting cost flow. This spreadsheet is discussed in more detail in Section 6.1.4

6.1.2 Other Key Analytical Parameters

Other important analytical parameters for the analysis are (1) the discount rate, (2) the time frame for the analysis, (3) the "no controls" baseline growth rate for U.S. methyl bromide consumption, and (4) the projected use of methyl bromide in nations other than the United States (the rest-of-the-world).

The discount rate used in this analysis is three percent and represents a consumption rate of time preference. This rate is within the range that has been supported and used by EPA's Office of Policy, Planning, and Evaluation in some recent analyses of environmental regulations. The discount rate is used to determine the present value of the incremental costs of reducing methyl bromide in future years.

The incremental costs and health benefits of reduced ozone depletion are estimated for the period from 1994 to 2010. The year 2010 was chosen as the end point of time frame of the analysis because it is difficult to forecast the course of the technological innovation after this point in time. Importantly, 2010 will only represent the last year baseline methyl bromide emissions will be considered. The ozone depletion and resulting health effects of emissions before 2010 will be accounted for even though they will occur many years later.

For the "no-controls" U.S. methyl bromide consumption baseline, a 5.5 percent growth rate was used from 1994 until 2000, and a 2 percent growth rate was used thereafter. The U.S. rate from 1994 to 2000 reflects historical growth in world production from 1984 to 1990. The U.S. rate beyond 2000 reflects the *Chemical Marketing Reporter*'s projection for future methyl bromide demand in the United States.

In the rest-of-the-world, it was assumed that nations would follow the schedule set by the Copenhagen Revisions to the Montreal Protocol, which call for a freeze at 1991 levels in 1995. It is assumed that the rest-of-the-world would follow this schedule under both the "no controls" baseline and under the U.S. phaseout scenario.

6.1.3 Incremental Cost of Alternatives and Substitution Scenarios

This section describes the methodology used to develop the incremental cost inputs. To estimate the total social cost of the proposed methyl bromide phaseout, one must forecast the incremental cost and likely prevalence of the various methyl bromide alternatives in each end use. This required data on the following:

- The future cost of the likely alternatives (inclusive of chemical, labor, material, and other costs);
- The necessary application rates needed to perform the treatment with each alternative;
- The likely market share that each alternative will capture in each end use; and
- The efficacy of each of the alternatives and the resulting impact on crop yields or commodity throughput (such losses are included in incremental costs).

Obtaining and summarizing this information is a difficult task for two reasons. First, there is a great deal of variability within each end use regarding the choice of alternatives, appropriate application rates, and the resulting efficacy levels. This variability is due to differences in the characteristics of various crops and commodities and to differences in the soil and weather conditions in various parts of the country.

Second, there is a great deal of uncertainty regarding estimates of costs, application rates, market shares, and efficacy levels. This uncertainly is especially great because predictions need to be made for the year 2000 and beyond when most of the costs of the proposed phaseout would take place.

Due to the lack of precise data and to account for variability and uncertainty, incremental cost distributions were developed for each end use. These distributions are inputs to a Monte Carlo model described in Section 6.1.4. Incremental cost distributions allow one to assign probabilities to a variety of specific incremental cost estimates, rather than choose a single cost estimate for the entire end use.

For this analysis, the incremental costs are expressed in dollars per pound of methyl bromide replaced. To perform computations in the spreadsheet model, there are two restrictions to the input data: (1) probabilities can only be assigned to incremental costs of \$0, \$1, \$2, \$3, \$5, \$10, and \$50[1]; and (2) probabilities must be assigned in 5 percent increments. Neither of these restrictions significantly affect the validity of the results. In other words, the results would not change substantially if either cost inputs or probabilities could be entered in finer increments.

The incremental unit cost distribution in each end use was developed using cost data collected for the fact sheets contained in Part 3 of this report and professional judgement regarding the mix of alternatives expected to be chosen in each end use. The fact sheets present cost estimate ranges in terms of cost per acre treated for soil end uses and cost per 1,000 cubic feet treated or cost per pound of commodity treated for commodity and structural end uses. To develop incremental cost distributions, these ranges were recalculated using information on methyl bromide application rates and expressed in terms of the cost per pound of methyl bromide avoided. Costs represent long-term equilibrium prices (i.e, those that users are likely to experience in the year 2000, when the phaseout occurs). Costs estimates also account for the fact that some users may experience yield or commodity losses as a result of the potentially lower efficacy levels of alternatives. Professional judgement was used to determine the likelihood of particular values within these ranges.

Even though some alternatives may potentially be less expensive than methyl bromide, the lowest incremental cost used in the analysis is \$0 per pound of methyl bromide replaced. The economic rationale for not including negative incremental costs is that if the incremental cost of an alternative were in fact negative, current methyl bromide users should already be using that alternative because it would be profitable for them to do so. In this paradigm, if the cost of an alternative is estimated to be cheaper than methyl bromide then either: (1) users should be expected to switch to the alternative over time with or without the methyl bromide phaseout; or (2) there is a hidden cost factor that is being overlooked in the incremental cost estimates. In the first case, the cost savings

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[1] These values were chosen because they reflect the most likely range of incremental unit costs that users would be expected to incur as a result of the phaseout. The upper end values (\$5, \$10, and \$50) are spaced more widely than the lower end values (\$0, \$1, \$2, and \$3) because they are expected to be much less likely to occur. For example, if the values \$49 and \$51 were available, one would most likely assign probabilities lower than five percent to these values, but the model is not structured to accept such probabilities. The upper end values, thus, represent an average of a range of upper end costs.

are not attributed to the rule because they would also occur in its absence.[2] In the second case, no cost savings actually take place.[3]

Exhibit 6-1 presents the incremental cost distribution for each end use. The remainder of this section discusses the basis for each of the incremental cost distributions in each of the methyl bromide end uses.

Soil Fumigation - Small Fruits and Vegetables

Chemical substitutes such as Vorlex® (if reregistered), Telone C-17® (if it passes current special review regarding its toxicity), dazomet (if ground water contamination concerns are answered), and metam-sodium (if ground and surface water contamination concerns are answered) are likely to be the leading alternatives in this end use. It is also possible that new chemicals will be introduced by the date of the phaseout. In most cases, the use of these alternatives will result in incremental costs of approximately one to two dollars per pound of methyl bromide replaced. Once growers are familiar with the alternatives, however, many of them may be able to perform successful treatments without incurring any additional costs relative to methyl bromide (zero incremental cost). On the other hand, a small percentage of growers are expected to experience yield losses of up to 20 percent due to the lack of methyl bromide. These yield losses can represent from five to ten dollars of incremental cost per pound of methyl bromide replaced.

Integrated Pest Management (IPM) techniques and combination treatments are expected to become more popular over time, perhaps eventually reaching a 20 percent market share. In general, these treatments will probably have higher probabilities of failure than chemical treatments and, therefore, are more likely to result in incremental costs of $5 to $10 per pound of methyl bromide replaced. If successful, however, these treatments may often be cheaper to administer in the long run than chemical treatments.

Soil Fumigation - Orchards and Vineyards

The cost distribution in this end use is very similar to the distribution in the Small Fruits and Vegetables end use, in large part because similar alternatives are expected to be implemented. On average, alternatives are expected to be slightly less expensive in this end use because historically there has been more research on pest control options in orchard and vineyard applications, especially in the case of replant diseases and fungi complexes. In addition, plants in this end use often may be more resistant to pests than those in other end uses and, therefore, could potentially tolerate alternatives that might be infeasible in other end uses. Another reason why incremental costs may be lower is that crop values in this end use often do not justify the cost of expensive treatments.

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[2] Alternatives such as metam-sodium and controlled atmosphere are examples of this case. These alternatives are expected to be cheaper than methyl bromide in many applications, but research and development and field experience are needed before these alternatives can be more widely used. The increase in their use would be accelerated by a methyl bromide phaseout, but would eventually occur even if the proposed rule were not promulgated.

[3] Phosphine is an example of this case. It is cheaper on a unit basis than methyl bromide, but many users do not currently use it because the application period for phosphine is longer than for methyl bromide and because there is some risk inherent in switching to any alternative. Factors such as increased application time and risk are very difficult to quantify and are highly dependent upon individual user characteristics. Nevertheless, these cost factors are real.

EXHIBIT 6-1

INCREMENTAL COST DISTRIBUTIONS FOR EACH END USE

(Table entries represent the probability that users in the end use will incur the given incremental unit cost)

End Use	Sub End Use	Incremental Cost ($/lb. methyl bromide replaced)						
		0	1	2	3	5	10	50
Soil Fumigation	Small Fruits & Vegetables	25%	40%	20%	5%	5%	5%	0%
	Orchards & Vineyards	25%	45%	15%	5%	5%	5%	0%
	Nursery	15%	40%	25%	10%	5%	5%	0%
Commodity Fumigation	Perishable	10%	35%	35%	15%	0%	0%	5%
	Non-perishable	30%	50%	15%	0%	0%	5%	0%
	Quarantine	10%	15%	30%	20%	10%	10%	5%
Structural Fumigation	-	5%	20%	40%	20%	5%	5%	5%

Soil Fumigation - Nurseries

Although similar alternatives are likely to be employed, incremental costs in this end use are likely to be higher than those in other soil fumigation end uses. This is because this end use has considerably greater efficacy requirements and, as a result, more money must be spent on training and monitoring. Application rates for alternatives in this end use are also expected to be higher than those in other soil fumigation end uses.

Commodity Fumigation - Perishable

Modified or controlled atmosphere, thermotherapy, and irradiation are eventually expected to be the leading alternatives in this end use. Combination treatments are also expected to be quite prevalent. The use of most of these alternatives will result in incremental costs ranging from one to three dollars per pound of methyl bromide replaced, although in some instances costs may be roughly equivalent to those now incurred with methyl bromide.

Treatments are expected to fail in only a small percentage of total cases. When they do fail, however, incremental costs could be about $50 per pound of methyl bromide replaced because of the high value of the commodities undergoing fumigation.

Commodity Fumigation - Non-Perishable

The leading alternatives in this end use are phosphine, contact insecticides, and modified or controlled atmosphere. In addition, IPM and combination treatments may capture up to a quarter of the total market in this end use. Irradiation is expected to capture approximately five percent of the total market. Irradiation will most likely not be as popular in non-perishable commodity fumigation as it is in perishable commodity fumigation because it is significantly more expensive than other treatments, and its key advantage (speed) is not usually as important a factor for non-perishable goods.

On average, fumigation treatments will most likely be less expensive in the non-perishable end use than they are in the perishable end use because phosphine should be a feasible and widely available alternative. In fact, a large portion of this end use is already using phosphine. The use of the chemical is expected to be only marginally more expensive than methyl bromide in most cases.

Commodity Fumigation - Quarantine

In the quarantine end use, no well-developed alternatives yet exist. Previously used chemicals are likely to be the most common alternative until other alternatives are approved. Many of these are comparable in cost to methyl bromide. Nevertheless, users are expected to switch to new alternatives when they become available because of health and safety concerns with the previously used products. Irradiation is expected to be one of the leading new alternatives.

In general, alternatives are expected to be more expensive in the quarantine end use than in any other end use. This is primarily due to the extremely high efficacy requirements (up to 99.9968 percent kill rate for most import applications). New alternatives may also be more expensive because they will often be designed for small market segments and, therefore, may need to be priced higher in order for manufacturers to recoup research and development costs. In some cases, the lack of methyl bromide may cause importers and exporters to discontinue trade in certain commodities because no feasible alternatives will be available. In other cases, approved alternatives may fail during application and the treated commodities will need to be destroyed.

Structural Fumigation

Sulfuryl fluoride and combination treatments (particularly the use of crack and crevice sprays) are likely to be the leading alternatives in this end use. Modified or controlled atmosphere techniques and thermotherapy may also acquire some share of the market.

Users employing these alternatives are expected to, in general, incur incremental costs ranging from two to three dollars per pound of methyl bromide replaced. Some users may experience costs above or below this range. In particular, if treatments need to be reapplied frequently or if expensive equipment or other items need to be replaced as a result of treatment failure then incremental costs could range from $10 to $50 per pound of methyl bromide replaced. Serious failures, however, are not expected to occur in more than five percent of the total cases.

6.1.4 Monte Carlo Algorithm

Cost estimates were generated using a Monte Carlo simulation of the proposed phaseout. In a Monte Carlo simulation, inputs are statistical distributions rather than point estimates. Consequently, the cost estimates produced by the simulation are also in the form of a distribution rather than a single point estimate. The advantage of this approach is that it allows one to (1) formally express uncertainty regarding the incremental unit cost estimates in each end use, (2) determine the range of possible total cost outcomes, and (3) assess the likelihood of particular outcomes within that range.

The simulation also is based on a step demand framework. As discussed in Section 6.1.1, the step demand framework simplifies the calculation of social costs. In this framework, current methyl bromide users with access to the least cost controls reduce their consumption first, and others progressively implement more expensive controls as needed to meet the consumption targets. Importantly, controls must be implemented during the production "freeze" that precedes the ultimate phaseout because consumption growth in the baseline causes consumption to exceed the levels set by the "freeze."

The algorithm used by the cost model involves the following five step procedure:

Step 1: Randomly sample the incremental unit cost for each end use from the corresponding cost distribution for that end use. These distributions are presented in Exhibit 6-1 in Section 6.1.3. The likelihood of sampling a particular incremental unit cost for a particular end use is the percentage listed for that outcome in the Exhibit. Each end use is sampled independently from the rest. Once the incremental unit cost is chosen, it assumed that all the users in that end use will face that incremental unit cost throughout the time frame of the analysis.

Step 2: Sort end uses by cost. As mentioned, end uses with the cheapest controls act first. Sorting by cost essentially creates the step demand function discussed above.

Step 3: Determine the reductions from the baseline needed in each year to meet the consumption targets. In the "freeze" years preceding the phaseout, the needed reduction is the difference between the baseline consumption quantity and the quantity at which the production "freeze" is set. In the years following the phaseout, users must eliminate all of baseline consumption.

Step 4: In each year, reduce consumption in the least cost end use until the target is met. If consumption is not great enough in that end use, also reduce consumption in more expensive end uses (beginning with the second to least expensive end use) until the target is met. In economic terms, this is equivalent to finding the equilibrium of supply and demand. Importantly, users only reduce consumption by the amount required.

Step 5: Given reduction quantities in each year, calculate the total social cost of compliance. In the step demand framework, the social cost of compliance for a particular end use in a given year is the incremental unit cost assigned to that end use times the quantity of methyl bromide reduced in that year (relative to the baseline). The total social cost of compliance is the present value of aggregate annual compliance costs over the time frame of the analysis.

These steps generate one total cost estimate based on the sampled cost inputs. To derive a distribution of total cost estimates the steps are repeated 125,000 times. This number of repetitions is sufficiently large to develop enough information on the resulting distribution of total costs. The random selection of cost inputs each time causes the resulting distribution of outputs to reflect the information contained in the cost input distributions.

6.1.5 Limitations of the Cost Analysis

The key limitations of the Monte Carlo simulation are as follows:

- Variability within end uses is not fully addressed by the algorithm used in the Monte Carlo model. For any given iteration, the model selects a single incremental cost for each end use and applies it to all reductions in that end use. A more sophisticated model might assign each end use a <u>set</u> of incremental costs and market shares for each of these costs. The use of such a model would reduce the likelihood of extreme outcomes (on both the low and high end) and would reduce the variance in the output distribution.

- The model does not simulate changes in the costs of alternatives over time. Rather, once the incremental cost for a particular end use is sampled, it applies to that end use throughout the time frame of the analysis. In reality, costs are likely to decline over time as the production of alternatives increases and technological innovations take place. To some extent, the incremental cost estimates account for this phenomenon because they represent long-term equilibrium costs, not the costs the users would experience today if methyl bromide were no longer available.

- The model assumes that costs in each end use are independent from those in other end uses. Although this is a reasonable assumption, in reality there probably is some correlation within, for example, the soil fumigation end uses (i.e, if chemical alternatives are unlikely to control pests in the Small Fruits and Vegetables end use, there is a greater probability that they will also fail in the Orchards and Vineyards end use). Incorporating covariances between end uses into the analysis would not affect estimates of the expected value of total social costs, but to some extent would affect the shape and variance of the resulting total cost distribution.

- Several analytical parameters, such as the annual growth rates in methyl bromide consumption, were entered as fixed values rather than as random variables. Ideally, all inputs should be random variables in a Monte Carlo analysis. If these inputs had been entered as random variables, the estimates of the variance in the total social cost distribution would be greater than they are in this analysis.

- The incremental unit cost distributions are discrete rather than continuous distributions. For instance, incremental unit costs can be either $0 or $1 but they cannot be some number between these two estimates. Continuous sampling distributions would allow any incremental cost within the specified range to be chosen. If continuous distributions had been used, the summary statistics for the total social cost distribution would not have been substantially different. The distribution, however, would not have been multi-modal (i.e., the smaller peaks shown in the probability distribution are an artifact of the discrete nature of the input distributions).

6.2 Cost-Effectiveness Methodology

The cost-effectiveness of a regulation is defined as the social cost per premature fatality avoided. It is calculated by dividing an estimate of the projected total social cost of the regulation by an estimate of the number of fatalities that could be avoided by compliance with the regulation. The methodology used to estimate the numerator was discussed in the previous section. The remainder of this section discusses the calculation of the denominator.

6.2.1 Overview of the Atmospheric and Health Effects Framework (AHEF)

EPA has used AHEF to estimate the benefits of numerous regulations designed to protect stratospheric ozone. For this analysis, AHEF was used to produce estimates of the number of skin cancer fatalities that would be avoided as a result of the methyl bromide phaseout.

More specifically, the model was used to estimate the number of skin fatalities avoided each year from 1994 to 2160, as a result of methyl bromide emissions reductions resulting from the proposed rule in the period from 1994 to 2010. Emissions reductions are tracked over the same period for which social costs are considered. Health effects, however, are considered long after this period because they do not occur until many years after methyl bromide is released to the atmosphere.

The estimation process involves the following four general steps:

Step 1: Create the "no controls" baseline and U.S. phaseout emissions profiles. This is accomplished using current estimates of methyl bromide consumption in the U.S., and growing this quantity over time at the rates specified in Section 6.1.2. It is assumed that 50 percent of the U.S. methyl bromide consumption in the end uses covered in this report is released to the atmosphere. The remainder is broken down in soils and other treatment media and is, therefore, never released to the atmosphere.

Step 2: Estimate the extent of ozone depletion that would result from each of the emissions profiles created in Step 1. This is accomplished using the Atmospheric Stabilization Framework (ASF), one of the modules in the AHEF. The analysis assumes that bromine is 40 times as effective as chlorine at destroying stratospheric ozone, and that 25 percent of methyl bromide emissions are anthropogenic.

Step 3: Estimate the skin cancer fatalities that would result in each year from each of the ozone depletion scenarios forecasted in Step 2. This is accomplished using the Health Effects module of AHEF.

Step 4: Determine the incremental impact of the phaseout. This is accomplished by taking the difference of the baseline and phaseout skin cancer mortality estimates produced in Step 3.

The remainder of this section discusses the ASF (used in Step 2) and the Health Effects module (used in Step 3).

Atmospheric Stabilization Framework

ASF predicts changes in stratospheric ozone and tropospheric (ground-level) temperature associated with changes in atmospheric composition. ASF computes the globally and annually averaged concentrations of climatically important atmospheric constituents, taking into account various feedbacks between climate parameters and the constituents themselves. Examples of feedbacks accounted for in ASF are:

- The dependence of a compound's atmospheric lifetime on column (stratospheric) ozone and temperature;
- Radiative and chemical feedbacks due to water vapor;
- Ocean absorption;
- Atmospheric circulation effects; and
- Chemical interactions between compounds.

ASF relies on simple empirical relations based either on observations or on the results of more complex models in order to quantify physical feedbacks. In particular, the dependence of model ozone on stratospheric chlorine is adjusted so that it predicts a historical ozone depletion equal to that observed for the current atmosphere. In addition, ASF input parameters are adjusted to give column ozone and temperature changes that are consistent with consensus ODP and GWP estimates.

The ASF is a "consensus" model developed by a committee of prominent atmospheric scientists in government, academia, and private consulting firms. It was designed to approximate the behavior of more sophisticated two and three-dimensional physical models without requiring the computing power needed for physical simulations. Additional information on the ASF can be found in National Aeronautics and Space Administration Conference Publication 3023, *An Assessment Model for Atmospheric Composition* (NASA 1988).

Human Health Effects

The ozone column changes predicted by the ASF are inputs to a health effects model that estimates the number of skin cancer fatalities that result from the scenario modeled. Estimates of skin cancer fatalities include both non-melanoma (both basal and squamous cell) and melanoma cancers, and represent all fatalities experienced by individuals born in the United States before 2075.

In order to quantify the human health impacts of ozone depletion in the U.S., the globally averaged ozone depletion predicted by ASF is converted to estimates of depletion by latitude. This latitudinal variation is estimated using simple regression techniques from a prior two-dimensional modeling study. (Isaksen 1986). Results from a separate UV model are in turn used to estimate changes in UV-B intensity associated with the latitudinally-varying ozone depletion.

Human health effects are computed by AHEF as a function of UV-B exposure. The effective exposure of various population cohorts, representing different sexes and age groups, is estimated using appropriate factors that weight exposure at various stages during a person's lifetime. Empirical "dose-response" relationships for each cohort are then used to predict changes in skin cancer mortality over time.

6.2.2 Limitations of the Cost-Effectiveness Analysis

The key limitations of the cost-effectiveness analysis are as follows:

- The number of skin cancer fatalities is only one indicator of the damage to human health and the environment that results from increases in UV-B radiation due to ozone depletion. Increased UV-B radiation can cause a wide variety of additional human health problems, including non-fatal skin cancers, cataracts, actinic keratosis (a skin disease), and immune system disorders. Increased UV-B levels also lead to higher concentrations of tropospheric ozone (smog) that can adversely impact human respiratory and pulmonary systems. Furthermore, the impact of ozone depletion is not limited to humans; plants and animals can also suffer serious consequences from UV-B radiation.

- The analysis only estimates the number of avoided skin cancer fatalities in the United States. People in other countries, however, would benefit from the proposed phaseout and this is not accounted for in the cost-effectiveness estimates.

- The analysis does not address the uncertainties in the estimates. These include incomplete understanding of:
  - the physical and chemical processes that govern ozone depletion;
  - the relationship between changes in ozone depletion and exposures to ultraviolet radiation; and
  - the dose-response coefficients relating exposures to UV-B to skin cancers.

A Monte Carlo analysis was not performed for estimates of human health effects because the complexity of AHEF makes such analyses prohibitively complex.

7. RESULTS OF THE COST AND COST-EFFECTIVENESS ANALYSES

The proposed methyl bromide phaseout is expected to cost an estimated $1.7 billion during the period from 1994 to 2010. In addition, emissions reductions during this period would result in a reduction of approximately 2,800 skin cancer fatalities in the United States. Section 7.1 presents the cost estimates in more detail. Section 7.2 presents the results of the cost-effectiveness results.

7.1 Costs

This section presents the results of the Monte Carlo simulation of social costs. It also discusses how sensitive the cost estimates are to the discount rate, the consumption growth rate, and demand elasticity assumptions.

7.1.1 Monte Carlo Results

As mentioned in Section 6.1.4, Monte Carlo simulations generate distributions rather than point estimates. The mean or expected value of the total cost distribution generated for this analysis is $1.7 billion. More detailed information on the distribution is presented in the following exhibits:

- **Exhibit 7-1** presents the key summary statistics for the distribution, including the minimum and maximum cost estimates, the mean and median cost estimates, and the standard deviation of the distribution;
- **Exhibit 7-2** graphically displays the probability density function of the total cost distribution, and provides information on the likelihood of various cost outcomes within the range of possible values; and
- **Exhibit 7-3** graphically displays the cumulative distribution function for the total cost distribution.

Exhibit 7-1

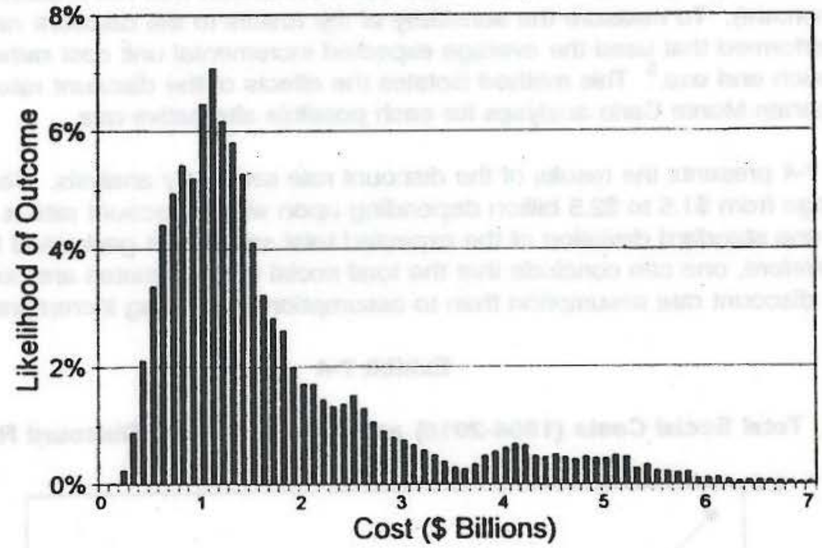
Summary Statistics for Total Social Cost (1994-2010) Distribution Generated by Monte Carlo Simulation

Statistic	Estimated Value
Mean	$1.7 Billion
Median	$1.3 Billion
Minimum	$24 Million
Maximum	$12.2 Billion
Standard Deviation	$1.3 Billion

The cumulative distribution function presented in Exhibit 7-3 indicates, for each total social cost outcome, the probability that total social costs will be below that level. As the graph shows, the Monte Carlo simulation estimates that there is an approximately 30 percent chance that total social costs (1994-2010) will be below $1.0 billion and an approximately 85 percent chance that they will be below $3 billion. On the other hand, the Monte Carlo simulation estimates that there is an

Exhibit 7-2

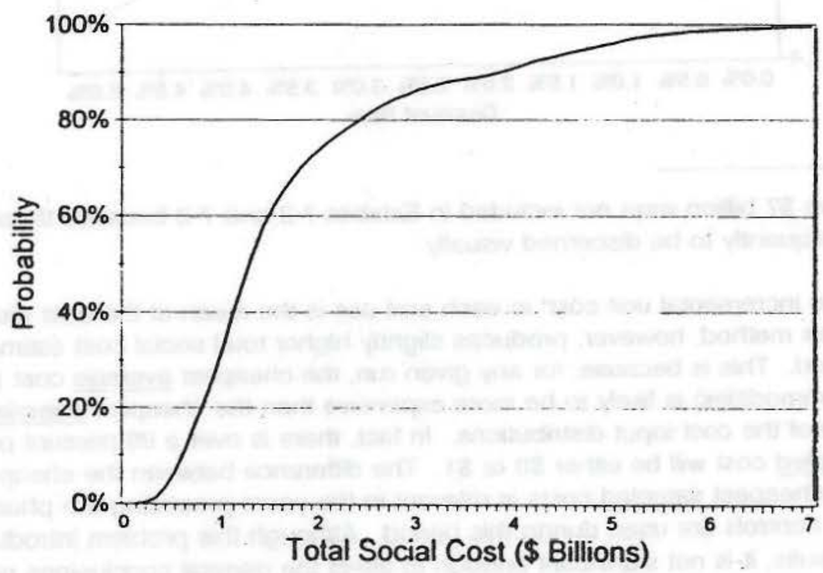
Total Social Costs (1994-2010): Probability Density Function



Note: The probability density function is displayed here as a discrete rather than a continuous function. The graph shows the probability that estimates will fall within given cost intervals. Each interval represents a range of $100 million.

Exhibit 7-3

Total Social Costs (1994-2010): Cumulative Distribution Function



approximately 0.2 percent chance that total social costs (1994-2010) will exceed $7 billion.[4]

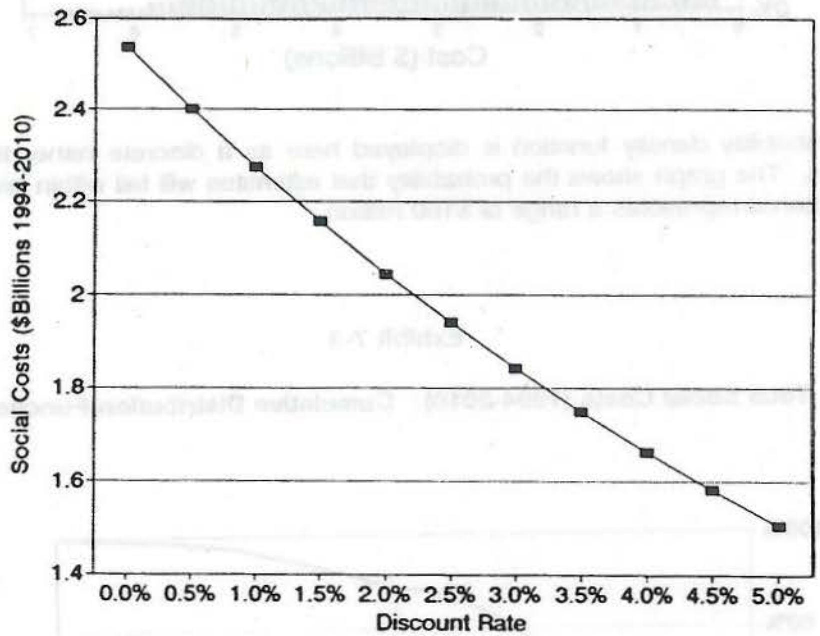
7.1.2 Sensitivity to the Discount Rate

The discount rate assumed for the Monte Carlo simulation was not a distribution but a single fixed value (3 percent). To measure the sensitivity of the results to the discount rate, an independent analysis was performed that used the average expected incremental unit cost rather than a cost distribution in each end use.[5] This method isolates the effects of the discount rate without conducting separate Monte Carlo analyses for each possible alternative rate.

Exhibit 7-4 presents the results of the discount rate sensitivity analysis. Total social costs (1994-2010) range from $1.5 to $2.5 billion depending upon which discount rate is chosen. This range is within one standard deviation of the expected total social cost generated by the Monte Carlo simulation. Therefore, one can conclude that the total social cost estimates are not significantly more sensitive to the discount rate assumption than to assumptions regarding incremental costs.

Exhibit 7-4

Total Social Costs (1994-2010) as a Function of the Discount Rate



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[4] Values above $7 billion were not included in Exhibits 7-2 and 7-3 because these values were generated too infrequently to be discerned visually.

[5] The "average incremental unit cost" in each end use is the mean of the cost distribution used in each end use. This method, however, produces slightly higher total social cost estimates than the Monte Carlo method. This is because, for any given run, the cheapest <u>average</u> cost (i.e, $1.30 for non-perishable commodities) is likely to be more expensive than the cheapest <u>sampled</u> costs due to the skewed nature of the cost input distributions. In fact, there is over a 99 percent probability that the cheapest <u>sampled</u> cost will be either $0 or $1. The difference between the cheapest <u>average</u> cost and the expected cheapest <u>sampled</u> costs is relevant in the years preceding the phaseout because only the cheapest controls are used during this period. Although this problem introduces a slight bias in the final cost results, it is not significant enough to affect the general conclusions reached with the sensitivity analysis.

7.1.3 Sensitivity to Methyl Bromide Consumption Growth Rates

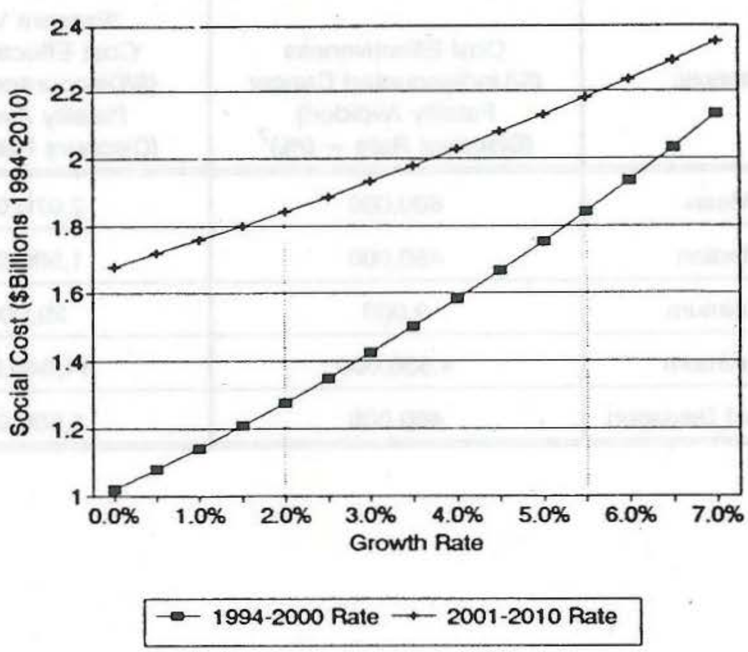
The Monte Carlo simulation did not use growth rate distributions but rather employed specified growth rates for each year during the time frame of the analysis. As discussed in Section 6.1.2, a 5.5 percent annual growth rate in methyl bromide consumption was used from 1994 to 2000 and a 2 percent annual growth rate was used from 2001 to 2010.

To measure the sensitivity of the results to these growth rates, a similar analytical technique to that used in the discount rate sensitivity analysis was employed. This technique involved using average costs for each end use rather than cost distributions, thereby eliminating the need to conduct a Monte Carlo simulation for each of the possible growth rates. Two analyses were performed, one for each of the two growth rates. In each analysis, one of the growth rate was fixed at its original value and the other was varied from 0 to 7 percent. The results are displayed together in Exhibit 7-5.

The dotted vertical lines in Exhibit 7-5 mark the original growth rates chosen for the two periods. As expected, social costs are equal at these rates. Because the slope of the curve for the period 1994-2000 is greater than the slope for the period 2001-2010, one can conclude that the results are more sensitive to the growth rate chosen for the earlier period than they are for the later one.

Exhibit 7-5

Total Social Costs (1994-2010) as a Function of Methyl Bromide Consumption Growth



7.2 Cost-Effectiveness

If promulgated, the proposed methyl bromide phaseout would be expected to result in a reduction of approximately 2,800 skin cancer fatalities in the United States. Given expected total social costs of $1.7 billion, this results in a cost effectiveness estimate of $600,000 per cancer fatality avoided. If health benefits are discounted at the same rate as costs (3 percent), then the "present value" cost effectiveness estimate would be $2.1 million per present value cancer fatality avoided.

Both of these estimates are below typical unit mortality risk reduction values used in many EPA analyses of environmental regulations.[6] This suggests that the decision to promulgate the proposed rule may be socially beneficial when compared to the decision to take no action. Moreover, it must recognized that cancer mortality is only one measure of the benefits of stratospheric ozone protection. If other benefits were included, the case for promulgation would be even stronger.

Although the cost-effectiveness estimates presented are point estimates, the cost-effectiveness estimates can be expressed as distributions. In fact, the distribution of these estimates is of the same general form as that generated by the Monte Carlo simulation for total social costs. Exhibit 7-6 presents the summary statistics for the distributions for the cost-effectiveness and "present value" cost effectiveness distributions.

Exhibit 7-6

Summary Statistics for Cost-Effectiveness Distributions

Statistic	Cost-Effectiveness ($/Undiscounted Cancer Fatality Avoided) (Discount Rate = 0%)[7]	"Present Value" Cost Effectiveness ($/Discounted Cancer Fatality Avoided) (Discount Rate = 3%)
Mean	600,000	2,070,000
Median	460,000	1,580,000
Minimum	9,000	29,000
Maximum	4,330,000	14,840,000
Standard Deviation	460,000	1,580,000

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[6] For example, EPA's Office of Air and Radiation has historically used unit mortality risk reduction values of $3 and $12 million for its analyses of stratospheric ozone protection regulations.

[7] The zero percent discount rate only refers to the discounting of health effects. The estimate of costs used in the cost-effectiveness estimates is always based on a three percent discount rate.

PART 3

FACT SHEETS ON ALTERNATIVES TO METHYL BROMIDE

This part of the report contains a series of 23 fact sheets that present information on each of the major potential alternatives to methyl bromide. This part of the report also has an addendum that provides additional data regarding toxicity and exposure limits for several of the alternative pesticides.

Organization of the Fact Sheets

The facts sheets are divided into two groups:

- Soil fumigation alternatives, which can be used in the soil fumigation end uses (small fruits and vegetables, orchards and vineyards, and nursery production); and
- Non-soil fumigation alternatives, which can be used in the commodity fumigation end uses (perishable, non-perishable, and quarantine) and the structural fumigation end use.

Exhibit A lists the alternatives and the end uses in which they can be utilized. These end uses, however, are general and, therefore may not capture crop and commodity-specific attributes that can affect the feasibility of alternatives for specific applications.

In both the soil and non-soil use areas, there are two general types of alternatives:

- Chemical alternatives, such as Vorlex®, Telone C-17®, dazomet, metam-sodium, Enzone®, formalin/formaldehyde, phosphine, and sulfuryl fluoride; and
- Non-chemical alternatives, such as steam, solarization, hydroponics, plant modification, controlled atmosphere, and thermotherapy.

Chemical alternatives are referred to by their formulation trade name rather than by their active ingredients. This is because the characteristics of the total formulation often have implications for the effectiveness of an alternative that are independent from the characteristics of the active ingredients.

Users can also combine alternatives to meet their specific needs. Combination treatments can involve the use of two or more chemical alternatives, a mix of chemical and non-chemical treatments, or a combination of non-chemical treatments. Separate fact sheets address issues relating to combination treatments for both soil and non-soil use areas.

Content of the Fact Sheets

Each fact sheet evaluates an alternative or group of alternatives based on the following four criteria:

- Efficacy: The proportion of the relevant pest population that is killed as a result of the treatment relative to the proportion that would have been killed by methyl bromide;
- Registration Status: The current registration status of the alternative;
- Market Infrastructure: The state of factors such as manufacturing capacity, user training, and consumer awareness; and
- Cost: The cost of the alternative (e.g., chemical, equipment, training) relative to the cost of methyl bromide.

Health and safety concerns are addressed in the context of the registration process. For more information on the health and safety characteristics of alternatives, see the Addendum.

Exhibit A. Potential Alternatives and Their Use Areas

ALTERNATIVES	SOIL USE AREAS			NON-SOIL USE AREAS			
	Small Fruits and Vegetables	Nursery Production	Orchards and Vineyards	Perishable Commodities	Non-Perishable Commodities	Quarantine	Structures
Vorlex®	Fact Sheet #1	Fact Sheet #1	Fact Sheet #1	N/A	N/A	N/A	N/A
Telone C-17®	Fact Sheet #2	Fact Sheet #2	Fact Sheet #2	N/A	N/A	N/A	N/A
Dazomet	Fact Sheet #3	Fact Sheet #3	Fact Sheet #3	N/A	N/A	N/A	N/A
Metam-sodium	Fact Sheet #4	Fact Sheet #4	Fact Sheet #4	N/A	N/A	N/A	N/A
Enzone®	Fact Sheet #5	N/A	Fact Sheet #5	N/A	N/A	N/A	N/A
Formalin/Formaldehyde	Fact Sheet #6	Fact Sheet #6	Fact Sheet #6	N/A	N/A	N/A	N/A
Steam	Fact Sheet #7	Fact Sheet #7	N/A	N/A	N/A	N/A	N/A
Solarization	Fact Sheet #8	Fact Sheet #8	Fact Sheet #8	N/A	N/A	N/A	N/A
Hydroponics	Fact Sheet #9	N/A	N/A	N/A	N/A	N/A	N/A
Non-fumigant Pesticides	Fact Sheet #10	Fact Sheet #10	Fact Sheet #10	N/A	N/A	N/A	N/A
Organic Matter	Fact Sheet #12	Fact Sheet #12	Fact Sheet #12	N/A	N/A	N/A	N/A
Plant Modification	Fact Sheet #13	Fact Sheet #13	Fact Sheet #13	N/A	N/A	N/A	N/A
Integrated Pest Management	Fact Sheet #14	Fact Sheet #14	Fact Sheet #14	N/A	N/A	N/A	N/A
Future and Preliminary Research Alternatives	Fact Sheet #15	Fact Sheet #15	Fact Sheet #15	N/A	N/A	N/A	N/A
Irradiation	N/A	N/A	N/A	Fact Sheet #16	Fact Sheet #16	Fact Sheet #16	N/A
Phosphine	N/A	N/A	N/A	N/A	Fact Sheet #17	Fact Sheet #17	Fact Sheet #17
Sulfuryl Fluoride	N/A	N/A	N/A	N/A	N/A	Fact Sheet #18	Fact Sheet #18
Previously Used/ Limited Use Alternatives	N/A	N/A	N/A	N/A	N/A	Fact Sheet #19	N/A
Controlled/Modified Atmosphere	N/A	N/A	N/A	N/A	Fact Sheet #20	Fact Sheet #20	Fact Sheet #20
Thermotherapy	N/A	N/A	N/A	Fact Sheet #21	Fact Sheet #21	Fact Sheet #21	Fact Sheet #21
Combination Treatments	Fact Sheet #11	Fact Sheet #11	Fact Sheet #11	Fact Sheet #22	Fact Sheet #22	Fact Sheet #22	Fact Sheet #23

Introduction to the Rating System

To summarize the information in each of the fact sheets, each alternative has been assigned a qualitative rating for each of the four basic criteria. The rating classification for each of these criteria are as follows:

Efficacy

Comparable	As effective as methyl bromide and has the same broad spectrum of activity.
Comparable within Spectrum	Does not have the same spectrum of activity as methyl bromide, but is as effective within its spectrum of activity.
Lower	Not as effective as methyl bromide within its spectrum of activity.
Unknown	Little available efficacy information on the alternative, primarily because it is in the beginning stages of development or it has only been tested under laboratory conditions.

Registration Status

Registered	Currently registered by EPA (Note: although some alternatives have been registered, none of have been reregistered).
Registration Cancelled	Previously registered but EPA cancelled registration due to its health, safety, or environmental risks.
Voluntarily Cancelled	Previously registered but no longer available because the registrant has voluntarily cancelled the registration.
Registration Started	The registration process has begun and should be completed in one to three years.
Not Registered	The registration process has not begun, although the manufacturers may have received a Experimental Use Permit. The alternative probably will not be commercially available for three or more years.
Not Required	The registration process is not applicable

Market Infrastructure

In Place	The manufacturer is ready to distribute the product and growers are familiar with its use and do not require training on how to apply it.
Needs Development	Requires either grower training, some research, or new equipment. One to three years are needed to develop infrastructure.
Little or None Exists	Requires three to ten years or more of intensive research or development before they it can be fully commercialized.

Cost

More Expensive	Generally more expensive than methyl bromide, primarily because large capital investments are required.
Slightly More Expensive	More expensive than methyl bromide, but does not require large capital investments.
Comparable	Costs are within the average cost range of methyl bromide
Less Expensive	Less expensive than methyl bromide, but could require up-front costs such as training or the purchase of new equipment.

Exhibits B and C summarize the ratings for each of the potential soil and non-soil alternatives to methyl bromide.

Exhibit B. Potential Soil Alternatives and Their Ratings

ALTERNATIVES	USE AREA			RATINGS			
	Small Fruits/ Vegetables	Nursery Production	Orchards/ Vineyards	Efficacy	Registration Status	Market Infrastructure	Cost
Vorlex®	✓	✓	✓	comparable	voluntarily cancelled	in place	slightly more expensive
Telone C-17®	✓	✓	✓	comparable within spectrum	registered	in place	comparable
Dazomet	✓	✓	✓	comparable	some uses registered/ registration started for others	in place	slightly more expensive
Metam-sodium	✓	✓	✓	comparable within spectrum	registered	needs development	less expensive
Enzone®	✓		✓	unknown	not registered/ experimental permit granted	needs development	less expensive
Formalin/ Formaldehyde	✓	✓	✓	comparable within spectrum	registration voluntarily cancelled	needs development	unknown
Steam	✓	✓		comparable	not required	little or none exists	more expensive
Solarization	✓	✓	✓	lower	not required	little or none exists	less expensive
Hydroponics	✓			comparable	not required	little or none exists	more expensive
Non-Fumigant Pesticides	✓	✓	✓	lower	registered	in place	less expensive
Combination Soil Treatments	✓	✓	✓	comparable	registered	little or none exists	comparable
Organic Matter	✓	✓	✓	unknown	some registered/some not registered/some not required	little or none exists	unknown
Plant Modification	✓	✓	✓	unknown	some not required/ some not registered	little or none exists	unknown
Integrated Pest Management	✓	✓	✓	comparable	some registered/some not registered/some not required	little or none exists	unknown
Future and Preliminary Research Alternatives	✓	✓	✓	unknown	not registered	little or none exists	unknown

Exhibit C. Potential Commodity and Structural Alternatives and Their Ratings

ALTERNATIVES	USE AREA				RATINGS			
	Perishable Commodities	Non-Perishable Commodities	Quarantine	Structural	Efficacy	Registration Status	Market Infrastructure	Cost
Irradiation	✓	✓	✓		comparable	registered	little or none exists	more expensive
Phosphine		✓	✓	✓	comparable within spectrum	registered	in place	less expensive
Sulfuryl Fluoride			✓	✓	comparable	registered	in place	slightly more expensive
Previously Used/Limited Use			✓		comparable	some registered/ some cancelled	in place	comparable
Controlled/Modified Atmosphere	✓[a]	✓	✓	✓	comparable within spectrum	not required	needs development	less expensive
Thermotherapy	✓	✓	✓	✓	comparable within spectrum	not required	needs development	slightly more expensive
Combination Quarantine and Commodity Treatments	✓	✓	✓		comparable	registered	little or none exists	slightly more expensive
Combination Structural Treatments and IPM				✓	comparable	some registered/ some not registered	needs development	slightly more expensive

[a] Controlled/modified atmospheres can be used to treat perishable commodities, however they are usually used in combination with other pest control techniques and are, therefore, addressed in the fact sheet on combination commodity treatments.

FACT SHEETS FOR SOIL FUMIGATION

Small Fruits and Vegetables

Nursery Production

Orchards and Vineyards

VORLEX®

Use Area: Soil fumigation -- small fruits and vegetables, nursery production, and orchards and vineyards.

Efficacy: Comparable
Registration: Voluntarily cancelled
Market Infrastructure: In place
Cost: Slightly more expensive

Vorlex® (40% 1,3-dichloropropene and 20% methyl isothiocyanate) is a liquid fumigant that is usually applied with a chisel apparatus attached to a tractor in a manner similar to that used for methyl bromide. After application, a 3 week waiting period is required before planting in order to prevent plant death. Nor-Am, the manufacturer, traditionally has marketed Vorlex® only in Southern Florida.

- **Efficacy:** Vorlex® is a broad spectrum pesticide that can be used to control all soil pests. It is believed to be 90 to 100 percent as effective as methyl bromide. Because Vorlex® contains methyl isothiocyanate (MITC) and 1,3-dichloropropene, it is effective against fungi, weeds, soil insects, and nematodes.

- **Registration:** Nor-Am, the manufacturer of Vorlex®, voluntarily requested that its registration be cancelled in November 1991 due to the high costs of reregistering it. Nor-Am sold the remaining stocks of this fumigant in November 1992. Hence, Vorlex® may not be a viable alternative to methyl bromide. However, this cancellation decision was made before the proposed phaseout of methyl bromide, and with a potentially larger market, Nor-Am may reconsider its decision. If Nor-Am decides not to reregister Vorlex®, the company may decide to sell the patent rights to another pesticide manufacturer. Finally, the reregistration of Vorlex® could be difficult because of the ground water contamination potential of MITC.

- **Market Infrastructure:** Growers are familiar with application techniques for Vorlex® because it has been used before and is applied in a fashion similar to methyl bromide. Nor-Am has traditionally marketed Vorlex® only in Southern Florida and may experience problems establishing a distribution chain in other growing regions.

- **Cost:** The cost of applying Vorlex® is slightly more expensive than that of applying methyl bromide. The application techniques and equipment used are the same for both chemicals in that both are restricted use fumigants that require the use of injection equipment and often involve the use of tarpaulins. The higher cost of Vorlex® is due to the higher raw material costs. Raw material costs range from $20 to $32 per gallon and application rates average between 30 gallons and 50 gallons per acre. Total costs, including equipment and labor, are expected to be between $1,000 and $1,500 per acre.

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United States Department of Agriculture. 1993. Workshop on Alternatives for Methyl Bromide. June 29-July 1. Crystal City, Virginia.

TELONE C-17®

Use Area: Soil fumigation -- small fruits and vegetables, nursery production, and orchards and vineyards.

Efficacy: Comparable in spectrum (may be a less effective herbicide)
Registration: Registered
Market Infrastructure: In place
Cost: Comparable

Telone C-17® (83% 1,3-dichloropropene and 17% chloropicrin) is manufactured by DowElanco. It is a liquid fumigant that releases a gas after application. Usually, it is injected in to the soil with a chisel or shank, and the soil is then covered with a tarpaulin. Growers must wait from 3 to 6 weeks after application, depending on the temperature and humidity, before planting in order to prevent plant death.

- **Efficacy:** Telone C-17® can be used for all soil fumigations to control nematodes, fungi, and insects. It is 100 percent as effective as methyl bromide at killing these pests because 1,3-dichloropropene is an extremely effective nematicide and chloropicrin is a very good fungicide. It is only 80 percent as effective as methyl bromide at controlling weeds, however, because 1,3-dichloropropene is not as effective an herbicide as methyl bromide. In addition, chloropicrin can stimulate weed germination.

- **Registration:** Telone C-17® is registered by the EPA, but it is not available to growers in California. California EPA suspended Telone C-17® because of environmental and safety concerns. DowElanco believes it will be on the market again in California within three years. Future availability is uncertain because Telone C-17® is currently under special review by the Office of Pesticide Programs at U.S. EPA because of concerns regarding the high volatilization rate of 1,3-dichloropropene, its potential for off-site movement (e.g., ground water contamination and worker safety), and tumorigenicity in mice.[1] Hence, Telone C-17® may not be a viable alternative to methyl bromide. DowElanco is planning to introduce lower application rates and improved application methods to decrease environmental and safety risks.

- **Market Infrastructure:** Telone C-17® has been available to growers and they are familiar with the application parameters and techniques. It is applied in a similar manner to methyl bromide and its expanded use would not require additional grower or applicator training.

- **Cost:** The cost of applying Telone C-17® is comparable to that for methyl bromide. Telone C-17®, like methyl bromide, must be applied by or under the direct supervision of a certified applicator and requires special injection equipment. Additional costs may be incurred if herbicides are used in combination to control weeds. The raw material costs are approximately $12 per gallon and application rates range from 10 to 50 gallons per acre depending on the pest population levels and pests present. Total costs, including equipment and labor, are expected to range from $750 to 1,000 per acre.

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[1] These are not as large as concerns for other formulations that contain 1,3-dichloropropene (e.g., Vorlex®), because much less of the chemical is in the formulation and less is applied to the soil.

References:

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DAZOMET (Basamid G®)

Use Area: Soil fumigation -- small fruits and vegetables, nursery production, and orchards and vineyards.

Efficacy: Comparable (may be a less effective nematicide)
Registration: Some uses registered/registration started for others
Market Infrastructure: In place
Cost: Slightly more expensive

Dazomet, a granular fumigant manufactured by BASF Corporation, is applied by spreading it over a field and then tilling the field so that it is evenly distributed within the soil. Moisture in the soil causes the granular formulation to release the active ingredient methyl isothiocyanate (MITC) and other active ingredients such as formaldehyde that are present in the formulation. The soil moisture, temperature, and pH determine the release rate into the soil, the depth of penetration into the soil, and the length of time before the active ingredients dissipate from the soil. The advantage of dazomet over other formulations containing similar active ingredients is that the granular formulation slows down the gas release rate and prevents premature dissipation. Soil compaction and the use of tarpaulins can also be used to contain the released gases Because of dazomet's slow dissipation rate, the waiting period between application and planting averages 21 days compared to 10 to 14 days for methyl bromide.

- **Efficacy:** If dazomet is applied within the narrow application parameters recommended by the manufacturer, it is effective for all soil fumigation treatments to control all soil pests. In some cases, however, dazomet may not be as effective as methyl bromide in controlling nematodes, in which case the use of an additional nematicide may be necessary. For some pests, the use of a tarpaulin or soil compaction with water may improve efficacy. Irrigation may be necessary in some areas to insure proper incorporation in the soil. Dazomet may not be as effective as methyl bromide under adverse temperature conditions, and if soil moisture and pH are not closely regulated. For example, in dry soils dazomet MITC release may be limited by a lack of soil moisture.

- **Registration:** Dazomet is currently registered in the U.S. as a non-restricted use fumigant for the control of soil pests in the production of non-food crops (e.g., tree nurseries, tobacco). The registration process for high cash value food crops has been started and dazomet should be commercially available to commercial applicators and/or growers for these crops in 1 to 3 years. The registrant, BASF, may not pursue registration for all methyl bromide uses, especially those crops with low production acreage, because of the expense of expanding registration to a crop that would utilize a small quantity of pesticide annually. Also, state environmental agencies and the EPA may place additional restrictions on the use of dazomet because MITC is a potential ground water contaminant. UNEP also has voiced concerns over ground water contamination. Currently, dazomet is used on food crops in Europe.

- **Market Infrastructure:** Growers are familiar with dazomet application and the restrictive application parameters (i.e., the soil temperature, moisture, and pH must be within the narrow range required for full release of the active ingredients) because it has been used in the U.S. for many years in the production of non-food crops. Applicators, however, may need to learn how to better control the application parameters.

- **Cost:** The cost of applying dazomet is slightly higher than the costs associated with using methyl bromide. This is because of the higher raw material cost. Dazomet is a non-restricted use pesticide and does not have to be applied by a certified applicator or under the direct supervision of a certified applicator. No special equipment is required. Additional costs could be incurred due to the longer waiting period associated with its use compared to methyl bromide. Dazomet costs approximately $3.00 per pound and application rates range from 260 pounds per acre to 540 pounds per acre. An application rate of 300 pounds per acre is considered equivalent to 350 pounds per acre of methyl bromide. Total costs are expected to be between $1,000 and $1,500 per acre. The chemical and labor costs of dazomet may decrease as growers become more familiar with its use. BASF has stated that by the time dazomet is registered for food crops, costs could be as low as $750 per acre.

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METAM-SODIUM (Vapam®, Busan®)

Use Area: Soil fumigation -- small fruits and vegetables, nursery production, and orchards and vineyards.

Efficacy: Comparable in spectrum (may be a less effective nematicide)
Registration: Registered
Market Infrastructure: Needs development
Cost: Less expensive

Metam-sodium, a methyl isothiocyanate releaser, is applied to the ground as a liquid, followed by tilling and irrigation for soil incorporation and distribution. After application, a three week waiting period is required before planting to prevent plant death versus the 10 to 14 day waiting period for methyl bromide. Release in the soil is dependent on the moisture, temperature, and pH. Metam-sodium releases only one active ingredient, methyl isothiocyanate (MITC). While it can be difficult to obtain an even distribution in the soil with metam-sodium, pests can be controlled at a greater depth than is possible with granular formulations, because the liquid can be injected deeply into the ground.

- **Efficacy:** Metam-sodium can be used for all soil fumigation treatments to control all soil pests, but may not be as effective in the control of nematodes when compared to methyl bromide. Depending on soil conditions and the number and types of pests present, metam-sodium is approximately 80 percent as effective at killing nematodes and can be as effective at killing all other pests. Recently, the effectiveness of metam-sodium has been improved through the implementation of new application techniques using an agricultural foam that assists in distributing the active ingredient throughout the soil. The use of tarpaulins can also assist in containing the released gas and increasing efficacy.

- **Registration:** Metam-sodium is currently registered for use in the production of food and non-food crops. It has not been reregistered and may face difficulties during the reregistration process because MITC is a potential ground water contaminant. The use of metam-sodium, like that of dazomet, could be geographically restricted. Additionally, environmental fate and toxicity testing may be required to maintain active registration status. Currently, Vapam®, a metam-sodium formulation manufactured by ICI Americas Inc., is used in the production of low cash value crops, as well as fruits and vegetables destined for the processed market. It should be noted that UNEP has indicated concerns over off-site movement and ground water contamination.

- **Market Infrastructure:** While metam-sodium is registered and available to growers, it may take 1 to 3 years before the new application techniques using agricultural foams are available to and fully adopted by the growers. Without the improved application techniques in place, the adoption of metam-sodium will most likely be limited because of its lower efficacy without such techniques.

- **Cost:** The cost of applying metam-sodium is less expensive than that for methyl bromide. This is because the raw material costs are lower and the grower can apply it, because metam-sodium is a non-restricted use pesticide and does not have to be applied by a certified applicator. No special equipment is currently required, but extensive tilling for soil incorporation may be necessary. The new foam application technique may require current equipment to be modified. Additional costs could be incurred by the longer waiting period. Metam-sodium costs $3.00 per gallon and application rates range from 75 gallons to 100 gallons per acre. Total costs, including equipment and labor, are estimated to range from $250 to $750 per acre.

- **Other Considerations:** Metam-sodium may have an objectionable odor, especially when applied by sprinkler irrigation. This can pose serious problems for farms located near residential areas.

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ENZONE® (GY-81)

Use Area: Soil fumigation -- small fruits and vegetables, and orchards and vineyards.

Efficacy: Unknown
Registration: Not registered/experimental permit granted
Market Infrastructure: Needs development
Cost: Less expensive

Enzone® (sodium tetrathiocarbonate), produced by Unocal Corporation, is a relatively new fumigant that is still in the experimental and registration stages. An additional 2 to 3 years of extensive field testing will be required before its value as a substitute for methyl bromide can be assessed. It has, however, been registered in Spain and is pending registration in France for crops such as tomatoes, strawberries, and citrus. It can be applied as a liquid or granular formulation with the use of irrigation to distribute the chemical and assist in its degradation. Enzone® can be applied at relatively high rates if there is a one to four week waiting period before planting or it can be applied one to three times at lower rates after planting. Upon exposure to soil moisture, Enzone® degrades to carbon disulfide (the main active ingredient), ammonium (a fungicide), and sulfur (a fungicide, acaricide, and insecticide). Enzone® has a low vapor pressure, is not flammable, can be applied evenly, and because it breaks down slowly, can be contained in the soil.

- **Efficacy:** Enzone® has been tested in controlling nematodes, soil insects, fungi, and other soil-borne pathogens, and has been found to be especially effective against fungi and nematodes. It is not, however, an effective herbicide. Efficacy is dependent on the availability of water that is necessary for its even distribution in the soil.

- **Registration:** Enzone® is not currently registered, but experimental use permits have been granted for a wide range of applications. The registration process has been started for pre- and post-plant applications in the production of grapes and citrus, but avian toxicity and environmental fate studies still need to be completed. It should be noted that UNEP has indicated concern over ground water contamination.

- **Market Infrastructure:** Because the application methods for Enzone® are similar for those of other pesticides, little training would be required. Growers would need some time, however, to become familiar with the new product.

- **Cost:** The cost of applying Enzone® is likely to be less than that for methyl bromide. This is because the raw material costs are lower and tarpaulins are not usually used. The raw material cost for Enzone® is \$6 to \$8 per gallon of active ingredient. The application rate is approximately 30 gallons of active ingredient per year per acre. Equipment and application methods parallel those already in practice for other pesticides. Total costs for the raw material are estimated to be between \$150 and \$270 per acre. Estimates on labor costs and equipment are not currently available.

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FORMALIN/FORMALDEHYDE

Use Area: Soil fumigation -- small fruits and vegetables, nursery production, and orchards and vineyards.

Efficacy: Comparable in spectrum (less effective nematicide and herbicide)
Registration: Voluntarily cancelled
Market Infrastructure: Needs development
Cost: Unknown

Formaldehyde is one of the oldest soil sterilization methods used in agricultural production, but because of its strong odor, high phytotoxicity, and potential adverse health impacts, it has been replaced with other methods. Formaldehyde is available in aqueous solutions (formalin) and granular formulations (paraformaldehyde). Granular formulations can be applied with better accuracy and allow for better soil distribution and incorporation. In addition to the development of a granular formulation, a recently invented application method enables liquid formalin to be applied with a slurry spreader which enhances even distribution in the soil and more exact regulation of the amount applied. After formaldehyde is applied, irrigation is needed to disperse the excess chemical and prevent phytotoxicity. A waiting period of one to two weeks (or longer in cold weather) is required before planting.

- **Efficacy:** Formaldehyde is as effective as methyl bromide at controlling fungi, but it is less effective in its ability to control nematodes and weeds. Because of these considerations, the use of a nematicide in combination with formaldehyde would be required in many applications. Formaldehyde's ability to control fungi complexes (e.g., replant disease in apples and damping-off in conifer seedling production) is actually better than methyl bromide and many of the substitutes to methyl bromide.

- **Registration:** The registration of formaldehyde for use in the production of food products was voluntarily cancelled by its manufacturers in the late 1980s because of health, safety, and environmental concerns. It is still used in the disinfection of some medical supplies. Formaldehyde may not be registered for other uses or reregistered because it has been found to be carcinogenic in animal studies and is listed as a B1 carcinogen.

- **Market Infrastructure:** If formaldehyde were reregistered for large-scale uses it would require new application techniques to be refined and made available to applicators to minimize the health and safety risks associated with its use. The equipment changes needed, such as adding a filter to an enclosed cab tractor to minimize cab concentrations of formaldehyde, would most likely not be major and could be completed in a relatively short period of time.

- **Cost:** Because formaldehyde is not available for soil fumigation applications, cost data is currently not available.

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STEAM

Use Area: Soil fumigation -- small fruits and vegetables and nursery production.

Efficacy: Comparable (for small scale applications)
Registration: Not required
Market Infrastructure: Little or none exists
Cost: More expensive

Steam treatments that raise soil temperatures to 158°F and maintain that temperature for half an hour can be used to control soil pests. The process may take from 4 to 8 hours depending on the method used. Steam can be applied to the surface of the soil or with a pressure system utilizing pipes installed underground. Steam can be applied from the surface using a number of means including via a tractor that has a metal section that covers the soil and releases steam or with a portable boiler and fan system that blows steam under tarpaulins covering the soil. After steaming, crops can be planted as soon as the soil is cool (up to 5 days). In some cases waiting periods may be longer if the steamed microflora release large amounts of ammonia or if the crop to be planted is very sensitive to heat or ammonia (e.g., lettuce). Also, organic matter may need to be added to the treated soil to replenish soil nutrients that may have been destroyed during the steaming process. Steam is a technically feasible disinfestation method for all soil applications; however, it is not practical to use on a large scale (e.g., more than 1 to 2 acres) because only tractor applications would be possible, which could require up to 100 hours per acre.

- **Efficacy:** Steam can be used to control all soil pests in most applications. It is believed to be up to 100 percent as effective as methyl bromide, depending on the length of time that steam is applied, the soil temperature that is achieved, and the depth of penetration. Steam may not be completely effective, however, in low permeability soil.

- **Registration:** Steam is currently available for use. It does not require registration because no chemicals or potentially toxic substances are used.

- **Market Infrastructure:** It may take up to ten years before steaming is widely available to U.S. growers because equipment and contract services for steam are not readily available. Steam applications do not require a certified applicator, but training in proper steam application would also be necessary. It is important to note that steam is currently used successfully in Europe.

- **Cost:** The total cost of steam, based on European costs, are estimated to be between $2,500 and $5,000 per acre and include costs of natural gas, labor, water, tarpaulins and machinery. Machinery costs include equipment installation for underpressure steaming in permanent facilities (e.g., greenhouse), steam facilities for potting/container soil production systems, and steam equipment for non-permanent facilities and larger areas. If growers choose not to purchase equipment, contract services similar to those for methyl bromide could be used.

- **Other Considerations:** When steam is applied properly, and if it is used in combination with crop rotation and sanitary management practices (e.g., equipment is cleaned before being brought into the area to make sure that soil pathogens are not being transported), then the soil only needs to be treated once every two to three years.

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SOIL SOLARIZATION

Use Area: Soil fumigation -- small fruits and vegetables (only in areas with long growing seasons), nursery production, and orchards and vineyards.

Efficacy:	Lower
Registration:	Not required
Market Infrastructure:	Little or none exists
Cost:	Less expensive

Soil solarization is a pest control method that utilizes solar heat to sterilize the soil. Tarpaulins 1 to 4 mils (.001 to .004 inches) thick are spread over a field. The tarpaulins are struck by sunlight that heats the soil and raises its temperature to between 105°F and 122°F at depths of 2 inches to 8 inches. The length of treatment is determined by how quickly the soil reaches killing temperatures and how long the temperatures must be maintained to be efficacious against the pests present. Soil temperature is affected by weather conditions, soil moisture, and the type of tarpaulin used and may require from 4 to over 12 weeks to achieve the required temperatures. The long treatment period makes it an impractical treatment for "total kill" in most areas, because the growing season is short. It could potentially be used in some southern states and southern California, but would most likely only be used in combination with other control methods that reduce the treatment times. Also, short treatments with solarization may be effective in killing some target pests or decreasing the pest population below the economic threshold.

- **Efficacy:** Soil solarization can be used for all soil treatments to control most soil pests. The treatment parameters required to obtain efficacy levels comparable to methyl bromide in the U.S. may not be possible in all geographic areas because, as noted above, the growing season is too short and killing temperatures cannot be achieved. Efficacy is believed to be 70 to 100 percent as effective as methyl bromide, depending on the temperatures that can be reached, the moisture content of the soil, and the treatment duration.

- **Registration:** Solarization does not use chemicals or other potentially hazardous substances and therefore does not require registration.

- **Market Infrastructure:** Although solarization is currently available, the treatment parameters, best types of plastic to use, and methods to increase the rate of soil heating need to be researched and refined before this is a viable alternative. Research could take from one to five years and growers may need one or more years to accept and implement solarization techniques.

- **Cost:** The actual cost of solarization is very low, because the main treatment materials are tarpaulins. However, labor for laying down the sheets of plastic and the extremely long waiting period can substantially increase the expense of solarization. Solarization costs \$150 to \$450 per acre for sheets and labor, depending on whether full bed or partial bed covering is used and \$50 per acre for removal and disposal of used or damaged tarpaulins. Total costs are estimated to range from \$200 to \$500 per acre.

- **Other Considerations:** Current research indicates that combining solarization with chemical pesticides or fumigants could shorten the treatment time significantly. Completion of this research and verification of the data could take three to five years. These combinations show more potential as alternatives than solarization by itself because the shortened treatment time enables growers to still plant one or two crops per year.

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HYDROPONICS

Use Area: Soil Fumigation -- small fruits and vegetables (except for root crops).

Efficacy: Comparable
Registration: Not required
Market Infrastructure: Little or none exists
Cost: More expensive

Hydroponics is a relatively new plant production system that does not utilize soil, thereby eliminating the threat posed by soil pests (e.g., nematodes, soil-borne fungi, weeds). Hydroponic culture involves growing plants on a substrate (e.g., sand, perlite, foam blocks, or other substances that can retain water) and then pumping nutrient-containing water to the substrate containers. The flow and nutrient content of the water can be regulated by computer and recycled to prevent waste. To prevent fungal infestations, the substrate must be treated with steam or another disinfectant on a yearly or biyearly basis and the water must be treated or cleaned on a regular basis. Hydroponic systems already are in widespread use in the Netherlands and are being introduced in California and Florida. They are used for the production of strawberries, many vegetables (e.g., tomatoes, peppers, lettuce) and some floriculture crops, but cannot be used for root crops (e.g., carrots). Hydroponic systems usually enable growers to produce 2 to 3 crops per year and yields are usually higher than those achieved in soil production systems.

- **Efficacy:** Because soil is not used, most of the pests controlled with methyl bromide are not present and therefore control measures are not required.

- **Registration:** Hydroponic systems are currently available and are being introduced in the U.S. These systems do not require registration because hydroponics is a change in the production method and not a pest control method.

- **Market Infrastructure:** Some companies are marketing hydroponic systems, but the level of production and marketing is limited in the U.S. Support services that would be required with a hydroponic system include contract services for annual steaming of the substrate, substrate suppliers, charts of nutrient requirements, and computer programming for watering and nutrient administration. Based on the need for developing significant amounts of infrastructure and support services, it could take ten or more years before hydroponics could be widely accepted.

- **Cost:** The start up costs for hydroponic systems can be very high and include at a minimum, either a glasshouse or raised beds for outdoor production, a water nutrient delivery and monitoring system, and substrate investment. In the long run, however, a hydroponic system can be economically feasible because total yield on a per acre basis can be substantially increased, less land is needed because more plants can be grown in a smaller area and many pests are eliminated, reducing total pesticide costs. Costs of installing a hydroponic system are high, but rates of return can be up to 40 percent. Some growers have achieved a recovery of investment in 3 years; however, the predicted rate of recovery is 10 to 15 years.

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NON-FUMIGANT NARROW SPECTRUM PESTICIDES

Use Area: Soil fumigation -- small fruits and vegetables, nursery production, and orchards and vineyards.

Efficacy: Lower
Registration: Registered
Market Infrastructure: In place
Cost: Less expensive

Non-fumigant narrow spectrum pesticides are either granular or liquid formulations that can be spread or sprayed on the soil to control specific pests (nematodes, weeds, insects, fungi, or bacteria). Depending on the specific product, the condition to be controlled, and the crop being treated, these non-fumigant pesticides can be used before and after planting. Because products in this category are narrow spectrum, more than one herbicide, nematicide, and/or fungicide may be required to accomplish the control for the same spectrum of pests as for methyl bromide. This approach to pest control is designated as a combination treatment.

- **Efficacy:** A combination treatment using three or more non-fumigant pesticides (a preemergence and post emergence herbicide, a nematicide, and a fungicide) can achieve efficacy levels of 70 percent or more compared to methyl bromide. This general level of efficacy can be improved by varying the specific products being used and the levels of treatment. Efficacy also depends on individual factors such as location, pest species and populations, and weather and soil conditions. In general, the levels and types of pesticides required to maintain pest population levels below the economic threshold limits is most likely within established residue limits, although residue limits may affect efficacy in some cases. The achievable level of efficacy could be reduced in the future if pest resistance to specific products increases.

- **Registration:** Some of the major non-fumigant nematicides used in combination treatments are listed in the table below. Each of these products is registered in the U.S. as restricted or non-restricted use pesticide for particular crops and site areas, and therefore all non-fumigant pesticides are not available for all crops in all states. For example, although carbofuran is registered in most states for use in tobacco production, it is only registered in Oregon and Washington for use in strawberry production.

Nematicides	Herbicides	Fungicides
aldicarb	basagran	benomyl
carbofuran	glyphosate	captan
ethoprop	metribuzin	metalaxyl
fenamiphos	pendimethalin	metiram
oxamyl	sethoxydim	PCNB

Many non-fumigant pesticides, especially the nematicides, have not yet been reregistered primarily because their limited use for minor crops does not warrant the expense of reregistration, but also because they may pose significant health and/or environmental risks. Of the narrow spectrum pesticides, nematicides face the most difficulty in being reregistered because aldicarb, carbofuran, and oxamyl are potential ground water contaminants and fenamiphos and ethoprop are organophosphates.

- **Market Infrastructure:** Many of these pesticides are currently used and growers are familiar with application techniques such that no additional training would be required.

- **Cost:** The costs associated with applying non-fumigant narrow spectrum pesticides are likely to be lower than the cost of applying methyl bromide. This is because the raw material costs are much lower. In some cases, however, the use of narrow spectrum pesticides in combination can result in higher costs because many of these pesticides cannot be mixed together and applied at the same time and thus separate applications are required. In addition, for such combination treatments to achieve 70 percent efficacy requires up to four applications during the growing season (as compared to one application for methyl bromide). Raw material costs (i.e., chemical costs only) for three to four applications of a combination of pesticides are estimated to range from $155 to $200 per acre.

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COMBINATION SOIL CHEMICAL TREATMENTS

Use Area: Soil fumigation -- small fruits and vegetables, nursery production, and orchards and vineyards.

Efficacy:	Comparable (application specific)
Registration:	Registered
Market Infrastructure:	Little or none exists
Cost:	Comparable

Combination treatments, the use of a variety of narrow spectrum pesticides and/or fumigants, have the potential to control all pests and/or maintain pest populations below economic threshold levels in the production of many different types of crops. Technically feasible combination treatments include:

(1) one or more narrow spectrum pesticides combined with a fumigant, solarization, or steam;
(2) a combination of fumigants (e.g., 1,3-dichloropropene, an MITC releaser, and chloropicrin); and
(3) a fumigant combined with solarization.

Research is needed to identify the best application rates for new fumigant combinations, the treatment length and application rates for fumigants with solarization, and the best method of rotating chemicals to prevent pest resistance from developing.

- **Efficacy:** Combination treatments can be used to control all soil pests in almost all production settings. Combination treatments can achieve efficacy levels similar to those obtained with methyl bromide, but exact levels of efficacy are dependent on the combination treatment used. For example, if a grower elects to use a short solarization period in combination with 1,3-dichloropropene (which is most effective against nematodes), effective control of fungi may not be achieved and yield losses may result.

- **Registration:** Most of the pesticides used in combinations are registered or in the process of being registered/reregistered. The use of some narrow spectrum pesticide combinations could be prohibited because of chemical reactions or environmental contamination.

- **Market Infrastructure:** Additional research is needed to develop the most effective combination treatments (e.g., the use of MITC releasers in combination with solarization is only in the preliminary research stage) and grower training would be required to ensure that treatments are instituted properly.

- **Cost:** The costs associated with combination soil chemical treatments can be comparable to those for methyl bromide. While pest surveys and soil testing are required in order to choose the best products for combination, these treatments usually require lower levels of fumigant or narrow spectrum pesticides. Narrow spectrum pesticides cost from $2 to $200 dollars per acre depending on the application rate and the number of applications, while fumigants cost from less than $500 to over $1,500 dollars per acre. Total costs, including labor and equipment, are estimated to range from $750 to $1,500 per acre (based on most likely combinations).

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ORGANIC MATTER

Use Area: Soil fumigation -- small fruits and vegetables, nursery production, and orchards and vineyards.

Efficacy: Unknown
Registration: Some registered/some not registered/some not required
Market Infrastructure: Little or none exists
Cost: Unknown

Organic matter such as neem cake, chitin (Clandosan®), straw, sawdust, mustard cake, and green animal manure can be incorporated into soil to control soil pests such as nematodes and weeds. These products, which are often referred to as soil amendments because they can alter the composition of the soil, work in a variety of ways. Some products, such as chitin, work by both killing nematodes and by providing a favorable environment for the growth of fungi and bacteria that are antagonistic to parasitic plant nematodes. Chitin, which releases urea, can be phytotoxic to plants, and therefore must be applied one or more weeks before planting. Other organic materials are toxic to nematodes or suppress their feeding and can be applied before, during, or after planting. Material such as straw can also decrease weed growth. While the use of organic material is an old agricultural technique, the identification of better materials to use and the most efficacious application rates make this method a potentially viable alternative if it is used in combination with other techniques.

- **Efficacy:** Little information is currently available concerning the general efficacy of organic material and therefore it is difficult to establish an effectiveness rating. Experimental results, however, indicate that efficacy, at least against nematodes, can be as high or higher than that achieved with some non-fumigant nematicides such as carbofuran.

- **Registration:** Organic amendments manufactured or distributed for the express purpose of pest control must be registered. Chitin, the only major organic soil amendment that is currently being manufactured and distributed on a large scale, is registered. Other amendments such as straw and sawdust would only require registration if they were being sold as pest control methods. While organic amendments are often considered "environmentally friendly", some substances release urea or ammonia when they degrade both of which can be potentially toxic.

- **Market Infrastructure:** Except for chitin, there are few manufacturers or distributors of organic amendments. Also, except for traditional amendments such as manure and straw, growers are unfamiliar with their use and application and would need to learn how to incorporate their use into current management production systems.

- **Cost:** Organic amendments are usually inexpensive, but large amounts must be applied and incorporated into the soil (as much as 2.75 tons per acre). Total costs are dependent on the type of amendments being used. The raw material costs of the amendments can vary widely. For example, the raw material cost of chitin ranges from $800 to $2,400 per acre depending on the application rate, while the raw material cost of living mulch, green manure, and mixtures average $260 to $375 per acre.

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PLANT MODIFICATION

Use Area: Soil fumigation -- small fruits and vegetables, nursery production, and orchards and vineyards.

Efficacy: Unknown
Registration: Some not required/some not registered
Market Infrastructure: Little or none exists
Cost: Unknown

Plant modification using techniques such as breeding selection, rootstock grafting, and genetic engineering may be used in the future to develop plants that are resistant[1] or antagonistic[2] to soil pests. These techniques can be defined as:

(1) breeding selection: crossbreeding cultivars that exhibit resistance with cultivars that have desirable production characteristics such as high yields or large fruit.

(2) rootstock grafting: grafting shoots with desirable production characteristics onto roots that have resistant or antagonistic traits. This technique can only be used on trees and vines.

(3) genetic engineering: creating new plant cultivars by changing their genetic make-up to include genes that produce toxins or pheromones or will impart resistance.

These techniques will require intensive research before their potential as alternatives can be quantified.

- **Efficacy:** The overall effect of this approach as a replacement for methyl bromide is uncertain, because the crops on which methyl bromide is used have undergone little testing. Laboratory tests, field tests, and commercial use of modified plants have been successful for some crops such as potatoes, soybeans, sugarbeet, and cotton that usually are not treated with methyl bromide. Also, current commercial use has involved cultivars that are resistant or antagonistic to a limited number of specific pest species. For example, potatoes have been developed to be resistant to cyst nematodes and semi-resistant to other nematodes, but they have not been developed to be resistant to nematodes and fungi.

- **Registration:** Cultivar breeding and rootstock grafting do not require registration, although the use of genetically altered plants would require EPA and/or FDA approval.

- **Market Infrastructure:** Research is needed in all areas of plant modification including the development of resistance or antagonistic traits. All of the techniques require not only identification and development of these traits, but also significant efforts to incorporate the identified traits into target plants.

- **Cost:** The costs associated with developing and implementing these techniques cannot be estimated because research is still in the preliminary stages.

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[1] Resistant plants are plants that can sustain more pest feeding and fungi colonization than other plants before exhibiting yield decreases.

[2] Antagonistic plants are those that 1) produce chemicals that are toxic to pests, 2) have some change in their physiological structure that inhibits pest feeding and fungi colonization, or 3) produce pheromones that inhibit pest growth and development.

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INTEGRATED PEST MANAGEMENT

Use Area: Soil fumigation -- small fruits and vegetables, nursery production, and orchards and vineyards.

Efficacy: Comparable (maintains pest populations below the economic threshold, does not sterilize the soil)
Registration: Some registered/some not registered/some not required
Market Infrastructure: Little or none exists
Cost: Unknown

Integrated pest management (IPM) relies on knowledge about pest population levels to determine the appropriate type of treatment and/or management practice to prevent populations from reaching damaging levels. A good IPM program attempts to maintain population levels below damaging levels using a variety of techniques such as cultural practices (e.g., crop rotation and interplanting), biological controls, organic amendments (see Fact Sheet #12), and cultivar selection (see Fact Sheet #13). Growers must monitor pest population levels so that controls can be implemented before damage occurs. By using a control method at an early stage, less pesticide usage is required, but the pesticide must be very narrow in its spectrum of activity or else other soil organisms could be affected.

- **Efficacy:** IPM programs do not achieve the same levels of efficacy as methyl bromide but can result in similar yields. IPM programs are not intended to completely eradicate all pests, but to instead maintain the pest population levels below the economic threshold level. Strict pest monitoring and a good understanding of crop production, pest, soil, temperature, and crop growth stage interactions are necessary to achieve high efficacy and good crop yields. However, the current scientific level of knowledge regarding the soil ecosystem and crop production interactions is limited, and intensive research would be required to guarantee the effectiveness of IPM systems.

- **Registration:** Most of the pesticides required in IPM systems are registered or in the process of being registered/reregistered. Other techniques used in IPM systems are changes in the management practices and do not require registration. However, some of the biological control methods and some of the cultivars that are being developed must be registered either by the EPA or approved by the FDA or EPA if genetic manipulation of plants or other organisms are involved.

- **Market Infrastructure:** More research is needed to develop the most effective IPM programs. Research is also needed to develop more biological controls, identify more antagonistic species, increase the general scientific knowledge about the soil ecosystem and its balance, perfect genetically modified species with increased resistance to pests. Grower training also is required in order for the systems to be implemented efficaciously.

- **Cost:** The cost of implementing IPM systems is dependent upon the crop, pest, and control method selected, since the amount of labor, number of pest surveys, and amount of chemicals needed will be unique to each situation. Initial adoption costs can be very expensive because of the need for grower training or hiring of an IPM field advisor. Some of the basic costs in an IPM program are for pest surveys, soil testing, the purchase of specially developed cultivars, and labor. The cost of IPM programs may decrease as growers become more familiar with the techniques and as IPM programs are refined. It is estimated that total costs, including labor and equipment, could be as high as $1,000 per acre. However, pest population monitoring may significantly reduce the need for pesticides, thereby lowering overall costs. In addition, secondary costs of pesticide use can be cut by utilizing machinery and related equipment when needed. Depending on the amount of labor and chemicals used, costs could, however, be as low as $200 per acre, equivalent to the cost for non-fumigant narrow spectrum pesticides.

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FUTURE AND PRELIMINARY RESEARCH ALTERNATIVES

Use Area: Soil fumigation -- small fruits and vegetables, nursery production, and orchards and vineyards.

Efficacy: Unknown
Registration: Not registered
Market Infrastructure: Little or none exists
Cost: Unknown

Many toxic substances and non-chemical treatments have been identified in the laboratory that may be potential soil pest control methods. These methods include the use of:

New and Modified Pesticides

(1) inorganic ions to control nematodes;
(2) azides to control various soil pests;
(3) toxic plant extracts such as furfural for nematode, fungi, and/or weed control; and
(4) bromonitromethane, a methyl bromide related chemical, with a lower vapor pressure.

Biocontrol Methods

(5) antagonistic bacteria or fungi species to control plant pathogenic organisms (e.g., egg destroying fungi such as *P. lilacinus* and *V. chlamydosporium*); and
(6) beneficial organisms (rhizobacteria) that promote plant growth and resistance.

Genetic Engineering

(7) genetically altered organisms that are antagonistic or parasitic to plant pathogens; and
(8) species specific antagonistic organisms to control weeds such as nutsedge.

- **Efficacy:** Most of these potential alternatives have not been tested in the field and it is, therefore, difficult to determine their efficacy. Some alternatives, however, such as furfural and azides, have been tested and are believed to be as effective as methyl bromide within the spectrum of activity.

- **Registration:** Most of these types of alternatives, because they will be manufactured and/or distributed specifically as pest control methods, will require registration. The EPA has not set up guidelines yet for the registration of genetically engineered biological controls. However, it is believed that the EPA will include their registration with other "safer" pesticides which have fewer testing requirements and lower registration fees. Additionally, the level of research on some of these alternatives varies significantly with some being field tested and others requiring 10 or more years before product development is possible.

- **Market Infrastructure:** Because these potential alternatives are in the beginning research stages, market infrastructure has not yet developed.

- **Cost:** The costs associated with these potential substitutes is not known because most of them are still in the preliminary development stage.

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FACT SHEETS FOR NON-SOIL APPLICATIONS

Perishable Commodities

Non-Perishable Commodities

Quarantine

Structures

COMBINATION SOIL CHEMICAL TREATMENTS

Use Area: Soil fumigation -- small fruits and vegetables, nursery production, and orchards and vineyards.

Efficacy: Comparable (application specific)
Registration: Registered
Market Infrastructure: Little or none exists
Cost: Comparable

Combination treatments, the use of a variety of narrow spectrum pesticides and/or fumigants, have the potential to control all pests and/or maintain pest populations below economic threshold levels in the production of many different types of crops. Technically feasible combination treatments include:

(1) one or more narrow spectrum pesticides combined with a fumigant, solarization, or steam;
(2) a combination of fumigants (e.g., 1,3-dichloropropene, an MITC releaser, and chloropicrin); and
(3) a fumigant combined with solarization.

Research is needed to identify the best application rates for new fumigant combinations, the treatment length and application rates for fumigants with solarization, and the best method of rotating chemicals to prevent pest resistance from developing.

- **Efficacy:** Combination treatments can be used to control all soil pests in almost all production settings. Combination treatments can achieve efficacy levels similar to those obtained with methyl bromide, but exact levels of efficacy are dependent on the combination treatment used. For example, if a grower elects to use a short solarization period in combination with 1,3-dichloropropene (which is most effective against nematodes), effective control of fungi may not be achieved and yield losses may result.

- **Registration:** Most of the pesticides used in combinations are registered or in the process of being registered/reregistered. The use of some narrow spectrum pesticide combinations could be prohibited because of chemical reactions or environmental contamination.

- **Market Infrastructure:** Additional research is needed to develop the most effective combination treatments (e.g., the use of MITC releasers in combination with solarization is only in the preliminary research stage) and grower training would be required to ensure that treatments are instituted properly.

- **Cost:** The costs associated with combination soil chemical treatments can be comparable to those for methyl bromide. While pest surveys and soil testing are required in order to choose the best products for combination, these treatments usually require lower levels of fumigant or narrow spectrum pesticides. Narrow spectrum pesticides cost from $2 to $200 dollars per acre depending on the application rate and the number of applications, while fumigants cost from less than $500 to over $1,500 dollars per acre. Total costs, including labor and equipment, are estimated to range from $750 to $1,500 per acre (based on most likely combinations).

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ORGANIC MATTER

Use Area: Soil fumigation -- small fruits and vegetables, nursery production, and orchards and vineyards.

Efficacy: Unknown
Registration: Some registered/some not registered/some not required
Market Infrastructure: Little or none exists
Cost: Unknown

Organic matter such as neem cake, chitin (Clandosan®), straw, sawdust, mustard cake, and green animal manure can be incorporated into soil to control soil pests such as nematodes and weeds. These products, which are often referred to as soil amendments because they can alter the composition of the soil, work in a variety of ways. Some products, such as chitin, work by both killing nematodes and by providing a favorable environment for the growth of fungi and bacteria that are antagonistic to parasitic plant nematodes. Chitin, which releases urea, can be phytotoxic to plants, and therefore must be applied one or more weeks before planting. Other organic materials are toxic to nematodes or suppress their feeding and can be applied before, during, or after planting. Material such as straw can also decrease weed growth. While the use of organic material is an old agricultural technique, the identification of better materials to use and the most efficacious application rates make this method a potentially viable alternative if it is used in combination with other techniques.

- **Efficacy:** Little information is currently available concerning the general efficacy of organic material and therefore it is difficult to establish an effectiveness rating. Experimental results, however, indicate that efficacy, at least against nematodes, can be as high or higher than that achieved with some non-fumigant nematicides such as carbofuran.

- **Registration:** Organic amendments manufactured or distributed for the express purpose of pest control must be registered. Chitin, the only major organic soil amendment that is currently being manufactured and distributed on a large scale, is registered. Other amendments such as straw and sawdust would only require registration if they were being sold as pest control methods. While organic amendments are often considered "environmentally friendly", some substances release urea or ammonia when they degrade both of which can be potentially toxic.

- **Market Infrastructure:**. Except for chitin, there are few manufacturers or distributors of organic amendments. Also, except for traditional amendments such as manure and straw, growers are unfamiliar with their use and application and would need to learn how to incorporate their use into current management production systems.

- **Cost:** Organic amendments are usually inexpensive, but large amounts must be applied and incorporated into the soil (as much as 2.75 tons per acre). Total costs are dependent on the type of amendments being used. The raw material costs of the amendments can vary widely. For example, the raw material cost of chitin ranges from $800 to $2,400 per acre depending on the application rate, while the raw material cost of living mulch, green manure, and mixtures average $260 to $375 per acre.

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Integrated pest management (IPM) relies on knowledge about pest population levels to determine the appropriate type of treatment and/or management practice to prevent populations from reaching damaging levels. A good IPM program attempts to maintain population levels below damaging levels using a variety of techniques such as cultural practices (e.g., crop rotation and interplanting), biological controls, organic amendments (see Fact Sheet #12), and cultivar selection (see Fact Sheet #13). Growers must monitor pest population levels so that controls can be implemented before damage occurs. By using a control method at an early stage, less pesticide usage is required, but the pesticide must be very narrow in its spectrum of activity or else other soil organisms could be affected.

- **Efficacy:** IPM programs do not achieve the same levels of efficacy as methyl bromide but can result in similar yields. IPM programs are not intended to completely eradicate all pests, but to instead maintain the pest population levels below the economic threshold level. Strict pest monitoring and a good understanding of crop production, pest, soil, temperature, and crop growth stage interactions are necessary to achieve high efficacy and good crop yields. However, the current scientific level of knowledge regarding the soil ecosystem and crop production interactions is limited, and intensive research would be required to guarantee the effectiveness of IPM systems.

- **Registration:** Most of the pesticides required in IPM systems are registered or in the process of being registered/reregistered. Other techniques used in IPM systems are changes in the management practices and do not require registration. However, some of the biological control methods and some of the cultivars that are being developed must be registered either by the EPA or approved by the FDA or EPA if genetic manipulation of plants or other organisms are involved.

- **Market Infrastructure:** More research is needed to develop the most effective IPM programs. Research is also needed to develop more biological controls, identify more antagonistic species, increase the general scientific knowledge about the soil ecosystem and its balance, perfect genetically modified species with increased resistance to pests. Grower training also is required in order for the systems to be implemented efficaciously.

- **Cost:** The cost of implementing IPM systems is dependent upon the crop, pest, and control method selected, since the amount of labor, number of pest surveys, and amount of chemicals needed will be unique to each situation. Initial adoption costs can be very expensive because of the need for grower training or hiring of an IPM field advisor. Some of the basic costs in an IPM program are for pest surveys, soil testing, the purchase of specially developed cultivars, and labor. The cost of IPM programs may decrease as growers become more familiar with the techniques and as IPM programs are refined. It is estimated that total costs, including labor and equipment, could be as high as $1,000 per acre. However, pest population monitoring may significantly reduce the need for pesticides, thereby lowering overall costs. In addition, secondary costs of pesticide use can be cut by utilizing machinery and related equipment when needed. Depending on the amount of labor and chemicals used, costs could, however, be as low as $200 per acre, equivalent to the cost for non-fumigant narrow spectrum pesticides.

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FUTURE AND PRELIMINARY RESEARCH ALTERNATIVES

Use Area: Soil fumigation -- small fruits and vegetables, nursery production, and orchards and vineyards.

Efficacy: Unknown
Registration: Not registered
Market Infrastructure: Little or none exists
Cost: Unknown

Many toxic substances and non-chemical treatments have been identified in the laboratory that may be potential soil pest control methods. These methods include the use of:

New and Modified Pesticides

(1) inorganic ions to control nematodes;
(2) azides to control various soil pests;
(3) toxic plant extracts such as furfural for nematode, fungi, and/or weed control; and
(4) bromonitromethane, a methyl bromide related chemical, with a lower vapor pressure.

Biocontrol Methods

(5) antagonistic bacteria or fungi species to control plant pathogenic organisms (e.g., egg destroying fungi such as *P. lilacinus* and *V. chlamydosporium*); and
(6) beneficial organisms (rhizobacteria) that promote plant growth and resistance.

Genetic Engineering

(7) genetically altered organisms that are antagonistic or parasitic to plant pathogens; and
(8) species specific antagonistic organisms to control weeds such as nutsedge.

- **Efficacy:** Most of these potential alternatives have not been tested in the field and it is, therefore, difficult to determine their efficacy. Some alternatives, however, such as furfural and azides, have been tested and are believed to be as effective as methyl bromide within the spectrum of activity.

- **Registration:** Most of these types of alternatives, because they will be manufactured and/or distributed specifically as pest control methods, will require registration. The EPA has not set up guidelines yet for the registration of genetically engineered biological controls. However, it is believed that the EPA will include their registration with other "safer" pesticides which have fewer testing requirements and lower registration fees. Additionally, the level of research on some of these alternatives varies significantly with some being field tested and others requiring 10 or more years before product development is possible.

- **Market Infrastructure:** Because these potential alternatives are in the beginning research stages, market infrastructure has not yet developed.

- **Cost:** The costs associated with these potential substitutes is not known because most of them are still in the preliminary development stage.

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FACT SHEETS FOR NON-SOIL APPLICATIONS

Perishable Commodities

Non-Perishable Commodities

Quarantine

Structures

IRRADIATION

Use Areas: Perishable and Non-Perishable Commodity and Quarantine Fumigation.

Efficacy:	Comparable (stops pest development, does not kill them)
Registration:	Registered
Market Infrastructure:	Little or none exists
Cost:	More expensive

Irradiation consists of using approved low levels of gamma radiation to sterilize and/or kill pests. Sterilized pests cannot breed or further develop, feeding activity may decrease, and in many cases the pests will die after a short period of time. Commodities to be treated can be carried on a conveyor belt into the treatment facility, treated, and then transported out. Electron beams can also be used to control pests on grain while on a conveyor belt. In addition to controlling quarantine and non-quarantine pests, irradiation can improve the shelf life of perishables, by slowing down the ripening process.

- **Efficacy:** Irradiation can be used on most foods and feeds and is 100 percent as effective as methyl bromide. Although irradiation does not kill pests outright, it sterilizes them, preventing them from reproducing and causing further damage.

- **Registration:** Many tolerance levels for irradiation of food and feeds have been set by the FDA and the EPA. Irradiation is currently used to treat some small fruits and spices for interstate shipments; however, no uses have been certified by APHIS as quarantine treatments. It would require up to 4½ years for APHIS approval of irradiation as a quarantine treatment.

  APHIS certification will most likely be contingent on the availability of a method to identify that a commodity has been treated at the level required for pest sterilization. The efficacy of other treatments can be verified by checking for dead versus live pests, while with irradiation most of the pests are still alive. Therefore a method must be found that will enable APHIS personnel to distinguish between either irradiated commodities and non-irradiated commodities or sterilized pests versus non-sterilized pests. One technique being considered consists of enclosing commodities in crates that have markers on them that will change color based on the level of irradiation exposure. As long as the marker is the correct color and the crates have not been tampered with, APHIS personnel could assume that the commodities within the crates have been exposed to the proper level of irradiation. Large amounts of research have been conducted worldwide proving the efficacy of irradiation and developing marking methods, however, APHIS will have to verify these experiments and formulate standard treatment methods before quarantine approval.

- **Market Infrastructure:** Food irradiation facilities are currently operating in the U.S. in Florida and parts of the Northeast. Many smaller irradiation facilities are being used to sterilize medical supplies, and there are contract services available for building facilities and irradiating products. Despite the availability of these services, irradiation has not become an acceptable treatment method for two reasons: APHIS approval has not been granted (as discussed above) and consumers are wary of irradiation. In England, public awareness programs on the safety of irradiation and consumer taste tests have increased the acceptance of irradiation. Similar experiences in some areas of the U.S. have also increased consumer acceptance of irradiated foods, however, further public information campaigns and a change in labeling laws may be required before widespread acceptance.

- **Cost:** The cost of irradiation is likely to be higher than that for methyl bromide. Construction of irradiation facilities is the main expense associated with their use. USDA studies have shown that facilities at a few key entry/exit ports can be economical, but at smaller ports of entry this may not be the case. Another cost associated with irradiation is handling and disposal of spent cobalt, a low level radioactive waste. However, Nordion International, Inc., the main irradiation facility construction company, takes back and recycles the spent cobalt in the facilities that it builds. A typical irradiator with a capacity of over 66,000 tons per year costs between $1 and $3 million. The cost of irradiation is estimated to be $0.006 per pound of fruit or vegetable and less than $0.91 per ton of grain. These costs include all operating costs plus depreciation of the capital based on a 10 year amortization of equipment, a 15 year amortization of cobalt, and a 25 year amortization of buildings.

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PHOSPHINE GAS (Phostoxin®, Fumi-Cel®)

Use Areas: Structural, Non-Perishable Commodity, and Quarantine Fumigation.

Efficacy: Comparable in spectrum (some tolerance has developed)
Registration: Registered
Market Infrastructure: In place
Cost: Less expensive

Phosphine gas, a fumigant, is produced when magnesium or aluminum phosphide is exposed to moisture. Magnesium and aluminum phosphide, manufactured by Degesch America, Inc., are formulated into pellets, tablets, bags, dust, or plates which can be placed by the user into the treatment area or container. The treatment takes from 2 to 10 days, depending on the temperature and humidity. The use of phosphine is limited in structural treatments to facilities such as silos and grain bins because under high moisture conditions it can react with copper, silver and gold that may be present in switches or electronic equipment in homes, commercial/industrial buildings, or other facilities.

- **Efficacy:** Phosphine can be used to control numerous pests in some structures and on a wide variety of commodities. It is currently used as a quarantine treatment for some commodities and is the recommended fumigant for on-farm treatment. It is believed to be between 90 percent and 100 percent as effective as methyl bromide in the allowed structural and commodity treatments and 100 percent as effective in the quarantine treatments. The main concern with the use of phosphine is potential pest resistance caused by improper application.

- **Registration:** Phosphine is currently registered for use on many commodities including raw agricultural commodities (e.g., grains, almonds, vegetable seed, corn), animal feed and feed ingredients such as barley, millet, oats, processed foods (corn grits, processed nuts, chocolate, cereal flours), and non-food commodities (feathers, leather products, tobacco). It can be used for the disinfestation of grain storage facilities and has been approved by APHIS as a quarantine treatment for tobacco exports, wood products with borers, cottonseed, cotton and cotton products with boll weevil, and baled hay.

- **Market Infrastructure:** Infrastructure development is not needed because applicators are already familiar with the application of phosphine gas.

- **Cost:** The cost of using phosphine is likely to be less expensive than methyl bromide because the raw material costs are lower and little labor is involved in applying the chemical. Phosphine products cost approximately $27 to $36 per pound and average application rates are 0.073 lbs per 1,000 ft^3 resulting in chemical costs of between $2 and $3 per 1,000 ft^3. The use of phosphine could hold up shipment deliveries and increase costs because of its long treatment time. With better treatment/shipment coordination, this problem could be overcome.

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SULFURYL FLUORIDE (Vikane®)

Use Areas: Structural and Quarantine Fumigation

Efficacy: Comparable (not as effective against eggs)
Registration: Registered
Market Infrastructure: In place
Cost: Slightly more expensive

Sulfuryl fluoride, manufactured by DowElanco, is applied as a liquid fumigant. It has good penetration and dissipation properties and becomes gaseous after application. It can be used in the disinfestation of homes and other structures (e.g., automobiles, surface ships, factories) and can be used for some non-food quarantine treatments. Facilities to be treated must be covered with tarpaulins, and food and food products must be removed from the facility because a food tolerance has not been set for sulfuryl fluoride. After application, the facility must be aerated and cannot be reoccupied until the concentration is below 5 ppm. The total treatment period including aeration ranges from 2 to 4 days. Sulfuryl fluoride does not react adversely with urethane and polyester foams and is often preferred over methyl bromide in residential fumigations for this reason. It is the only chemical fumigant allowed for structural fumigation in Hawaii, is used for 70 percent of the house treatments in Florida, and 50 percent of the house treatments nationwide.

- **Efficacy:** Sulfuryl fluoride is 100 percent as effective as methyl bromide in most structural treatments and 100 percent as effective in approved quarantine treatments. It is the preferred treatment for drywood termites, the main house pest requiring fumigation, because it does not soak into foam in household furnishings. It is not, however, as effective as methyl bromide against powder post beetle eggs unless the application rate is significantly increased, which poses aeration problems after treatment.

- **Registration:** Sulfuryl fluoride is currently registered for use in houses, warehouses, food processing facilities, and other structures, and has been approved by APHIS for particular quarantine treatments in fumigation chambers, though some tarpaulin treatments are possible. The use of sulfuryl fluoride has been limited, especially in food processing facilities, because no tolerance has been set for food or feeds. The future registration status of sulfuryl fluoride is uncertain because of mutagenicity, carcinogenicity, and reproductive toxicity concerns.

- **Market Infrastructure:** Applicators currently use sulfuryl fluoride for many treatments and are well aware of the application techniques, therefore no additional training would be necessary.

- **Cost:** The cost of using sulfuryl fluoride for structural and quarantine fumigation is slightly higher than the cost of methyl bromide, because the raw material costs are higher. Raw material costs for sulfuryl fluoride are approximately $8 per pound, with application rates from 8 ounces to 12 ounces per 1,000 ft^3, resulting in chemical costs of about $4.00 to $6.24 per 1,000 ft^3. Costs previously associated with the long reentry period (the period of time required for aeration of the structure) compared to methyl bromide have been mitigated by the change in reentry times for methyl bromide in California (one of the primary areas where homes are treated).

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PREVIOUSLY USED/LIMITED USE ALTERNATIVES

Use Areas: **Quarantine Fumigation**

Efficacy: Comparable
Registration: Some registered/some cancelled
Market Infrastructure: In place
Cost: Comparable

Fumigants that previously have been used for quarantine treatments or have been used in limited applications have the potential to be reregistered or have registration expanded to include other commodity treatments. These fumigants include ethylene oxide, hydrogen cyanide, ethylene dibromide, carbon disulfide, and ethylene dichloride, which have been cancelled or restricted because they pose health, safety, and environmental risks. APHIS has previously obtained Section 18 exemptions[1] (emergency use permits that allow a product to be used when it is not registered) for these fumigants for particular applications to control specified pests on specified commodities. While these fumigants are effective, they are not potential alternatives in other use areas because of the risks associated with their use. APHIS could potentially use these alternatives, however, because they would be applied in a much more controlled environment than that used in other application areas.

- **Efficacy:** These fumigants have been approved by APHIS as quarantine treatments and, therefore, are 100 percent as effective as methyl bromide.

- **Registration:** Ethylene oxide is registered by the EPA and the other potential alternatives have been registered in the past although they have been removed because of health and safety concerns (e.g., ethylene dibromide is a carcinogen, hydrogen cyanide is extremely toxic, carbon disulphide is explosive, and ethylene dichloride is flammable). Renewing the registration of these alternatives could be difficult because of the risks associated with their use. If they are not registered, however, they may still be used under Section 18 exemptions, if no other treatment is available.

- **Market Infrastructure:** These alternatives have been used before and applicators are familiar with their use. Also, APHIS has established application parameters for these products.

- **Cost:** These chemicals are similar in cost to methyl bromide. The additional safety precautions and testing that would most likely be required for their use may increase their cost slightly. Because these chemicals are no longer used, it is difficult to estimate current costs, however, chemicals such as ethylene dibromide used to be comparable in cost and sometimes less expensive than methyl bromide and could potentially cost $1.00 to $1.50 per 1,000 ft^3. The labor and equipment costs for these chemicals should be similar to methyl bromide, because they are restricted use fumigants and they are applied in a similar manner.

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[1] Section 4.2.1, page 16 provides further details about Section 18 exemptions.

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MODIFIED/CONTROLLED ATMOSPHERES (MA/CA)

Use Areas: Structural, Non-perishable Commodities, and Quarantine.

Efficacy: Comparable in spectrum
Registration: Not required
Market Infrastructure: Needs development
Cost: Less expensive

MA/CA treatments suffocate pests by exposing them to decreased amounts of oxygen and/or increased amounts of carbon dioxide or nitrogen for periods ranging from 4 hours to 30 days. The MA/CA is achieved by either introducing carbon dioxide into the storage area, purging the storage area with nitrogen, or burning oxygen to lower the oxygen level in the storage area. These treatments are effective in structural and non-perishable commodity and quarantine treatments; however, they have the most potential as non-perishable commodity treatments. However, in combination with low temperatures, this method may have potential for some perishable commodities. UNEP indicates that research for application of MA/CA to perishable commodities is on-going. Unless the treatment time can be decreased, these techniques may not be viable alternatives for quarantine treatments because the long treatment period associated with them can delay shipping.

- **Efficacy:** MA/CA is believed to be between 80 percent and 100 percent as effective as methyl bromide and can be used to control numerous types of insect pests and some fungi species, preserve food, and prevent reinfestations in structures and on non-perishable and some perishable commodities. To achieve high efficacy levels, treatment facilities must be completely sealed which may pose a problem in large food processing facilities or silos. The procedures needed to achieve consistently high efficacy levels when multiple pest species are present also is uncertain, but efficacy can be improved if combination treatments (e.g., heat or phosphine) are used.

- **Registration:** MA/CA does not require EPA registration, but safety guidelines, OSHA exposure limits, and required applicator safety equipment have been set. No quarantine uses have been approved by APHIS.

- **Market Infrastructure:** MA/CA treatments are currently available, however, full adoption of these treatment methods could require from 1 to 5 years. The waiting period before adoption is primarily due to the cost of sealing facilities, the lack of familiarity with MA/CA, and the time needed to perform studies to determine the best concentration of CO_2/O_2 to use. A few U.S. fumigation and specialty companies provide MA/CA services to control pests in large and small food processing facilities, in other structures, and for some commodities (e.g., grains and nuts). These services, however, are not widely available in the U.S.

- **Cost:** There are four main cost considerations in the use of MA/CA: (1) sealing facilities, (2) purchasing equipment, (3) transporting or generating the required gases, and (4) the extensive treatment period. Sealing already constructed silos and storage facilities averages \$5 per 100 ft^3, but the seals can last 5 to over 15 years. The current cost in the U.S. for trucking and introducing CO_2 into a facility is approximately \$133 per 1,000 ft^3, however, the cost of MA/CA in Australia and other areas where it is extensively used is less than the cost of methyl bromide.

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THERMOTHERAPY

Use Area: Perishable and Non-Perishable Commodity, Quarantine, and Structural Fumigation.

Efficacy: Comparable in spectrum (efficacy is application specific)
Registration: Not required
Market Infrastructure: Needs development
Cost: Slightly more expensive

Thermotherapy treatments are the application of either high (up to 100°C) or low (-17°C) temperatures for exposure periods of 50 minutes to 30 hours to kill pests. Treatments include vapor heat, dry heat, hot water, quick freeze, and cold treatments. Because pest susceptibility to temperature extremes is species and development stage specific and because many commodities are sensitive to temperature extremes, thermotherapy treatment parameters must be very specific for each application. Structural thermotherapy applications also may have limitations depending on the type of building materials and the size of the area to be treated.

- **Efficacy:** Thermotherapy treatments can be used to control a broad spectrum of commodity and structural pests and are believed to be 80 percent to 100 percent as effective as methyl bromide. Pests, however, have different threshold tolerances to temperature extremes. Therefore, some combinations of pests may not be controlled with thermotherapy unless it is used in combination with another treatment. Also, in food processing plant treatments, temperatures cannot be raised high enough to control all pests because of the size of the facilities; instead 4 to 5 applications per year versus 1 to 2 with methyl bromide, are used to maintain the pest levels below acceptable limits.

- **Registration:** Registration of thermotherapy is not required for commodity or structural treatments. It has been certified by APHIS for some quarantine treatments and many other potential quarantine uses have been researched.

- **Market Infrastructure:** APHIS applicators are familiar with the use of thermotherapy techniques, but other applicators, especially structural applicators, may not be as familiar with these techniques. Applicators have been experimenting with these techniques, however, and have begun testing them in the field.

- **Cost:** The main costs associated with thermotherapy are the building of treatment facilities and the cost of monitoring equipment. In structural treatments, the use of thermotherapy can be labor and time intensive. Because of the longer treatment times, extensive monitoring requirements, additional labor, and repeat applications, it is believed that thermotherapy is more expensive than methyl bromide. Structural treatments cost, including labor and equipment, approximately \$6 per 1,000 ft^3 per application and \$24 to \$30 per year. Commodity treatments, including labor and equipment, cost from \$0.015 to \$0.05 per pound of commodity treated.

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COMBINATION QUARANTINE AND COMMODITY TREATMENTS

Use Area: Quarántine and Perishable and Non-Perishable Commodity Fumigation.

Efficacy: Comparable (efficacy is application specific)
Registration: Registered
Market Infrastructure: Little or none exists
Cost: Slightly more expensive

Combination treatments potentially can be used to control and/or kill most pests on most commodities and in quarantine treatments; however, combinations have not been identified for all commodities or pests. Some typical and potential combination treatments are the use of:

(1) phosphine with controlled atmosphere;
(2) controlled atmosphere with irradiation;
(3) thermotherapy with controlled atmosphere; and
(4) thermotherapy with irradiation.

These treatments involve the use of an initial treatment that will make the pests more susceptible to the second treatment and result in a higher kill level. For example, irradiation would be used to sterilize the pests and weaken them, which could then be followed by a short exposure to a controlled atmosphere which would kill the weakened pests. In other combination treatments, the two methods can be used simultaneously in order to shorten the treatment time and increase the efficacy of the treatment.

- **Efficacy:** Combination treatments have the potential to be comparable to methyl bromide in efficacy for commodity and most quarantine pests, if the proper combinations and treatment parameters are identified and used. Treatment parameters must be closely regulated for the systems to work, and combination treatments have not yet been designed that are effective for all commodities or all pests. Combination treatments may be less effective against certain pest life stages.

- **Registration:** Both phosphine and irradiation are allowed in the U.S. for commodity treatments. None of the combination treatments, however, are certified for quarantine treatments. Each combination treatment must be certified separately. Also, if chemical combinations are used, the EPA must register or approve the combination to ensure that no adverse chemical reactions occur.

- **Market Infrastructure:** The infrastructure for this alternative needs development including training of applicators, the development of contract service companies, and users need to become familiar with the techniques.

- **Cost:** The cost of applying combination treatments is slightly higher than the cost of methyl bromide, because it is more labor intensive and some of the raw material costs are higher. In certain circumstances, the cost of combination treatments could be less expensive, however the initial research and training costs could be high and would most likely be reflected in the fees charged to users. Also, the building of irradiation facilities and the sealing of facilities are capital intensive. While costs are dependent on the exact combination being used, one combination using phosphine, heat, and CO_2 is estimated to cost, including labor and equipment, \$35 per 1,000 ft^3. Because these systems are labor intensive, it is believed that other combination treatments, like this one, will also be more expensive than methyl bromide.

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COMBINATION TREATMENTS AND INTEGRATED PEST MANAGEMENT FOR STRUCTURES

Use Area: Structural Fumigation.

Efficacy:	Comparable (maintains pest populations below economic threshold, does not sterilize the facility)
Registration:	Some registered/some not registered
Market Infrastructure:	Needs development
Cost:	Slightly more expensive

Combination treatments and IPM programs can be used to control and/or kill pests in all structure types including storage facilities, homes, and food processing facilities. Some typical and potential combination treatments are the use of:

(1) phosphine and other fumigants with controlled atmosphere;
(2) thermotherapy with controlled atmosphere;
(3) "crack and crevice" sprays (non-fumigant insecticides) with biological controls and/or pheromone trapping;
(4) thermotherapy with pheromone trapping;
(5) "crack and crevice" sprays with thermotherapy and controlled atmospheres; and
(6) "crack and crevice" sprays combined with good housekeeping.

These treatments use the combined effect of each treatment to increase efficacy and decrease treatment time. Some of the IPM programs use pheromone trapping to indicate the best time to apply a treatment and obtain the highest efficacy. These treatments differ from the commodity and quarantine combination treatments in that their purpose is only to maintain pest populations below economic threshold levels.

- **Efficacy:** Combination treatments and IPM programs can be used to control almost all structural pests and are believed to be 80 percent or more as effective in controlling pest population levels as methyl bromide. At the current level of technology they may not be able to control dry wood termites, however, some research using detection devices with heat and/or controlled atmosphere shows potential in this area. Combination treatments can achieve efficacy levels similar to those obtained with methyl bromide. The IPM programs do not achieve the high efficacy, though they can maintain the pest populations below economic threshold levels.

- **Registration:** Phosphine, sulfuryl fluoride, and "crack and crevice" sprays such as chlorpyrifos-methyl and malathion are registered, but have not been reregistered. Also, if chemical combinations are to be used, EPA must approve the combinations. Additionally, some of the "crack and crevice" sprays are toxic to humans (e.g., chlorpyrifos-methyl and malathion are organophosphates) and their spectrum of activity usually is limited to insects and arachnids, though some may be toxic to rats and mice and others may assist in fungi control.

- **Market Infrastructure:** Some combination treatments and IPM programs have been used extensively by some application companies and food processing facilities, but other application companies and facilities are not familiar with these programs or trained in their use. While research has been conducted on many combination treatments, the most efficacious treatment parameters are not known for all treatment situations. Research, development, and more specialized application companies are needed.

- **Cost:** The cost of combination treatments and IPM systems for structures are slightly higher than the cost of methyl bromide. This is because some of the raw material costs are higher and the systems are more labor intensive. Certain combination treatments,however, could be less expensive than methyl bromide. The initial research and training costs could be high and would most likely be reflected in the fees charged to users. Also, because current use of detection devices, and thermotherapy generation and controlled atmosphere equipment is low, the equipment tends to be expensive. Treatment costs are dependent on the particular combination used and can range from \$5 to \$35 per 1,000 ft^3 for the raw materials.

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ADDENDUM

Health and Safety Characteristics of Methyl Bromide and Its Alternatives

The health and safety characteristics of methyl bromide and potential alternatives that are not addressed in the Fact Sheets are included in this appendix. The appendix contains descriptions of criteria used to judge the toxicity of a chemical and lists toxicity data for methyl bromide and potential alternatives in Exhibit D.

The relative toxicity of methyl bromide compared to its alternatives is difficult to summarize succinctly. Because physical state, chemical and physical properties, modes of action, potency, and other factors differ from pesticide to pesticide, as well as among various formulations, it is difficult to present a capsulized evaluation or quantification of the relative risks of alternatives. In spite of the unique health and safety concerns that make it difficult to rank overall risk, however, it is possible to infer general concerns regarding toxicity from various toxicity parameters. Exhibit D presents values in four toxicity categories for each chemical pesticide under consideration as a replacement for methyl bromide. The selected categories are: (1) acute mammalian toxicity, (2) environmental fate, (3) acute aquatic toxicity, and (4) occupational exposure limits; each of which provides some indication of relative toxicity when compared to methyl bromide.

Acute Mammalian and Aquatic Toxicity

Median lethal dose (LD_{50}) values are used as a standard for comparison of acute toxicity between toxicants and between various species (i.e., rat, mouse, rabbit). LD_{50} is defined as the quantity of a chemical which, when applied directly to test organisms, is estimated to be fatal to 50 percent of those organisms under the stated conditions of the test. Because LD_{50} values vary between species, the extrapolation of the acute toxicity of a toxicant between species is not exact. Another value, designated as mean lethal concentration (LC_{50}), is used in lieu of LD_{50} tests for aquatic and inhalation toxicity studies.

Environmental Fate

Environmental fate refers to a substance's persistence, degradation, and mobility in the environment. An indicator of environmental fate, Log Kow values, or octanol-water partition coefficients, refer to the solubility of a particular test substance in octanol and water. The result is helpful in predicting a chemical's tendency to partition to the lipid phase, and has been shown to correlate with the chemical's tendency to bioaccumulate. This correlation is based on the assumption that octanol is similar in polarity-hydrophobicity characteristics to the glyceryl esters that comprise the principal component of cell membranes. Presumably compounds that preferentially partition out of water into these membranes (and thus have high Kow values) will exert greater disruptive influence on membrane processes or will accumulate more when the cell is exposed to a contaminated aqueous environment (Conway 1990).

Occupational Exposure

Occupational exposure limits also provide an indication of the relative risk to humans for a chemical. Threshold Limit Value (TLV), a measure of occupational exposure, refers to airborne concentrations of substances and represents conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects. They are based on the best available information from industrial experience, from experimental human and animal studies, and when possible, from a combination of the three. The 8-hour Time Weighted Average TLV (TWA TLV) refers to the average concentration that a worker may be exposed to for a normal 8-hour workday and a 40-hour workweek without adverse health effects (ACGIH 1992).

Exhibit D. Summary of Toxicity Data for Methyl Bromide and Alternatives

Pesticides[1]	Acute Mammalian Toxicity	Environmental Fate	Acute Aquatic Toxicity	Occupational Exposure Limits[2]
Methyl Bromide	Oral LD_{50} (rat): 20 mg/kg	No data	No data	TWA: 5 ppm
Dazomet	Oral LD_{50} (rat): 519 mg/kg	Log Kow: 2.15	LC_{50}: 45-50 ppm	No data
Metam-sodium	Oral LD_{50} (rat): 820 mg/kg	Log Kow: 0.19	LC_{50}: 330 ppb	No data
Formaldehyde/ Formalin	Oral LD_{50} (rat): 800 mg/kg	No data	No data	TWA: 0.3 ppm
Phosphine Gas/Aluminum Phosphide	LD_{50} (human) (unspecified route): 20 mg/kg	No data	No effect at 187 ppb, LC_{50} would be higher	TWA: 0.3 ppm
Sulfuryl Fluoride	No data	No data	No data	TWA: 5 ppm
Methyl Isothiocyanate	Oral LD_{50} (rat): 95 mg/kg	Log Kow: 0.94	LC_{50}: 130 ppb	No data
Trans-1,3-Dichloropropene	Inhalation LC_{50} (rat): 1148 mg/L	Log Kow: 1.41	LC_{50}: 82.3 ppm	No data
Chloropicrin	Oral lethal dose (humans) 5-50 mg/kg	Log Kow: 2.44	LC_{50}: 16.5 ppb	TWA: 0.1 ppm
Carbon Disulfide	Inhalation LC_{50} (rat): 220 mg/L	No data	No data	TWA: 10 ppm
Sulfur	Oral LD_{50} (rats): >5.74 mg/L	No data	LC_{50}: 180 ppb	No data

1 The active ingredients for Vorlex® are 1,3-Dichloropropene and methyl isothiocyanate; for Telone C-17® are 1,3-Dichloropropene and chloropicrin; and for Enzone® are carbon disulfide, ammonia, and sulfur.

2 8-hr Time Weighted Average Threshold Limit Value.

References: ACGIH 1992; AQUIRE 1993; EEOL 1993; EFOL 1989; Farm Chemicals Handbook 1993; HSDB 1993; MSU 1993; OPPT/EEB 1993; Tox-One-Liner 1993.

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