2010 Report of the Methyl Bromide Technical Options Committee (MBTOC)

2010 Assessment

MONTREAL PROTOCOL ON SUBSTANCES THAT DEPLETE THE OZONE LAYER

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2010 Assessment

United Nations Environment Program

Montreal Protocol on Substances that Deplete the Ozone Layer

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Glossary of Acronyms

1,3-D	1,3-Dichloropropene
A5	Article 5 Party
CUE	Critical Use Exemption
CUN	Critical Use Nomination
CUN	Critical Use Nomination
DOI	Disclosure of Interest
EU	European Union
EPA	Environmental Protection Agency
EPPO	European Plant Protection Organisation
IM	Iodomethane
IPM	Integrated Pest Management
IPPC	International Plant Protection Convention
ISPM	International Standard Phytosanitary Measure
LPBF	Low Permeability Barrier Film (including VIF films)
MB	Methyl bromide
MBTOC QPS	Methyl Bromide Technical Options Committee, Quarantine and Preshipment Subcommittee
MBTOC S	Methyl Bromide Technical Options Soils Subcommittee
MBTOC SC	Methyl Bromide Technical Options Committee, Structures and Commodities Subcommittee
MBTOC	Methyl Bromide Technical Options Committee
MI	Methyl iodide
MITC	Methyl isothiocyanate
MOP	Meeting of the Parties
MS	Metham sodium
Non-A5	Non Article 5
NPPO	National Plant Protection Organisation
OEWG	Open Ended Working Group
Pic	Chloropicrin
QPS	Quarantine and Pre-shipment
SF	Sulfuryl fluoride
TEAP	Technology and Economics Assessment Panel
TIF	Totally Impermeable Film
USA	United States of America
VIF	Virtually Impermeable Film
VOC	Volatile Organic Compound

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1. Executive Summary

1.1. Mandate and report structure

Under Decision XIX/20(2) taken at the Nineteenth Meeting of the Parties to the Protocol in 2007, the Parties requested the Assessment Panels to update their 2006 reports in 2010 and submit them to the Secretariat by 31 December 2010 for consideration by the Open-ended Working Group and by the Twenty Third Meeting of the Parties to the Montreal Protocol, in 2011.

As required under Decision XIX/20(2), the MBTOC 2010 Assessment reports on advances since 2006 to replace Methyl Bromide (methyl bromide) used under Critical Use by non-Article 5 Parties and continued reduction in methyl bromide use in Article 5 countries to meet the required phase out schedule in 2015. It also reports on the situation of use for QPS presently exempt from controls under the Montreal protocol. It also shows trends in methyl bromide production and consumption in both Article 5 and non-Article 5 Parties, estimated levels of emissions of methyl bromide to the atmosphere, and strategies to reduce those emissions.

1.2. The Methyl Bromide Technical Options Committee (MBTOC)

As of December 2010, MBTOC had 39 members: 13 (33%) from Article 5 parties and 26 (67%) from non-Article 5 parties. Members come from 11 developing and 14 industrialised countries. In order to respond to the large number of tasks, TEAP subdivided MBTOC into three subcommittees in 2010: Soils (MBTOC-S), Structures and Commodities (MBTOC-SC) and Quarantine and Pre-Shipment (QPS).

1.3. Methyl bromide control measures

Methyl bromide was listed under the Montreal Protocol as a controlled ozone depleting substance in 1992. Control schedules leading to phase-out were agreed in 1995 and 1997. There are a number of concerns apart from ozone depletion that have also led countries to impose severe restrictions on methyl bromide use. These concerns include, toxicity to humans and associated operator safety and public health, and detrimental effects on soil biodiversity. In some countries, pollution of surface and ground water by methyl bromide and its derived bromide ion are also concerns.

The control measures, agreed by the Parties at their ninth Meeting in Montreal in September 1997, were for phase out by 1 January 2005 in non-Article 5 countries and for Parties operating under Article 5 of the Protocol (developing countries) a 20% cut in production and consumption, based on the average in 1995-98, from 1 January 2005 and phase out by 1 January 2015. Since 2003, nine non-Article 5 Parties have applied for 'critical uses' after 2005 for non-QPS purposes under Article 2H of the Montreal Protocol. Of the initial 106 applications for 18,700 tonnes, the number has declined to 36 applications for 1,453 tonnes in 2012. Use of methyl bromide under the 'Critical Use' provisions is available to 'Article 5 countries after 2015.

Article 2H also provides exemptions for the amounts of methyl bromide used for QPS purposes.

1.4. Production and consumption trends

At the time of writing this report, all Parties had submitted data to the Ozone Secretariat for controlled uses in 2009. Some countries have revised or corrected their historical consumption data at certain times, and in consequence official figures and baselines have changed. In the few cases where data gaps exist, data from the previous year were assumed to apply to methyl bromide production or consumption. All tonnages are given in metric tonnes in this report.

In 2009, global production for the methyl bromide uses controlled under the Protocol was 8,928 tonnes, which represented 13% of the 1991 reported production data (66,430 tonnes). Less than 5% of production occurred in Article 5 countries. Methyl bromide production in Article 5 countries for controlled uses peaked in the year 2000 at 2,397 tonnes, falling to 29% of the baseline, 403 tonnes, in 2009 (aggregate baseline for all Article 5 regions is 1,375 tonnes, i.e. average of 1995-98 production).

Global consumption of methyl bromide for controlled uses was reported to be 64,420 tonnes in 1991 and remained above 60,000 tonnes until 1998. Global consumption was estimated at 20,752 tonnes in 2005 falling to about 8,148 tonnes in 2009. Historically, in non-Article 5 regions, about 91% of methyl bromide was used for pre-plant and about 9% for stored products and structures. The official aggregate baseline for non-Article 5 countries was about 56,083 tonnes in 1991. In 2005 (the first year of critical use provisions), this consumption had been reduced to 11,470 tonnes, representing 21% of the baseline. Since soil uses of methyl bromide have predominated historically, the reduction in consumption of methyl bromide for soil fumigation has been the major contributor to the overall reduction in global consumption of methyl bromide. Consumption of methyl bromide for structural and commodity purposes has also declined significantly.

Many non-Article 5 countries have achieved complete phase out (Switzerland, New Zealand, countries of European Community). Israel and Japan have notified intention to phase out post 2011 and 2012 respectively (for preplant soil uses). For the remaining uses phase-out or substantial reductions have occurred in most sectors. Several Article 5 Parties previously included among the largest users now report complete phase-out (i.e. Brazil, Turkey, Lebanon). Other Article 5 Parties have made very significant reductions in their consumption since 2005 and aggregate consumption is now at 28% of the baseline (72% has been replaced).

In 2010, the Meetings of the Parties approved CUEs of 2,565 tonnes for use in 2011 and 1,534 tonnes for 2012 or about 3% of the non- Article 5 baseline.

1.4.1. Consumption trends at national level

In 1991 the USA, European Community, Israel and Japan used nearly 95% of the methyl bromide consumed in non-Article 5 countries. In 2007 the approved or licensed consumption for CUEs was reduced to 17%, 3% and 12% and 10% of the respective baselines. In 2009 permitted levels of consumption (for CUEs) in these four Parties was 11%, 0% and 8% and 4% of their respective baselines.

The Article 5 consumption aggregate baseline is 15,870 tonnes (average of 1995-98), with peak consumption of more than 18,100 tonnes in 1998. Many Article 5 countries increased their methyl bromide use during the 1995 – 1998 time period. Total Article 5 consumption has been reduced to 4,405 tonnes which is 28% of the baseline in 2009. A MBTOC survey of ozone offices, regional networks and national experts in 2010 provided information on the breakdown of methyl bromide uses in major methyl bromide-consuming countries. In 2009, an estimated 90% was used for soil and 10% for commodities/structures, not including QPS, in Article 5 regions.

The vast majority of Article 5 parties achieved the national freeze level in 2002. In 2005, 94% of Article 5 parties (136 out of 144) either reported zero consumption or achieved the 20% reduction step by the required date; and in many cases they achieved this several years earlier than required by the Protocol. Presently, all Article 5 Parties are in compliance with this reduction step. Further, in 2009, 90% of the Article 5 Parties (133 of 147 Parties) reported national consumption of less than 50% of the national baseline. A large proportion (78%) of Article 5 Parties (115 Parties) reported zero methyl bromide consumption in 2009.

1.5. Alternatives to methyl bromide

MBTOC assumes that an alternative (Refer Decision IX/6 1(a)(ii)) demonstrated in one region of the world would be technically applicable in another unless there were obvious constraints to the contrary e.g., a very different climate or pest complex. Additionally, it is recognised that regulatory requirements, or other specific constraints may make an alternative available in one country but unavailable in another specific country or region. When evaluating CUNs, MBTOC accounts for the specific circumstances of each Party.

MBTOC was able to identify alternatives for over 95% of controlled uses in 2009. Situations where no alternatives have been identified amount to less than 1,000 tonnes of methyl bromide. However these figures may be influenced by local regulatory restrictions on the alternatives for the remaining uses. Technically effective alternatives have not yet been identified by MBTOC for the following controlled uses of methyl bromide:

- For pre-plant uses: Certain nursery plants
- For post-harvest: stabilization of high-moisture fresh dates, cheese and cured pork products infested in storage in the USA, immovable museum artefacts (especially when attacked by fungi in some circumstances).

At this time, technically feasible alternatives have also been identified for many QPS applications, but there are QPS uses or particular instances where such alternatives are not presently feasible.

Further research or development, including refinement and extension of existing techniques is needed to address these areas. Additionally, the resolution of regulatory issues would also strongly contribute to the use of alternatives.

1.5.1. Impact of registration on availability of alternatives

MBTOC considers that technical alternatives exist for almost all remaining controlled uses of methyl bromide. However regulatory or economic barriers exist that limit the implementation of some key alternatives and this can affect the ability to completely phaseout methyl bromide in several non-Article 5 countries.

It should be noted that chemical alternatives in general, including methyl bromide, have issues related to their long-term suitability for use. In the EU, methyl bromide use was completely stopped (for all uses including QPS) in 2010, mainly due to health issues; in the USA and several other countries, methyl bromide and most other fumigants are involved in a rigorous review that could affect future regulations over their use.

In January 2011, the US Environmental Protection Agency (USEPA) proposed to eventually eliminate the previous approvals for the use of sulfuryl fluoride (SF) for foods and in food processing structures if there would be food contact. EPA's sulfuryl fluoride human health risk assessment shows that, in some US locations, aggregate exposure from drinking water containing fluoride from natural background sources is already too high for certain identifiable subpopulations, in particular children under the age of 7. Although sulfuryl fluoride residues in food contribute only a very small portion of total exposure to fluoride, when combined with other fluoride exposure pathways, including drinking water and toothpaste, EPA has concluded that the tolerance (legal residue limits on food) no longer meets the safety standard under the Federal Food, Drug, and Cosmetic Act (FFDCA) and the tolerances for sulfuryl fluoride should be withdrawn. The position of Australia is different: Australia reported that total Australian exposures to fluoride – including those from commodities treated with sulfuryl fluoride – do not exceed human health safety standards. Therefore approvals of sulfuryl fluoride in Australia will not change.

Thus, consideration of the long-term sustainability of treatments adopted as alternatives to methyl bromide is still vitally important; both chemical and non-chemical alternatives should be considered for adoption for the short, medium term and longer term.

1.5.2. Alternatives for soil treatments

The reduction in consumption of methyl bromide for soil fumigation has been the major contributor to the overall reduction in global consumption of methyl bromide with amounts used falling 85% from about 57,400 tonnes in 1992 to approximately less than 6,500 tonnes in 2009, in non-Article 5 Parties and about 3,960 tonnes in Article 5 Parties.

The main crops for which methyl bromide is still being used in non-Article 5 countries are strawberry fruit, nurseries for the production of propagation material for forests, and strawberries and ornamentals (cut flowers and bulbs) and to a lesser extent in vegetable crops such as cucurbits (melons and cucumbers), peppers, eggplants and tomatoes, in perennial fruit and vine crops (particularly replant). Some uses previously considered under the CUN process have been partially reclassified as QPS (e.g. forest nurseries). Crops still using methyl bromide in Article 5 Parties are similar (cucurbits, strawberry fruit, tomatoes and other vegetables), but use in nurseries is much smaller.

Since the 2006 MBTOC Report, adoption of chemical and non chemical alternatives to replace methyl bromide as a pre-plant soil fumigant has shown significant progress, particularly due to improved performance of new formulations of existing chemical fumigants (1,3 D/Pic, Pic alone, metham sodium) and new fumigants (methyl iodide, dimethyl disulfide), but also due to increased uptake of non chemical alternatives i.e. grafted plants on resistant rootstocks.

Since 2008, iodomethane (methyl iodide) has been registered in several countries (USA, New Zealand) and dimethyl disulfide (DMDS) in USA and others. On the other hand, some initially promising chemicals included in the 2006 assessment report have seen little further development, e.g. propargyl bromide, sodium azide, propylene oxide and are no longer regarded as potential alternatives to methyl bromide. Also, the world has seen an increase in regulations on alternatives, with tighter regulations on all fumigants in the US and a banning of many fumigants (Chloropicrin, Pic EC, 1,3-D/Pic) in the EU.

1.5.2.1. Chemical alternatives

The following fumigants are currently available in many regions and due to relative similar efficacy to methyl bromide are being adopted as alternatives.

- Iodomethane or methyl iodide (MI), a liquid fumigant which has been recently tested on a wide range of crops by drip and shank-injection and found to be highly effective at controlling a wide range of soilborne pathogenic fungi, nematodes, and weeds.
- Chloropicrin (trichloronitromethane) (Pic), which is effective for the control of soilborne fungi and some insects and has limited activity against weeds. Combination with virtually or totally impermeable films (VIF, TIF) is an effective strategy to reduce application rates keeping satisfactory efficacy. However, the increase in use of Pic in strawberry production in the USA and Israel and the move to in bed strip treatment of many fumigants following the phaseout of methyl bromide has resulted in increase in infestation with *Macrophomina phaseolina*. It is anticipated that other soil borne pathogens may emerge as well.
- 1,3-Dichloropropene (1,3-D), which is used as a nematicide and also provides effective control of insects and suppresses some weeds and pathogenic fungi. 1,3- D as a single application has no effect in controlling fungi or bacteria. As with chloropicrin, 1,3-D can be combined with virtually or totally impermeable films (VIF, TIF) with satisfactory efficacy.
- Fumigants which are based on the generation of methyl isothiocyanate (MITC), e.g. dazomet, metham sodium and metham potassium, are highly effective at controlling a wide range of arthropods, soilborne fungi, nematodes and weeds, but are less effective against bacteria and root-knot nematodes. For this reason their use is often found in combination with other chemical treatments or IPM controls. The efficacy of MITC against fungal pathogens is variable, particularly against vascular wilts.
- Dimethyl disulfide (DMDS), which has been registered recently, appears to be highly efficient against various nematodes, including *Meloidogyne* spp, but is less effective on fungal pathogens. Again, DMDS is more effective when combined with VIF or TIF films.

- Furfural, which has also been registered recently, appears to be highly efficient against nematode and fungi, particularly in golf courses.

The future of soil disinfestation lies in combining available fumigants with other methods, or other fumigants and non fumigants chemical to obtain acceptable performance.

1.5.2.2. Non chemical alternatives

- Solarisation, alone or combined with biofumigation or low doses of fumigants, has continued to gain wider adoption as a methyl bromide alternative in areas with sunny climates and where it suits the cropping season and the pest and disease complex (e.g. Morocco, Israel, Jordan, Brazil).
- Steaming has been adopted for high value crops grown in protected agriculture e.g. greenhouses, as more cost-efficient systems are developed.
- Biodisinfestation has been very effective on a limited scales where growers use high amounts of organic material and are committed to the techniques' success (e.g. southern Spain).
- Soilless culture is a rapidly expanding cropping practice worldwide, primarily for protected agriculture, which has offset the need for methyl bromide, especially in some flower crops, vegetables and for seedling production including forest seedlings. In particular, flotation systems, based on soilless substrates and hydroponics, have replaced the majority of the methyl bromide for tobacco seedling production worldwide. The adoption of this technique is currently expanding into vegetable production and some ornamentals.
- Soil reduction (redox) potential, where wheat or rice bran are mixed in the soil, which is then flooded with the water and covered to maintain high temperatures and anaerobic conditions is widely used in Japan to control nematodes and fungi attacking tomatoes and strawberries. The process encourages generation of organic compounds such as acetic acid. When combined with solarisation it is efficient even in cooler regions such as the northern part of Japan.
- Grafting, resistant rootstocks and resistant varieties are now commonly used to control soilborne diseases in vegetables, particularly tomatoes, cucurbits, peppers and eggplants in many countries. They are generally adopted as part of an integrated pest control system, or combined with an alternative fumigant or pesticide, and have led to the reduction or complete replacement of methyl bromide use in several sectors in different countries.

1.5.2.3. Combination of chemical and non chemical alternatives

The combination of chemical with a range of non-chemical alternatives continues to expand as effective strategies to overcome problems due to the narrow spectrum of activity of some single control methods. Soil solarisation and grafting vegetable crops onto resistant rootstocks for instance has proven to be a valuable non-chemical alternative. Similarly the efficacy of grafted plants can be greatly enhanced by combining it with biofumigation, green manures, and chemicals such as MITC generators, 1,3-D and non- fumigant nematicides. Combinations of fumigant alternatives (MI, 1,3-D/Pic, MNa/Pic) with LPBF or relevant herbicides have been shown to be effective for nutsedge (*Cyperus spp.*), which is the key target pest for several CUNs. Finding alternatives for nursery industries is proving difficult as growers are uncertain of the risk of spread of diseases provided by the alternative products. Also, regulators often lack the data to determine if alternatives meet the quality standards (e.g. certification requirements),

Crop specific strategies implemented both in non-Article 5 and Article 5 regions are discussed in detail in the 2010 Assessment Report. These include alternatives used for the major crops (strawberries, tomato, cucurbits, peppers, eggplants, forest, fruit and strawberries nurseries and ginger) using methyl bromide in specific climates, soil types and locations, as well as combinations of alternatives, application methods and others.

1.5.3. Alternatives for treatment of post-harvest uses: food processing structures and durable commodities (non-QPS)

Food processing structures that currently use methyl bromide include flour mills, bakeries and other food production and storage facilities. These structures are fumigated to control stored product (food) pests.

Durable commodities are primarily foods (and sometimes non-food products) with low moisture content that, in the absence of pest attack, can be safely stored for long periods. The remaining durable commodities fumigated with methyl bromide in some non-QPS applications include milled rice, various dried fruits and nuts, rice, fresh market chestnuts, dry cure ham and cheese in storage houses.

The main alternatives to the disinfestation of flour mills and food processing premises are sulfuryl fluoride (including combinations of SF and heat) and heat (as full site or spot heat treatments). Some pest control operators report that full control of structural pests in some food processing situations can be obtained without full site fumigation through a more vigorous application of IPM approaches. Other pest control operators report success using a combination of heat, phosphine and carbon dioxide.

Phosphine fumigation has emerged as the leading treatment of infested commodities. Treatment of commodities with sulfuryl fluoride has also expanded to significant levels.

1.5.3.1. Regulatory considerations

Many commercial companies have undertaken significant efforts and Parties to conduct research, apply for registration, and register alternatives to optimize their legal use. The cost of registration for a small market may be prohibitive. This can result in one Party having access to a technically effective alternative that is not available to other Parties.

In the European Community and the United States, methyl bromide and most other fumigants are involved in a rigorous (re-) review that could affect future regulations over their use. As examples of this, several contact insecticides previously used to control stored food pests have been deregistered in the European Union.

Additional registration issues arise where treatments will be used on food commodities or where treatments used in food processing buildings might transfer residues to food because the maximum residue limits (MRLs) for the residual chemicals must also be registered in importing countries. In recent years, some large methyl bromide-volume consuming countries have both published and revoked maximum residue levels for the residues of some methyl bromide alternatives in food commodities.

As an example, in France, approval of the use of SF on fresh chestnuts has been withdrawn. The SF treatment resulted in a fluoride residue in chestnuts which exceeded the European Union 25 ppm MRL.

Additionally, the US Environmental Protection Agency has recently proposed to phase in the deregistration of food uses for sulfuryl fluoride (SF) in the US. Adoption of SF has played a leading role in reductions in use of methyl bromide for stored product protection in the US.

This situation does not only affect the use of SF on food commodities. Lack of maximum residue limits (MRLs) for fluorine residues resulting from the use of SF has been cited as a reason for the continuing need for methyl bromide in several critical use nominations.

MBTOC also advises the Parties that environmental concerns about using sulfuryl fluoride amongst milling and food processing companies should not be underestimated as an obstacle to adoption of this methyl bromide alternative.

1.5.3.2. Defining IPM and its elements

IPM is a sustainable pest risk management approach combining biological, cultural, physical and chemical tools in a way that minimizes economic, health, and environmental risks. Although a reduction in use of pest control chemicals in food processing, and using less toxic chemicals is a goal of most IPM practitioners, MBTOC notes that onward from this point there is a divergence in the definition on IPM.

IPM is sometimes defined as not including full site chemical treatments, and also only including the very minimal or complete non-use of other pest control chemicals.
On the other hand, some people define IPM as a means of minimizing chemical use, but also incorporate full-site or curative treatments as part of an IPM programs. These may involve fumigation or other processes. In the context of phasing out methyl bromide, IPM should be considered a required pre-requisite to the use of full site chemical treatments by methyl bromide and other fumigants.

Given this divergence of definition, and to avoid confusion, MBTOC has placed information about full site treatments by fumigation or heat in the section on pest control in flour milling and food processing, whereas non-chemical IPM approaches and techniques are discussed in the extensive IPM section.

1.5.3.3. Pest control alternatives in flour mills and food processing facilities

Alternatives most often used in the milling and food processing sectors are, heat treatment (full site or as spot heat (combined with the use of a further pest barrier method) and sulfuryl fluoride (SF), either alone or with the addition of supplemental heat in a combination treatment.

Although concerns were reported with the use of each alternative, there were no reports indicating that any particular mill structure, type or conformation completely lacked a technically effective alternative treatment (while mindful that evidence from trials still does not indicate ideal efficacy of SF treatments in killing pest eggs).

1.5.3.4. Pest control alternatives for commodities

The most commonly used alternatives for control of pests in stored commodities are phosphine and sulfuryl fluoride.

Since the last Assessment Report in 2006, adoption of controlled atmosphere (CA) techniques has significantly increased and so this subject is covered in more detail, with its own section. The infested products are exposed to CA in airtight climate rooms equipped to handle variable sorts and quantities of products. The temperature, oxygen and humidity are controlled in each room within a specified range of parameters known to be lethal to the pest(s). The treatment normally requires 1 to 6 days, depending on the type infestation and product temperature.

Since pest control of dates is a problem of several countries, and since there have been separate decisions of the Montreal Protocol concerning pest problems of high moisture dates. MBTOC has prepared a separate section on this issue in Chapter 5 of the Assessment Report. Parties, particularly Algeria and Tunisia, have discussed with deep concern the problem of controlling pests in high-moisture dates. Currently methyl bromide is used by several Parties to disinfest dates and prevent fermentation. In the United States, dates are included in a commodity CUN.

Additionally, MBTOC has prepared two cautionary notes about the emergence of psocids in stored products and efforts needed to avoid and control pest resistance.

1.5.4. Rate of adoption of alternatives

Generally, time is required to allow the relevant industry to transition to available effective alternatives once these are identified. Since the critical use process commenced in 2005, most industries show a reduction in nominated quantity requested from that of the preceding year, reflecting progressive adoption of alternatives; while others have the same or similar quantities of methyl bromide nominated. Some CUNs show comparatively slow rates of adoption. Reviews show that in most instances the adoption rates varied between 10 and 25% per year. This includes Article 5 countries that have adopted alternatives through investment projects, where the rate of adoption is on average between 20 and 25% per year.

Analysis of the data indicates that by the end of 2009, 95% reduction of methyl bromide use or complete phase out of methyl bromide has occurred for tomato crops in Australia, Japan, New Zealand, Portugal, Spain, Greece, Belgium, and the UK; in strawberry fruit in Australia, Belgium, Greece, Japan, Portugal and Spain; and in peppers or eggplants in Australia, Greece, Israel, Malta, New Zealand, Spain and the UK. Reductions in the range of 40 - 80% have been made in the US and Israeli strawberry fruit industries and 70% in the US tomato industry since 2005. Israel has found transition difficult mainly because some formulations of alternatives are not registered and restrictions on the use of a key alternative, chloropicrin exist; also because of the occurrence of specific pests (*Verticillium dahliae* race 2, *Orobanche* spp.). Israel, however, recently informed Parties that it will no longer seek CUE's post 2011. Regulatory restrictions in the US have also limited uptake of a leading alternative, 1,3-D in California but recent high adoption rates of methyl iodide and a 3 way treatment (chloropicrin, 1,3-D, metham sodium) have seen substantial reductions in methyl bromide use in the southeast of the USA. Japan will phase out all methyl bromide soil fumigation in 2013 with alternatives such as IPM and other chemicals.

Many examples of successful phase-out or significant use reduction are available from Article 5 countries including several previously included in the list of largest users (e.g. Turkey, Brazil, China, Zimbabwe, Kenya, Morocco and others).

1.6. Alternatives to methyl bromide for quarantine and pre-shipment applications (exempted uses)

Since the 2006 Assessment Report, significant work was conducted by a Quarantine and Pre-Shipment Task Force (QPSTF) appointed by TEAP in response to Decision XX/6 and by MBTOC in response to Decision XXI/10. For quarantine and pre-shipment purposes, methyl bromide fumigation is currently often a preferred treatment for certain types of perishable and durable commodities in trade worldwide, as it has a well-established, successful reputation amongst regulatory authorities. However, in 2008 IPPC published recommendations for replacement or reduction of the use of methyl bromide as a phytosanitary measure.

Although QPS uses are usually for commodities in trade, (soil uses for strawberry, deciduous and rose nurseries have been identified since the first CUE), some Parties have identified some methyl bromide soils uses as being quarantine uses. Alternatives to these uses are discussed in the chapter on soils.

Usually quarantine treatments are only approved on a pest and product specific basis, and following bilateral negotiations. This process helps ensure safety against the incursion of harmful pests, but also often requires years to complete. For this and other reasons, replacing methyl bromide quarantine treatments can be a complex issue. Many non-methyl bromide quarantine treatments are, however, published in quarantine regulations, but they are often not the treatment of choice. Nevertheless, implementation of alternatives to methyl bromide for QPS has occurred since the 2006 MBTOC Assessment Report, and in response to Decision XXI/10 MBTOC has made initial estimates of amounts of methyl bromide used for QPS purposes that could be replaced with alternatives, for the major use categories.

Article 2H exempts methyl bromide used for QPS treatments from phaseout. The European Community banned all uses of methyl bromide in its 27 member states including QPS, as of March 2010. Other countries show significant reductions in their methyl bromide consumption for QPS; Brazil has announced that it will stop QPS use of methyl bromide in 2015.

Global production of methyl bromide for QPS purposes in 2009 was 8,922 tonnes, increasing by 6.5% from the previous year. Although there are substantial variations in reported QPS production and consumption on a year-to-year basis, there is no obvious long term increase or decrease. Israel, USA and China together accounted for 94% of the global QPS production in 2009.

Global QPS consumption was 11,256 tonnes in 2009, which was 26% more than in 2008 but close to the average for the past 11 years (11,197 tonnes). QPS consumption was reported to be 39% higher than non-QPS consumption in 2009, due to continued reduction in non-QPS consumption and increased QPS consumption from 2008 to 2009. MBTOC reports, however, indicate that non-QPS uses are higher than reported, as data on consumption does not match quantities exempted for CUE uses, Parties also continue to use methyl bromide from pre 2005 stockpiles and leakage is occurring from QPS stocks to non-QPS uses. It should also be noted that consumption is different to actual use.

Total Article 5 QPS consumption was 5,433 tonnes in 2009. Consumption of methyl bromide for QPS uses in Article 5 Parties shows an increasing trend over the past 10 years, while in non-Article 5 Parties it has been decreasing. Among the Article 5 Parties, nine reported consumption of more than 100 tonnes, accounting for 89% of the Article 5 QPS consumption in 2009. Total Non-Article 5 QPS consumption was 5,823 tonnes in 2009, which was 87% more than reported in 2008, largely due to an increase in Israel's consumption. Five non-Article 5 Parties consumed more than 100 tonnes in 2009, accounting for 99% of the QPS consumption in non-Article 5 Parties.

One hundred and fifty eight Parties (82%) either consumed less than 10 tonnes of QPS, or they reported zero or provided no report in 2009, or they had never reported consumption prior to 2009. Thirty Parties (16%) reported consumption of more than 10 tonnes in 2009 and of these, six reported consumption of more than 500 tonnes.

A discrepancy of about 1,300 tonnes for non-Article 5 Parties over the period 2003-2007 has existed between total consumption as represented by methyl bromide actually used, estimated by 'bottom-up' analysis, and total consumption reported as per Article 7 data. This error has mainly been attributed to reported QPS methyl bromide consumption by the US under Article 7 and estimates of its annual actual use as a fumigant. At this time the fate of this surplus is unidentified, but could include accumulation of QPS-labeled stocks of methyl bromide.

While there remain some data gaps and uncertainties, information supplied by the Parties allowed MBTOC to estimate that four uses consumed more than 70% of the methyl bromide used for QPS in 2008: 1) Sawn timber and wood packaging material (ISPM-15); 2) Grains and similar foodstuffs; 3) Pre-plant soils use; and 4) Logs. On the basis of these estimates and currently available technologies to replace methyl bromide for QPS, MBTOC calculated that 31% to 47% of consumption in 2008 these categories (or about 31% of global consumption) was immediately replaceable with available alternatives. Detailed descriptions of alternatives and their technical and economic feasibility are provided in Chapter 6 of the Assessment Report.

MBTOC estimated that in Article 5 Parties that more than 60% of the methyl bromide used in sawn timber and wood packaging material could be replaced by heat or alternative fumigants; less than 10% of the methyl bromide used as a quarantine treatment in grains and similar foodstuffs could be replaced by alternative fumigants and controlled atmospheres, and 30-70% for pre-shipment treatments in grains and similar foodstuffs could be replaced by fumigants, protectants, controlled atmospheres and integrated systems; and 10-20% of the methyl bromide used in *logs* could be replaced by alternative fumigants, conversion to sawn timber (lumber), immersion, debarking and heat. There was no categorisation of methyl bromide as QPS used on soil in Article 5 Parties.

In non-Article 5 Parties MBTOC estimated that more than 60-80% of the methyl bromide used in sawn timber and wood packaging material could be replaced by heat or non-wooden pallets; less than 10% of the methyl bromide used as a quarantine treatment in grains and similar foodstuffs could be replaced by alternative fumigants and controlled atmospheres, and more than 80% for preshipment treatments in grains and similar foodstuffs could be replaced by fumigants, protectants, controlled atmospheres and integrated systems; about 50-95% of the methyl bromide used in soil could be replaced by alternative fumigants, provided the alternatives meet certification standards and a key alternative (methyl iodide/ Pic) was available; and 10-20% of the methyl bromide used in logs could be replaced by alternative fumigants, conversion to sawn timber (lumber), immersion, debarking and heat.

For perishables, there are various approved treatments, depending on product and situation, including heat (as dry heat, steam, vapour heat or hot dipping), cold (sometimes combined with modified atmosphere), modified and controlled atmospheres, alternative fumigants, physical removal, chemical dips and irradiation.

The technical and economic feasibility of alternatives to methyl bromide used for QPS in all countries mainly depend on the efficacy against quarantine pests of concern, the infrastructural capacity of the country, end-use customer requirements, phytosanitary agreements where relevant, and logistical requirements and regulatory approval for the use of the alternative.

1.7. Progress in phasing-out methyl bromide in Article 5 parties

An analysis of progress in phasing-out methyl bromide in Article 5 Parties, remaining challenges and constraint to adoption of alternatives becomes more important as the 2015 deadline for complete phase out of methyl bromide in Article 5 Parties approaches. Phase out has been achieved mainly through MLF investment (or phase-out) projects and alternatives chosen generally follow those identified as successful through demonstration projects or research carried out in the same country or in regions with similar circumstances, including non-Article 5 countries. Costs, logistics and in some cases different resource availability may lead to preference for different alternatives in Article 5 compared to non-Article 5 countries.

The projects showed that for all locations and all crops or situations tested, one or more of the alternatives proved comparable to methyl bromide in their effectiveness in the control of pests and diseases targeted in the projects in these Article 5 countries. A demonstration and technical assistance project to identify alternatives for high moisture dates – which has been particularly difficult – is now underway, with phosphine and modified atmospheres (CO_2) giving encouraging results.

By December 2010 the Multilateral Fund (MLF) had approved a total of 373 methyl bromide projects in nearly 80 countries. This included 44 demonstration projects for evaluating and customising alternatives (now for the largest part finished); 126 initiatives for the preparation of new projects, awareness raising, data collection, policy development and others; and 113 investment projects for phasing-out methyl bromide (of which 41 are presently on-going). Additional methyl bromide phaseout activities have been funded directly by Article 5 countries and/or agricultural producers, bilateral assistance from some countries and the Global Environment Facility.

MLF projects approved by December 2010 are scheduled to eliminate a total of 12,794 metric tonnes of methyl bromide in Article 5 countries, generally ahead of the 2015 deadline. Of these, 10,320 tonnes had been replaced by December 2010. Phase out schedules agreed under the projects aim to replace methyl bromide at an average annual rate of about 22.5% per year, in a total of 4.4 years on average (range 3-6 years). This includes countries that are small, medium and large methyl bromide consumers.

Projects have encouraged the combination of alternatives (chemical and non-chemical) as a sustainable, long term approach to replacing methyl bromide. This has often implied that growers and other users change their approach to crop production or pest control and may even have to make important changes in process management. Adapting the alternatives to the specific cropping environment and local conditions (including economic, social and cultural conditions) is essential to success.

Early phaseout has brought by additional benefits to Article 5 Parties for example by improving production practices, making productive sectors more competitive in international markets and training large numbers of growers, technical staff and other key stakeholders.

In December of 2010, all Article 5 Parties had reported consumption of methyl bromide for controlled uses to the Ozone Secretariat and all Parties were in full compliance with Montreal Protocol commitments.

1.8. Economic criteria

The purpose of the economics chapter is to provide the framework within which decisions on the economic feasibility of Critical Use Nominations (CUNs) are made, and to survey the existing literature to provide an overview of economic information relating to alternatives as a guide to what is known about the economic impact of the methyl bromide phase-out. A review of the existing literature shows that there are three main methodological approaches that have been used to determine economic outcomes from adoption of alternatives to methyl bromide. These include:

- Articles that report only the changed (increased) costs of using methyl bromide alternatives;
- Articles that use some form of partial budgeting technique
- Articles that report the sector-wide or even economy-wide impact of the use of methyl bromide alternatives

The variation in the means of assessing economics highlights the fact that little research has been done to increase understanding of the actual impacts of the methyl bromide phase-out. The existing literature is narrow in the sense that it relates primarily to the USA and a narrow range of methyl bromide uses. Economic data is available in some Article 5 countries that are implementing MLF projects but the MBTOC economic group did not assess these data.

TEAP/MBTOC have been asked to assess the economic feasibility of Critical Use Nominations. However, although Decision Ex. I/4 lays out the general scope of work for Parties and TEAP, guidance concerning economic feasibility benchmarks is lacking.

The review in this Assessment Report has shown that much work is still needed to gain a better understanding of the true impacts of the methyl bromide phase-out. While the literature that has been reviewed here provides a useful starting point to the types of analysis that is required, it needs to be extended to countries outside of the USA (especially in Article 5(1) countries) and to a wider range of methyl bromide uses.

1.9. Emissions from methyl bromide use and their reduction

Estimates of the proportion of methyl bromide used that is released into the atmosphere vary widely due to differences in usage pattern; the condition and nature of the fumigated materials; the degree of gas tightness; and local environmental conditions Under current usage patterns, the proportions of applied methyl bromide eventually emitted to the atmosphere are estimated by MBTOC to be 46 – 91%, 85 - 98%, 76 – 88% and 90 - 98% of applied dosage for soil, perishable commodities, durable commodities and structural treatments respectively. These figures, weighted for proportion of use and particular treatments, correspond to a range of 59 - 91% overall emission from agricultural and related uses, with a mean estimate of overall emissions of 75%, 17,041 tonnes based on estimated use of 22,860 tonnes in 2009.

Emission volume release and release rate to the atmosphere during soil fumigation depend on a large number of key factors. Of these, the type of surface covering and condition; period of time that a surface covering is present; soil conditions during fumigation; methyl bromide injection depth and rate; and whether the soil is strip or broadacre fumigated are considered to have the greatest effect on emissions.

Studies under field conditions in diverse regions, together with the large scale adoption of Low Permeability Barrier Films (LPBF), have confirmed that such films allow for conventional methyl bromide dosage rates to be reduced. Typically equivalent effectiveness is achieved with 25 –50% less methyl bromide dosage applied under LPBF compared with normal polyethylene containment films.

The use of low permeability barrier films (VIF or equivalent) is compulsory in the European Union (EC Regulation 2037/2000). In other regions LPBF films are considered technically feasible for bed fumigation. However, in the State of California in the US a regulation currently prevents implementation of VIF with methyl bromide (California Code of Regulations Title 3 Section 6450(e). This regulation resulted from concerns of possible worker exposure to methyl bromide when the film is removed or when seedlings are planted due to altered flux rates of methyl bromide.

For QPS treatments, Decisions VII/5(c) and XI/13(7) urge Parties to minimize use and emissions of methyl bromide through containment and recovery and recycling methodologies to the extent possible. There has been limited research into the development of recovery and recycling systems for methyl bromide. There are now several examples of recovery equipment in current commercial use. All these units use are based on absorption of used methyl bromide on activated carbon. Some are designed for recycling of the recaptured methyl bromide while others include a destruction step to eliminate the sorbed methyl bromide, thus minimising emissions. There is increasing adoption of these systems, though this has been driven by considerations other than ozone layer protection, e.g. occupational safety issues or local air quality. In the absence of regulations, companies reported they would not invest in the systems, because their competitors (who had not made the investment) would then have a cost advantage.

2

2. Introduction to the Assessment

2.1. Methyl Bromide

Methyl bromide (MB) is a fumigant that has been used commercially since the 1930's (Anon, 1994). It has been used to control a wide spectrum of pests including fungi, bacteria, soil-borne viruses, insects, mites, nematodes and rodents and weeds or weed seeds. MB has features that make it a versatile material with a wide range of potential applications. In particular, it is a gas that is quite penetrative and usually effective over a broad range of temperatures. Its action is usually sufficiently fast and it airs rapidly enough from treated systems to cause relatively little disruption to commerce or crop production.

Methyl bromide was listed under the Montreal Protocol as a controlled ozone depleting substance in 1992. Additional control schedules leading to phase-out (with specific exceptions) were agreed in 1995 and 1997.

MB is also used for quarantine and preshipment (QPS) treatments, where it performs a dual role of facilitating trade as well as preventing the accidental import of exotic pests that can incur substantial costs for control and if possible eradication. The Protocol specifically excluded QPS from control measures in 1992 because at that time the Parties estimated that there were no alternatives to MB that gave the same level of protection for a diverse range of treatments carried out with this fumigant..

A number of concerns over methyl bromide apart from ozone depletion have also led countries to impose severe restrictions on its use. These concerns include residues in food, toxicity to humans and associated operator safety and public health, and detrimental effects on soil biodiversity. In some countries, pollution of surface and ground water by MB and its derived bromide ion are also concerns.

2.1.1. MB uses identified in Articles of the Protocol

MB is classified as a "controlled substance" under the Montreal Protocol (Article 1 and Annex E). The Articles of the Protocol refer to about four main categories of MB uses, and each is subject to different legal requirements. Table 1 lists the four categories, and indicates those for which information is provided in this MBTOC report.

Two of the categories - the non-QPS fumigant uses and laboratory and analytical (L&A) uses - are subject to the phase-out schedules under Articles 2 and 5, with authorised Critical

Use Exemptions. The phase-out schedules are summarized in Table 2 below. The other two categories of MB uses – QPS and feedstock used in industrial processes – are not subject to phase-out schedules but are subject to reporting requirements under the Protocol.

This report focuses primarily on the non-QPS and QPS fumigant uses. Feedstock is mentioned in this report only when discussing statistics on global MB production for all uses in Chapter 3. Laboratory and Analytical (L&A) uses are also included in general statistics on MB production in Chapter 3 but no breakdown is available. L&A uses are not discussed in MBTOC reports because they are assessed in the reports of the Chemical Technical Options Committee (CTOC).

TABLE 1 CLASSIFICATION OF MB USES UNDER THE MONTREAL PROTOCOL, INDICATING RELEVANT SECTIONS IN THIS ASSESSMENT REPORT

MB uses	Status under the Montreal Protocol	Information in MBTOC Assessment
Non-QPS fumigant uses	Subject to production and consumption phase-out schedules of Articles 2 and 5, trade and licensing controls of Article 4, and data reporting requirements of Article 7. Critical Use Exemptions can be authorised by the MOP for specific uses that meet the criteria in Decision IX/6 and other relevant decisions	Chapters 1-8 and 10
QPS fumigant uses	Exempted from reduction and phase-out schedules. Subject to Article 7 data reporting requirements	Chapter 9 and several sections in chapter 3
Laboratory and analytical uses	Subject to production and consumption phase-out schedules of Articles 2 and 5 except for the specific Critical Use Exemptions under Decision XVIII/15. Subject to data reporting under Annex II of the Sixth Meeting of the Parties	L&A uses are covered in CTOC reports. Chapter 3 statistics on MB production include L&A, but no breakdown is available
Feedstock used in the manufacture of other chemicals	Exempted from phase-out schedule under Article 1. Subject to Article 7 data reporting requirements	Chapter 3 statistics on MB production

2.2. MBTOC mandate

The Methyl Bromide Technical Options Committee (MBTOC) was established in 1992 by the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer to identify existing and potential alternatives to MB. MBTOC, in particular, addresses the technical and economic feasibility of chemical and non-chemical alternatives for controlled uses of MB. Additionally, from 2003, MBTOC has had the task of evaluating Critical Use Nominations submitted by non- Article 5 Parties to the Montreal Protocol and providing recommendations, for consideration by the Technology and Economic Assessment Panel (TEAP) and the Parties. In 2010 the Parties assigned TEAP and MBTOC tasks related to QPS uses of MB and their alternatives, continuing work which in previous years had been mostly carried out through special Task Forces (TF). To facilitate work, TEAP subdivided MBTOC into three subcommittees: Soils (MBTOC-S), Structures and Commodities (MBTOC-SC) and Quarantine and Pre-Shipment (QPS).

MBTOC is a subsidiary body of TEAP, the Panel that advises the Parties on scientific, technical and economic matters related to ozone depleting substances and their alternatives. MBTOC members have expertise in the uses of MB and alternatives to MB.

Information contained in MBTOC's reports contributes to the Parties' deliberations on appropriate controls for MB and on Critical Use Exemptions. Parties review MBTOC and TEAP's recommendations and may accept, reject of modify these recommendations when taking decisions on CUE requests.

TABLE 2 PHASE-OUT SCHEDULES AGREED AT THE NINTH MEETING OF THE PARTIES IN 1997

Year	Non-Article 5 countries	Article 5 countries
1991	Consumption/ production baseline	
1995	Freeze	
1995-98 average		Consumption/ production baseline
1999	25% reduction	
2001	50% reduction	
2002		Freeze
2003	70% reduction	Review of reductions
2005	Phaseout with provision for CUEs	20% reduction
2015		Phaseout with provision for CUEs

Critical and emergency uses may be permitted after phaseout if they meet agreed criteria.
Quarantine and pre-shipment (QPS) uses and feedstock are exempt from reductions and phaseout.
Decisions encouraging advanced phaseout:

- Countries may take more stringent measures than those required by the schedules (Article 2 of the Montreal Protocol).
- In applying the QPS exemption, all countries are urged to refrain from use of MB and to use non-ozone-depleting techniques wherever possible (Decisions VII/5 and XI/13).
- A number of developing and industrialised countries signed Declarations in 1992, 1993, 1995, 1997, 2003 and 2004 stating their determination to phase out MB as soon as possible.

Source: UNEP, Ozone Secretariat

2.3. Committee process and composition

At December 2010 MBTOC had 39 members; 13 (33%) from Article 5 and 26 (67%) from non-Article 5 countries. These members come from 11 Article 5 and 14 non- Article 5 countries. Representation from diverse geographic regions of the world promotes balanced review and documentation of alternatives to MB, based on the wide-ranging expertise of Committee members. Most Article 5 MBTOC members and many non- Article 5 members were nominated by their governments.

In accordance with the terms of reference of TEAP and TOCs, MBTOC members participate in a personal capacity as experts and do not function as representatives of governments, industries, non-government organisations (NGOs) or others (Annex V of the report of the Eighth Meeting of the Parties). Members of MBTOC contribute substantial amounts of work in their own time. For construction of this Assessment Report, MBTOC met formally in San Lúcar de Barrameda, Spain (2010) and San Jose, California, USA (2010). To produce each chapter as efficiently as possible, MBTOC sub-committees worked primarily on chapters covering their specific topics and topics affecting all chapters were discussed and agreed by the entire committee. Assessment structure and contents were agreed during the formal meetings. The Assessment was finalised by email, to produce a consensus document of the Committee.

MBTOC members and sub-committee chairs for the working groups within the MBTOC 2010 Assessment Report are listed in Appendix 1. The subcommittee chairs acted as coordinators and lead authors for the main chapters of this Assessment.

2.4. UNEP Assessments

The first interim assessment on MB for the Protocol was completed in 1992. A full assessment of the alternatives to MB was completed in 1994 and reported to the Parties in 1995 (MBTOC, 1995) as a result of Decisions taken at the fourth Meeting of the Parties to the Montreal Protocol held in 1992. The second MBTOC Assessment was presented to Parties in 1998 (MBTOC, 1998) the third in 2002 (MBTOC, 2002) and the fourth in 2006 (MBTOC, 2007). MBTOC progress reports on advances in alternatives to methyl bromide and other issues related to methyl bromide were included in annual TEAP reports to the Parties (1999; 2000; 2001; 2002; 2003; 2004; 2005 ab; 2006 ab; 2007 ab; 2008 ab; 2009 ab; 2010 ab). Assessment Reports and TEAP Progress and CUN Reports can be found at http://ozone.unep.org/teap/Reports/MBTOC/index.asp .

Under Decision XIX/20 (2) taken at the Nineteenth Meeting of the Parties to the Protocol in 2007, the Parties requested the Assessment Panels to update their 2006 reports in 2010 and submit them to the Secretariat by 31 December 2010 for consideration by the Open-ended Working Group and by the Twenty-Third Meeting of the Parties to the Montreal Protocol, in 2011. This MBTOC 2010 Assessment reports provides an update on advances since 2006.

2.5. Definition of an alternative

In this report, following guidance given in Annex 1 of 16 MOP report, MBTOC defined ‘alternatives’ as:

> *' any practice or treatment that can be used in place of methyl bromide. 'Existing alternatives' are those alternatives in present or past use in some regions. 'Potential alternatives' are those in the process of investigation or development.*
> *MBTOC assumed that an alternative demonstrated in one region of the world would be technically applicable in another unless there were obvious constraints to the contrary e.g., a very different climate or pest complex.*

This definition of ‘alternatives’ is consistent with that used in previous Assessments.

MBTOC is not required in its terms of reference to conduct economic studies on MB and alternatives. Additionally, it was recognised that regulatory requirements, environmental issues and social constraints may make an alternative unavailable in a specific country or region. MBTOC did not omit alternatives from consideration on such grounds in this Assessment report, although MBTOC reports on CUNs do fully consider the availability or lack of availability in specific locations.

2.6. Report structure

Chapter 3: Methyl bromide production, consumption and progress in phase-out for controlled uses provides statistics on MB production, consumption and major uses from 1991 to the present day, focusing on controlled uses. The chapter has been written in five major parts. The first part provides a brief overview of the major trends, the second part discusses MB production and supply, the third describes consumption in non-Article 5 countries, the fourth describes consumption in Article 5 countries, and the final part describes the trends in MB fumigant uses by crop or sector.

Chapter 4: Alternatives to Methyl Bromide for Soil Treatment covers a range of alternatives for this currently major MB-use area. Discussion includes:

- Commercial alternatives available at a large scale:
- Chemical and non chemical alternatives
- Combined alternatives
- Emerging chemical technologies
- Effective technologies for small scale farms
- Crop specific strategies
- Adoption of alternatives in Article 5 and non-Article 5 regions

Chapter 5: Structures and Commodities: Methyl Bromide Uses and Alternatives for Pest Control includes discussion on: alternative fumigants such as phosphine and sulfuryl fluoride (including regulatory issues), non-chemical methods such as heat treatment and controlled atmosphere. An extensive section covers the IPM approach combining several different chemical and non-chemical measures. A section dealing with the particular problem of high moisture dates is also included.

Chapter 6: Quarantine and Pre-shipment covers MB and alternative treatments for Quarantine and Pre-shipment (QPS) of durable and perishable commodities, including discussion of:

- Production and consumption of MB for QPS purposes
- Technical and economic feasibility of alternatives to the main categories of use
- Approved and available alternative treatments.
- Constraints to adoption of alternatives
- International (IPPC) standards influencing MB use for quarantine

Chapter 7: *Factors that have assisted with MB phase-out* discusses Multilateral Fund (MLF) projects carried out by Article 5 countries. It identifies the main types and objectives of MLF projects, the major technologies being implemented and alternatives adopted on a commercial scale. It discusses lessons learned and barriers to the adoption of alternatives. The chapter outlines other factors that have contributed to MB phase-out, such as voluntary efforts of growers and others undertaken in both Article 5 regions. It further includes some case studies illustrating the process of phasing out MB and adopting alternatives at the commercial level in several countries and sectors.

Chapter 8: Economic Issues Relating to Methyl Bromide Phase-out updates discussion on economic issues influencing adoption of alternatives to MB, in response to Decision Ex.I/4. The chapter outlines the main Decisions of the Parties relating to assessments of the economic feasibility of alternatives in critical use nominations. It covers a good number of recently published peer- reviewed publications on this topic and identifies the main categories and economic approaches used by different authors to date. It shows that further investigation would be needed to provide a better understanding of the economic impacts of the methyl bromide phase-out, in particular in countries outside of the USA (especially in Article 5 countries) and for a wider range of methyl bromide uses.

Chapter 9: Reducing Methyl Bromide Emissions discusses:

- Inadvertent and intentional MB emissions.
- Emissions estimated from soil, perishable and durable commodities and structural treatments.
- Containment techniques.
- Using "best practice" methods to reduce emissions
- Developments in MB recovery and recycling systems.

Appendix 1 contains:

List of MBTOC members and their contact details and disclosure of interest statements.

2.7. References

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3

3. Methyl Bromide production, consumption and progress in phase out (controlled uses)

3.1 Introduction

This chapter provides statistics on MB production, consumption and major uses from 1991 to the present day for non-exempted (controlled) uses. Information on production and consumption of MB is now available for controlled as well as exempted (QPS) uses, but exempted uses are dealt with in Chapter 6 of this Assessment Report.

The chapter has been written in five main parts. The first part provides a brief overview of the major trends, the second part discusses MB production and supply, the third describes consumption in Non-Article 5 countries, the fourth describes consumption in Article 5 countries, and the final part describes the trends in MB fumigant uses by crop or sector.

Most of the data in this chapter refer to non-QPS fumigant uses, generally referred to as controlled uses or controlled production/consumption, to distinguish them from other MB uses which presently do not have phase-out schedules under the Protocol, namely QPS and feedstock used in industrial processes. (The status of the various MB uses under the Protocol is summarised in Table 1 in chapter 2). Statistics on QPS are provided in Chapter 6 of this Assessment Report. Feedstock is mentioned in this chapter only when discussing statistics on global MB production for all uses in section 3.3.1. There are no statistics available on laboratory and analytical (L&A) uses of MB, although L&A uses lie within the general statistics on production and consumption. L&A uses are discussed in the reports of the TEAP Chemicals Technical Options Committee.

3.2 Overview of major trends in production and consumption of MB for controlled uses

This section provides an overview of major trends in production and consumption for controlled uses. More detailed descriptions and data sources are provided in the remaining sections of this chapter. An update on MB production and consumption for controlled uses was compiled primarily from the database on ODS consumption and production of the Ozone Secretariat available in December 2010. Under the Protocol, consumption at the national level is defined as 'MB production plus MB imports minus exports, minus QPS, minus feedstock'; it thus represents the national supply of MB for uses controlled by the Protocol (i.e. non-QPS).

Consumption may be different from actual use as a fumigant in a particular year for importing countries as imports in one year may be consumed in another. Also stocks of MB already accounted for as consumption may be used in later years. . Some countries have revised or corrected their historical consumption data, and as a consequence official figures and baselines have changed slightly from time to time. At the time of writing this report, all Parties had reported consumption for 2009 to the Ozone Secretariat, which allows for thorough analysis of consumption trends.

3.3 Methyl Bromide global production and supply for controlled uses

MB is normally supplied and transported as a liquid in pressurised steel cylinders or cans, since it is a gas at normal atmospheric pressure. Cylinders typically range in size from 10 kg to 200 kg capacity, although MB is also stored in much larger pressurised containers of more than 100 tonnes. In some countries, MB is also supplied as disposable canisters of approximately 1 lb or 0.5 kg (a 0.75 kg or 1.5 lb is also available). MB fumigation using disposable canisters was banned in the European Union as of 2000 (EC Regulation 2037/2000 Article 16(4)) and other non-Article 5 Parties, as well as in various Article 5 Parties (e.g. Chile, Kenya, Morocco, South Africa, Brazil). At present, cans are still used in Japan and several developing countries (including Mexico and China, large volume Article 5 users).

3.3.1. Global production for all purposes

The information on MB production in this section has been compiled primarily from the Ozone Secretariat data available by December 2010. The Ozone Secretariat database is compiled from the ODS data reports submitted by Parties under Article 7. For historical data, information from the Methyl Bromide Global Coalition and previous MBTOC reports were also used. All tonnes stated in this chapter are metric tonnes.

Table 3 below shows the trends in global production, as reported to the Ozone Secretariat by Parties, for the years in which data is available (1991 and 1995-2009). The table also shows MBTOC estimates of the allocation of total MB production for fumigant and feedstock in earlier years, based on estimates published in previous MBTOC reports and Ozone Secretariat data. The predominant use of MB is as a fumigant (a pesticide product), which is used for the control of soilborne pests (such as nematodes, fungi, weeds, insects) in specific high-value crops, and for the control of insects and other pests in certain types of commodities and structures.

A recent MBTOC analysis of 1991 production data indicated that some MB produced for QPS may have been included in the non-QPS data. Only three countries reported production for QPS in 1991 in the Ozone Secretariat database while industry data indicated that about four countries produced MB for QPS around that time (MBGC, 1994).

MBTOC's historical estimates do not take account of several potential data gaps that have recently come to light. The official data on MB production appears to be incomplete for 1991 and several subsequent years. Data on MB production in Ukraine for controlled uses is not yet available in the Ozone Secretariat database, however it would appear that Ukraine has compiled relevant statistics. Information from international experts (R. Cooke, pers com 2011) indicates that the Saki State Chemical Plant in Crimea (Ukraine) produced MB between 1967 and 2002. The plant's peak capacity was rated at approximately 4,000 tonnes/year. In 1991, the baseline year for phase out under the Copenhagen Amendment, 3,607 tonnes were produced according to the plant's records. This declined to approximately 1,400 tonnes in 1996 and thereafter fell to no more than 400 tonnes/year until 2000. 137 tonnes were produced in 2002, the final year of production.

In recent years several chemical companies in India have indicated (on internet sites) that they produce and supply MB. However India has not reported any MB production to the Ozone Secretariat since 2002 (UNEP Ozone Secretariat Data Access Centre, January 2011).

Trends in the reported production of MB for all controlled uses (excluding QPS and feedstock) in all non Article 5 and Article 5 countries are shown in Figure 1. Reported production of MB for QPS purposes may be found in Chapter 6 (section 6.9).

TABLE 3. REPORTED MB PRODUCTION FOR ALL PURPOSES, 1984-2009 (METRIC TONNES).

Year	Fumigant Non-QPS & QPS		Chemical feedstock		Total production [a]	
	MBTOC estimates	Reported by Parties	MBTOC estimates	Reported by Parties	MBTOC estimates	Reported by Parties
1984	41,575		3,997		45,572	
1985	43,766		4,507		48,273	
1986	46,451		4,004		50,455	
1987	52,980		2,710		55,690	
1988	56,806		3,804		60,610	
1989	60,074		2,496		62,570	
1990	62,206		3,693		65,899	
1991	73,602	69,995 [b]	3,610	3,610	77,212	73,605 [b]
1992	72,967		2,658		75,625	
1993	71,157		3,000		74,157	
1994	71,009		3,612		74,621	
1995		65,284		4,754		70,038
1996		67,979		3,104		71,082
1997		69,760		3,829		73,589
1998		70,875		4,448		75,323
1999		61,517		4,453		65,970
2000		56,533		13,132		69,665
2001		45,134		3,190		48,324
2002		40,236		4,331		44,567
2003		36,565		6,759		43,324
2004		35,970		8,012		43,982
2005		32,909		5,014		37,923
2006		29,910		4,475		34,385
2007		25,861		5,224		31.085
2008		19,158		5,097		24,255
2009		17,850		6,408		24,258

a. Total production includes laboratory and analytical uses, but no specific statistics are available on this use.

b. The reported total for 1991 does not include the production that occurred in Ukraine.

Sources: data estimates from MBTOC 2002 and 2006 Assessment Reports and Ozone Secretariat data available for 1991 and 1995–2009.

Table 4 shows the intended purposes of the total MB that was produced in 2009. Essentially equal amounts of MB are now produced for use as a fumigant for controlled uses, as for quarantine and pre-shipment uses. In 2009, about 37% of total global production was intended for controlled uses (non-QPS fumigant), while 63% was intended for uses that are not controlled under the Protocol, i.e. for QPS fumigant uses (37%) and feedstock (26%). 37% of the total production in 2009 (including feedstock) was intended for QPS.

QPS is "the largest unregulated emissive use of all ODS". A major US report on ODS in 2008 noted that nearly half of the global anthropogenic emissions of MB in 2005 arose from QPS uses which were not restricted by the Montreal Protocol (Ravishankara *et al*, 2008).The Scientific Assessment Panel report (scenarios) calculated that if MB production for QPS uses were to cease in 2015, the total chlorine and bromine in the atmosphere from 2007 to 2050 (equivalent effective stratospheric chlorine, EESC) would be reduced by 3.2%.[1] (SAP, 2007; Montzka, 2009)

TABLE 4. MB PRODUCTION IN 2009, BY INTENDED PURPOSE AS REPORTED TO OZONE SECRETARIAT

Intended purpose	**Reported MB production in 2009**	
	Metric tonnes	**%**
Fumigant non-QPS	8,928	37%
Sub-total of uses controlled by the MP	**8,928**	**37%**
Fumigant for QPS	8,922	37%
Feedstock	6,408	26%
Sub-total of uses not controlled by MP	**15,330**	**63%**
Total – all uses, controlled and not controlled	**24,258**	**100%**

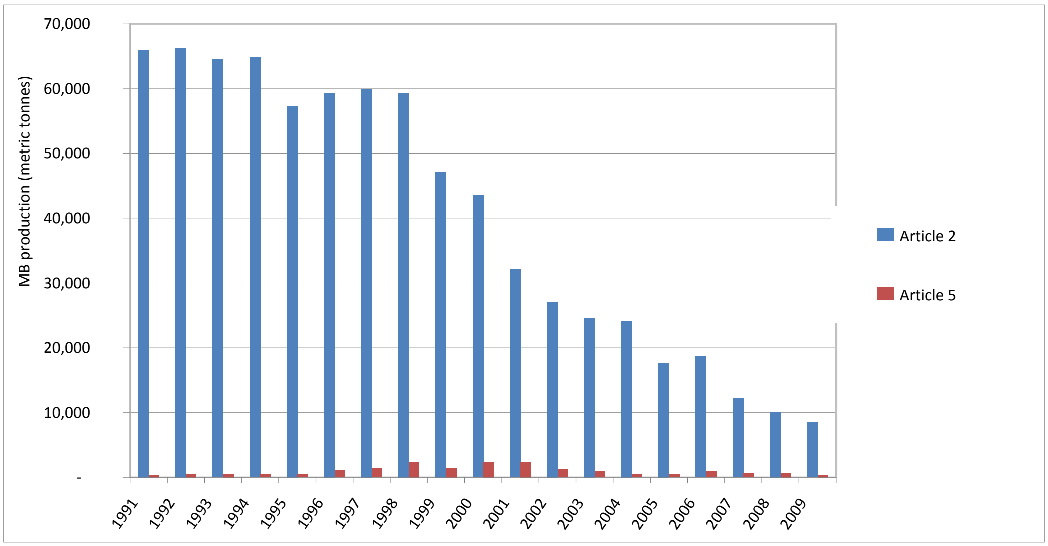
Source: Database of Ozone Secretariat of December 2010.

3.3.2. Global production for controlled uses

Figure 1 shows the trend in reported global MB production for all controlled uses from 1991 to 2009 (excluding QPS and feedstock).

[1] * Presentation by Scientific Assessment Panel (SAP) experts during the MoP QPS Workshop on 3 November 2009, based on scientific scenarios in the SAP assessment report of 2006. * SAP (2007) Scientific Assessment of Ozone Depletion: 2006. WMO, p.8.29.

FIGURE 1. HISTORICAL TRENDS IN REPORTED GLOBAL MB PRODUCTION FOR ALL CONTROLLED USES, EXCLUDING QPS AND FEEDSTOCK, 1991 - 2009 (METRIC TONNES)



Data for 1991 and 1995-2009 were taken from the Ozone Secretariat dataset of September 2010. Data for 1992-94 were estimated from Table 3.1 of MBTOC Assessment Report (2002), Table 3.1 of MBTOC Assessment Report (2007) and Table 3 above.

The figure illustrates that MB production has occurred primarily in non-Article 5 parties, and that significant reductions have occurred since the 1990's. In particular, the annual production of methyl bromide for controlled uses has been falling consistently since 1998 (except in 2006). In 2005, global production was 18,141 metric tonnes, which represented 27% of the production baseline (67,376 tonnes). In 2006, the global MB production increased to 19,635 tonnes (29% of baseline), although the consumption in both Article 5 and non-Article 5 countries decreased compared to the preceding year (details can be found in section 3.4). Global production for controlled uses in 2009 continued the downward trend, totalling 8,928 tonnes or 13% of the baseline.

Non-Article 5 countries have reduced their MB production for controlled uses from about 66,000 tonnes in 1991 (non-Article 5 baseline) to about 8,525 tonnes in 2009. Non-Article 5 production for controlled uses increased slightly to 18,666 tonnes in 2006 due to reported increased production in Israel. It decreased again in 2007 to approximately 12,191 tonnes and further to 8,525 tonnes in 2009. These figures include production for export to Article 5 countries (for Basic Domestic Needs).

Article 5 countries reduced their production for controlled uses from a peak of 2,397 tonnes in 2000 to 403 tonnes in 2009, which represents 29% of the Article 5 baseline (1,375 tonnes, average 1995-98). Article 5 countries have therefore reduced their MB production well in advance of the Montreal Protocol reduction schedule.

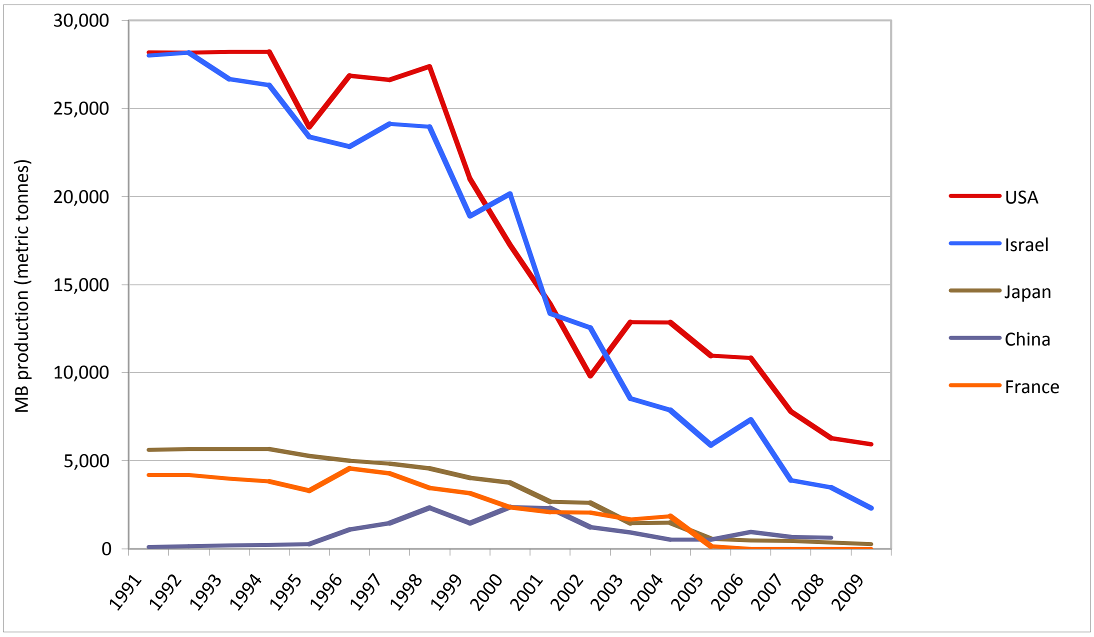
3.3.3. Major producer countries

Figure 2 below indicates the trends in reported MB production for controlled uses in 1991 - 2009 for the six countries that have produced MB in volumes greater than 1000 tonnes per annum (there are information gaps for 1992 and 1994; Ukraine reported production officially to the Ozone Secretariat only for 1995). Most countries have shown a downward trend in recent years, with some peaks for US and Israel in 2003 and 2006 respectively. France stopped production in 2005 and exported 6 tonnes in 2006 (recorded as negative production).

Israel and the US remain the major producers, accounting for 26% and 67% respectively, of global production for controlled uses. Together, the US and Israel accounted for 92% of production for controlled uses in 2009.

Since 2004, China is the only Article 5 country that has reported production of MB for controlled uses and a MLF project to phase-out this activity is approved and underway. Some chemical companies in India (see Table 5) have indicated on their websites that they produce MB some of which appears to be for controlled uses (e.g. soil fumigation).

FIGURE 2. REPORTED MB PRODUCTION FOR CONTROLLED USES, 1991-2009.



Source: Ozone Secretariat, December 2010

3.3.4. Production facilities

This section provides a list of known MB production facilities updating the information that was published in the MBTOC Assessment Report of 2006. The list may not be complete.

In 2000, about 14 facilities in eight countries produced MB for controlled and/or uncontrolled uses, and by 2006 the number fell to about 9 facilities in five countries. In 2010, about 20 facilities produced MB in five countries, as shown inTable 5 .

During the 1990s, six non-Article 5 countries produced MB (France, Israel, Japan, Romania[2], Ukraine and the US). Ukraine ceased production by 2003, while Romania and France ceased production by 2005 and 2006 respectively (Ozone Secretariat Data Access Centre, December 2010; V. Tsirkunov, 2006, *pers. comm.*; R. Morohoi, 2007, *pers. comm.*; European Commission, 2007, *pers. comm.*). As a result, the number of non-Article 5 countries that produce MB has fallen to three (Israel, Japan and US).

In the past, only three Article 5 countries produced MB (China, India and Korea DPR). Since 2002 only one Article 5 country (China) has officially reported any MB production. Korea DPR ceased production in 1996, and India was believed to have ceased production in 2003 (Ozone Secretariat Data Access Centre; Pak Chun Il, 1999, *pers. comm.*; S.K. Mukerjee, 2006, *pers. comm.*). However, as indicated above, several companies in India have indicated on the internet that they manufacture MB (for QPS, non-QPS and/or feedstock uses), and these companies have been added to Table 5 . Nevertheless, since 2002 India has not reported any MB production to the Ozone Secretariat under Article 7.

TABLE 5. COMPANIES THAT PRODUCED METHYL BROMIDE IN 2000, 2006 AND 2010, FOR ALL PURPOSES. Y – PRODUCTION. N – NO PRODUCTION

Country	MB manufacturers	2000	2006	2010		
				Non-QPS	QPS	Feedstock
China	• Lianyungang Seawater Chemical First Plant and Lianyungang Dead Sea Bromine Co. Ltd, Jiangsu Province .	Y	Y	Y	Y	Y
	LINHAI JIANXIN CHEMICAL CO LTD, ZHEJIANG. ALSO LISTED AS ZHEJIANG SUNCHEMICALS OR SUNRISE CHEMICALS CO.	N	N	Y	Y	Y
	• Changyi Chemical Plant, Shandong province		Y	Y	Y	Y
France	• Albemarle, formerly Elf Atochem, Port de Bouc	Y	N	N	N	N
India	• M/S Tata Chemicals Ltd, Mithapore, Gujurat State	Y	N	?	?	?
	• Intech Pharma Pvt. Ltd (IPPL), Goa	?	?	?	?	?
	• Jigchem Universal, Mumbai	?	?	?	?	?
	• Payal Chemexim PVT. Ltd. New Dehli	?	?	?	?	?
	• Sarthi Chem (P) Ltd., Gujarat	?	?	?	?	?
Israel	Dead Sea Bromine Group (company of ICL-Industrial Products), Beer Sheva	Y	Y	Y	Y	Y

[2] Romania has been re-classified as a non-Article 5 country.

Japan	Teijin Chemicals Ltd, Mihara, Hiroshima Prefecture. Nippoh Chemicals Co Ltd, Isumi, Chiba Prefecture. Dohkai Chemical Industry Co. Ltd (Asahi Glass SITec Co.Ltd), Kitakyushu, Fukuoka Prefecture. Sanko Chemical Industry Co. Ltd, Samukawa, Kanagawa Prefecture. Chemicrea Co Ltd, Chiba, Chiba Prefecture. Ikeda Kogyo Co. Ltd, Kitakyushu, Fukuoka Prefecture.	Y Y Y Y Y N	N Y N Y Y Y [a]	N Y Y Y N Y	N Y Y Y Y Y	N Y Y Y Y Y
Romania	SC Sinteza SA, Oradea	Y	N	N	N	N
Ukraine	Saki Chemical Plant, Saki, Crimea	Y	N	N	N	N
US	Chemtura Inc., formerly Great Lakes Chemical Corp., Arkansas	Y	Y	Y	Y	Y

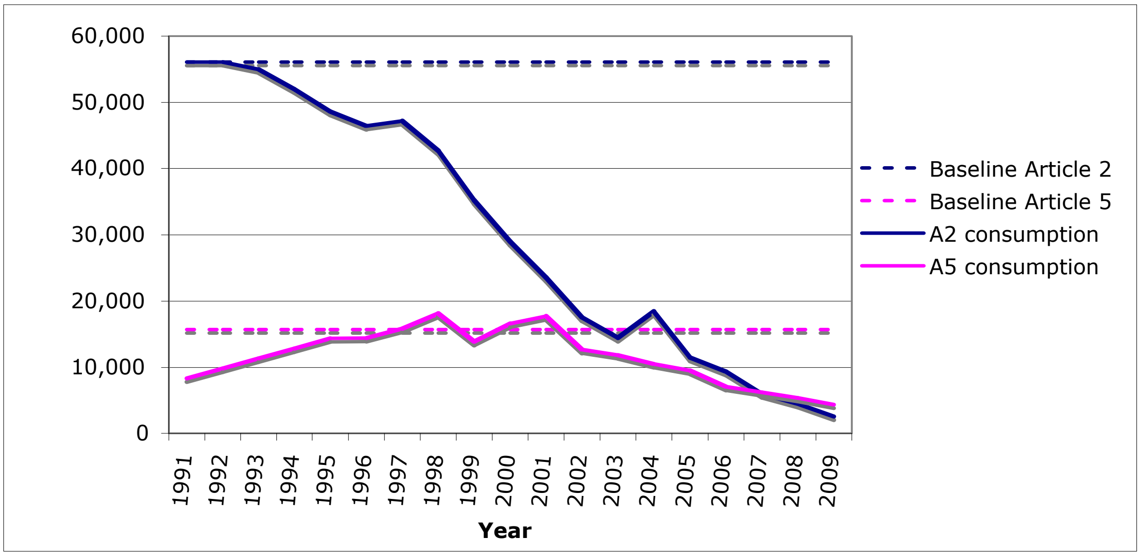
a. Manufacture was transferred to Ikeda Kogyo Co. Ltd. from other companies.
Sources of information: MBTOC Assessment Report of 2006, updated with information provided by national and international experts, company websites, NOUs, UNEP-CAP.
Websites for Indian companies:
Tata Chemicals: www.tatachemicals.net
Intech Pharma: http://www.ippl.co.in/company.html
Sarti Chem Ltd: http://sarthichem.com/ **and** http://sarthichem.com/product.html
Sang Froid Chemicals: http://trade.indiamart.com/search.mp?search=methyl+bromide and http://trade.indiamart.com/details.mp?offer=1505970
Chemtron Science Laboratories: www.chemtronscience.com and http://trade.indiamart.com/details.mp?offer=1819445033

3.4 Trends in global methyl bromide consumption (and phase-out) for controlled uses

On the basis of Ozone Secretariat data, global consumption of MB for controlled uses (i.e. fumigant uses, excluding QPS) was estimated to be about 64,418 tonnes in 1991. However the 1991 reported data did not include Ukraine's consumption data and may have included some QPS tonnage in error. These figures may be adjusted when further information becomes available. Consumption for controlled uses was estimated to be about 64,420 tonnes in 1991 and remained above 60,000 tonnes until 1998. Global consumption was reported as 45,527 tonnes in 2000, falling to about 8,148 tonnes in 2009 as illustrated by Figure 3.

Consumption in Article 5 Parties was higher than that of non-Article 5 Parties for the first time in 2007 (6,235 tonnes and 5,964 tonnes respectively). This trend continued into 2009, when all Article 5 Parties together reported a consumption of 4,405 tonnes (54% pf global consumption for controlled uses) whilst non-Article 5 Parties reported 3,741 tonnes (46% of the global consumption).

FIGURE 3. BASELINES AND TRENDS IN MB CONSUMPTION IN NON-A 5 AND A 5 REGIONS, 1991 – 2009 (METRIC TONNES)



Source: MBTOC estimates (for early years only) and Ozone Secretariat data as of December 2010.

3.4.1. Global consumption by geographical region

An analysis of Ozone Secretariat data revealed that the end of 2009 reduced global consumption of MB reduced by 90% with respect to the global aggregate baseline, as shown in Table 6 below.

TABLE 6 GLOBAL CONSUMPTION OF METHYL BROMIDE BY GEOGRAPHIC REGION, 2009 (MT)

Region	Regional baseline [a]	2009 consumption	% Reduction 1991-2009	Number of Parties
Africa	4,471	629	75%	53
Latin America & Caribbean	6,389	2,971	51%	33
Asia & Pacific [b]	14,657	2,245[e]	85%	58
Europe [c]	21,472	0	100%	49
North America [d]	25,729	2,300	91%	2
TOTAL	**72,718**	**8,145**	**89%**	**195**

a. Aggregate regional baselines as provided in the database of Ozone Secretariat of December 2010, compiled from 1991 consumption in non-Article 5 countries and 1995-1998 averages in Article 5 countries.
b. The relatively high baseline in this region arises from the historical consumption in Japan and Israel.
c. The European region comprises the EU, Eastern Europe, Switzerland, Scandinavia and CEIT countries.
d. The North American region comprises US and Canada.
e. Asia & Pacific comprises Asian countries (including the middle East), plus Australia and New Zealand. Israel reported a large negative consumption of 3426 metric tonnes (the negative value most probably resulting from large exports) that were not taken into account in this Table. Instead, 611 tonnes corresponding to the authorised CUE for 2009 was used as the consumption figure.

Source: Database of Ozone Secretariat of December 2010.

The geographical regions that have made the greatest reductions in consumption in the period 1991-2009 were Europe (100% phase-out), Asia & Pacific (85% reduction) and North America (91% reduction). Latin America made the smallest reduction (51%) in this period.

3.4.2. Number of countries using methyl bromide

Methyl bromide has been consumed for controlled uses by 131 out of the 195 countries that have reported data to the Ozone Secretariat since 1990. Many of these MB user countries (71% or 93 of 131) no longer consume MB indicating substantial progress in the phase out of MB. In 2009, MB was consumed in only 29% of countries that have used MB in the past.

Table 7 below summarises the number of current and former MB user countries in Article 5 and non-Article 5 regions.

TABLE 7. SUMMARY OF MB CONSUMPTION STATUS IN ARTICLE 5 AND NON-ARTICLE 5 COUNTRIES

Status of MB use	Number of Parties		
	Non-A 5 Parties (2009)	A 5 Parties (2009)	All Parties
Current users: Parties using MB	6 (c)	32	**38 (19%)**
Former users: Parties that used MB in baseline years and now have zero consumption (a, b)	37	56	**93 (48%)**
Parties with no MB consumption since 1990 (b)	5	59	**64 (33%)**
Total	**48**	**147**	**195* (100%)**

Source: MB consumption data reported by Ozone Secretariat, December 2010.

(a) 1991 for non-Article 5 Parties, average consumption for period between 1995-1998 in Article 5 Parties;

(b) Excluding QPS;

(c) Kazakhstan reported consumption of 112 tonnes of MB in 2009 (baseline 26 tonnes). However, Kazakhstan has not ratified the Copenhagen Amendment, and therefore is not bound by the control measures for methyl bromide. Israel reported a very large negative consumption in 2009 (3425.5 tonnes) however MB was used for CUEs.

3.5 Trends in methyl bromide consumption (and phase-out) in Non-Article 5 countries for controlled uses

The information about MB consumption in this section has been compiled primarily from the Ozone Secretariat data available at the end of December 2010, which is based on the ODS data reports submitted by Parties under Article 7 of the Protocol. At the time of making this analysis all non-Article 5 parties had submitted consumption data for 2009. Consumption data relating to 2009 and 2010 was compiled from the CUE consumption authorised by MOP Decisions (Decisions XIX/9 and XX/5) and the national authorisation/licensing documents of individual Parties.

Under the Protocol, consumption is calculated as MB production plus MB imports minus exports, minus QPS, minus feedstock. Consumption thus represents the national supply of MB (from new production or imports) for uses that are controlled by the Protocol, i.e. non-

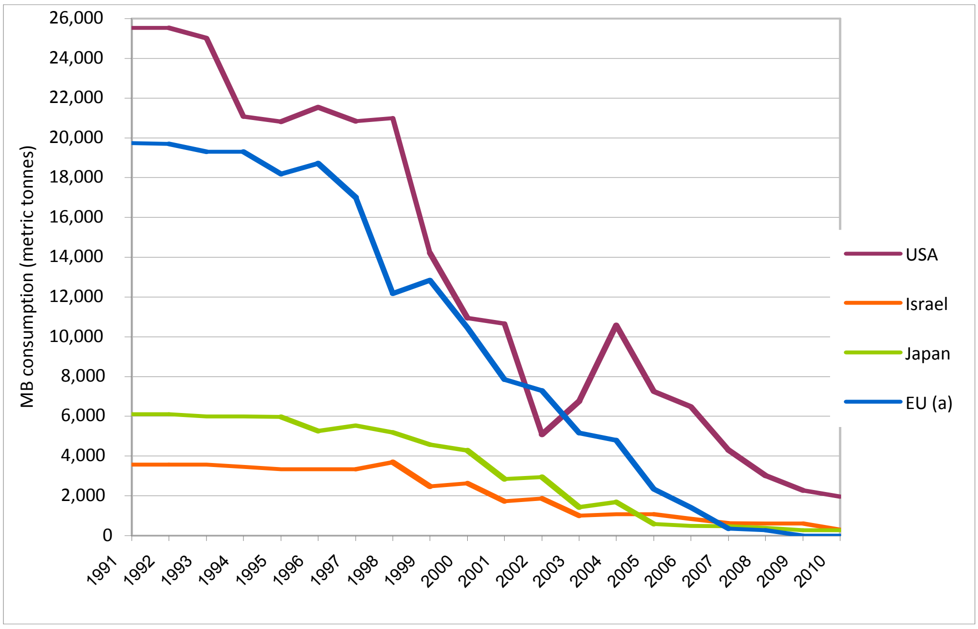
QPS fumigant uses. The consumption data in this section does not include QPS (consumption statistics for QPS can be found in Chapter 9 of this Assessment Report).

3.5.1. Total non-Article 5 consumption

Figure 4 shows the trends in MB consumption in the major Non-A 5 consuming countries for the period between 1991 and 2010. The official baseline for Non-A 5 countries was 56,084 tonnes in 1991 and since then the consumption has declined steadily. By 2003, this consumption had been reduced to about 14,613 tonnes, representing 26% of the baseline. In 2004, consumption appeared to increase to 18,454 tonnes (33% of baseline), however this occurred primarily because 3,310 tonnes scheduled for export to A 5 countries were not shipped before 31 December of that year and this consignment was counted as part of the official national consumption of a Non-Article 5 party. In 2008 the reported consumption amounted to 4,480 tonnes or 8% of the baseline. For 2009 consumption was reduced further to about 3,335 tonnes or about 6% of the baseline.

Israel reported a large negative consumption of -3,426 tonnes in 2009, which is most possibly explained as a result of exporting large quantities of MB to other countries. For the purposes of data analysis however, MBTOC used the authorized CUE amount of 611 tonnes as the consumption value for Israel, as the large negative figure would result in a misleading trend.

FIGURE 4. NATIONAL MB CONSUMPTION IN US, EU, JAPAN AND ISRAEL, 1991 – 2010.



Source: Database of Ozone Secretariat in December 2010, reports of the Meetings of the Parties to the Montreal Protocol, and national licensing and authorisation documents relating to consumption. MBTOC estimates for several data gaps in the period 1992 – 1996. (a) Aggregate data for the EU comprising all current member states.

3.5.2. National consumption trends in major non-Article 5 consumers

Trends in MB consumption in major Non-A 5 regions can be summarised as follows:

- In 1991 the USA, European Union, Israel and Japan used 95% of the MB consumed in Non-Article 5 countries.

- For 2009, permitted levels of MB amounted to 17%, 0%, 17% and 5% for the countries shown above, whilst for 2010 these figures came down to 11%, 0%, 8% and 4% respectively.

- In the past, MB was consumed for controlled uses by 43 out of 48 Non-A 5 countries. The majority of these countries no longer use MB (Table 7).

Of the eleven Parties applying for MB for CUEs in 2007 only five sought CUEs in 2010 (for either 2012 or 2013). Israel and Japan reduced their nominated amounts by 20% and 4% respectively in 2010 and have officially announced that they will no longer be applying for MB for any uses[1] in 2011and 2012 respectively.

- The US was the highest consumer of MB for much of the period from 1991 to 2010, and its consumption has fluctuated more than that of other countries. US consumption increased after 2002, and then fell to pre-2002 levels in 2007 and to about 11% of its baseline in 2010. Recategorisation of some controlled uses for preplant soil uses in nursery industries to QPS has assisted US meet this level. CUEs approved for 2011 and in particular 2012 have reduced requested amounts significantly, mainly as a result of the registration of additional alternatives.

- Consumption in the EU, the second-highest consumer, has shown a steady downward trend since 1999, falling to a low level of authorised consumption in 2008 and reaching 0% in 2009. Methyl bromide consumption ceased completely in the EU for both controlled and exempted uses in 2010 because MB failed to meet the safety requirements of EU pesticide legislation.

Table 8 summarises national MB consumption as a percentage of national baseline in Parties that were granted critical use exemptions (CUE).

The reported actual consumption was often lower than the authorised CUE tonnage (see Table 9. In general, Parties have made significant reductions in MB consumption for CUEs. Notably, the EU discontinued submission of CUNs by the end of 2008 and stopped all consumption of MB in 2010.

TABLE 8 METHYL BROMIDE CONSUMPTION[(A)] IN RELATION TO NATIONAL BASELINES IN NON-A 5 PARTIES THAT HAVE HAD CUES

Party	MB consumption [(a)], tonnes (percentage of national baseline)								
	1991 baseline	2003	2005	2006	2007	2008	2009	2010)	2011(a)
Australia	704	182 (26%)	119 (17%)	55 (8%)	46 (7%)	41 (6%)	33 (5%)	36 (5%)	35 (5%)
Canada	200	58 (29%)	54 (27%)	42 (21%)	38 (19%)	33 (16%)	28 (14%)	34 (17%)	22 (11%)
EU	19,735	5,162 (26%)	2,341 (13%)	1,410 (8%)	354 (3%)	275 (1%)	0 (0%)	0 (0%)	0 (0%)
Israel	3,580	992 (28%)	1,072 (30%)	841 (23%)	638 (18%)	600 (17%)	611d (17%)e	291 (8%)	225 (6%)
Japan	6,107	1,430 (23%)	595 (10%)	489 (8%)	479 (8%)	393 (6%)	279 (5%)	267 (4%)	240 (4%)
New Zealand	135	21 (15%)	30 (22%)	27 (20%)	7 (5%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Switzerland	43	11 (24%)	4 (9%)	4 (9%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
United States	25,529	6,755 (26%)	7,255 (28%)	6,475 (25%)	4,302 (17%)	3,028 (12%)	2,272 (9%)c	2,726 (11%)	1,855 (7%)

Source: MB consumption data for 1991-2009 from Ozone Secretariat dataset of December 2010. Figures for 2010 - 2011 are authorised or licensed CUEs from reports of Meetings of the Parties and licensing data.

- Consumption (imports/production) as reported by the Ozone Secretariat for 1991-2009, and as authorised by MOP decisions for 2010-2011.
- Consumption for CUEs authorised by MOP decisions (actual MB consumption has not yet been reported)
- Baseline of the 27 EU countries that were member states in 2005. The members of the European Union for which the MOP authorised CUEs in 2005/6 were Belgium, France, Germany, Greece, Ireland, Italy, Latvia, Malta, Netherlands, Poland, Portugal, Spain, and the United Kingdom (13 countries). The EU authorised CUEs for 2007 in France, Italy, Netherlands, Poland and Spain (5 countries) and for Poland and Spain for 2008 (2 countries).
- Israel reported a large negative consumption (-3425.5 tonnes) to the Ozone Secretariat most possibly arising from exports to other countries. The figure of 611 tonnes included in the Table corresponds to the CUE amount authorised for that year.

3.5.3. Number of countries consuming MB

About 90% of non-Article 5 countries, i.e. 43 of the total of 48 countries have consumed MB for uses controlled by the Protocol. Of these, 86% (37 of 43) no longer consume MB (as shown in section 3.4.2 above). Consumption data does not include QPS.

A total of 20 countries requested CUEs in 2005/6. In 2007 this number fell to 12 Parties, a reduction of 40% and in 2009 to 5 Parties. The member countries of the European Union provide an illustration of the changing patterns of MB use. In the past, 26 of the 27 current countries of the European Community consumed MB for uses controlled by the Protocol. In 2005/6, 13 of these countries still consumed some MB for CUEs. By 2008, only 2 EU countries consumed MB for CUEs, and phase out was completed by the end of 2008 as indicated in Figure 4

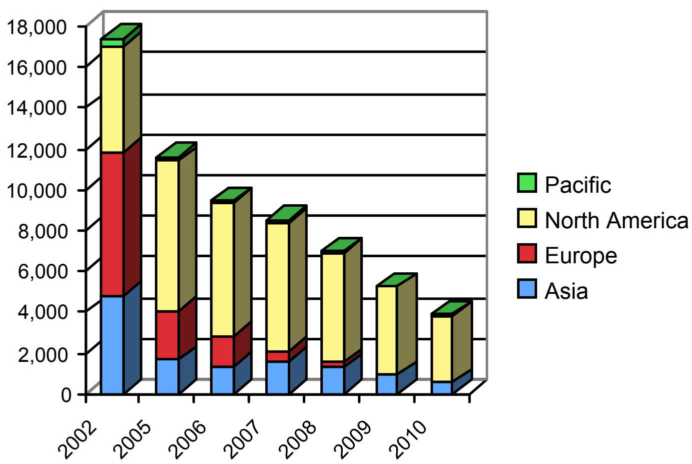
3.5.4. Consumption by geographical region

The proportions of consumption have changed substantially in non-Article 5 geographical regions since 2002 and particularly since 2006 as the CUE process developed. This is indicated in Figure 5.

There was a proportional change in consumption to North America (comprising the United States and Canada), which accounted for about 30% (5,181 tonnes) of total non-Article 5 consumption in 2002 and about 83% (3,269 tonnes) of total non-Article 5 authorised consumption in 2010 (3,954 tonnes). The European region's consumption changed from 41% (7,188 tonnes) of total non-Article 5 consumption in 2002 to 0% from 2009 onward.

FIGURE 5. MB CONSUMPTION IN NON-ARTICLE 5 COUNTRIES BY GEOGRAPHIC REGION, 2002 - 2010 (METRIC TONNES)

Europe: EU, other non-Article 5 Parties in Europe and non-Article 5 CEITs
Asia: Israel, Japan
Pacific: Australia, New Zealand
Source: Ozone Secretariat database, December 2010
North America: Canada and the United States



3.5.5. Trends in nominations for critical use exemptions

This section analyses trends in Critical Use Exemptions in non-Article 5 parties since the inception of the process in 2005. In addition to the quantities authorised for CUE consumption (production + imports), which were described in some sections above, Table 9 analyses the quantities authorised for CUE uses (called 'critical use categories' in MOP Decisions) up to 2008 for use in 2010. In addition, some stocks may have been used to support sectors seeking critical use or other sectors. The MOP Decisions on CUEs used in this analysis were Decisions Ex.I/3, XVI/2, Ex.II/1, XVII/9 and XVIII/13.

TABLE 9. TREND IN TOTAL TONNAGE OF CRITICAL USE EXEMPTIONS AUTHORISED 2005-2010.

Phase in procedure	2005	2006	2007	2008	2009	2010
Nominated amounts submitted to the MOP	18,704	15,615	10,678	8297.739	6244.487	4044.380
Amounts authorised* under the CUE 'use categories' by MOP Decisions	16,050	13,418	9,161	6996.115	5254.933	3572.183
MB "used" for CUEs reported by parties' in Accounting Frameworks (production + imports plus stocks used)	11540	9464	6097	4778	2559	Not reported

Source: Data compiled from TEAP/MBTOC reports, Decisions of MP meetings, national authorisations relating to CUEs, and Accounting Framework reports submitted to the Ozone Secretariat.

3.5.5.1. Trends for preplant soil uses

In the 2010 round, 27 nominations (CUNs) were submitted for preplant soil uses, 9 for 2011 and 18 for 2012. A further supplementary CUN was submitted by Australia for the strawberry runner sector in 2011 for 6 tonnes. Amounts approved by the Parties totalled 230 tonnes for 2011 and 1164 t for 2012 (Table 10).

MBTOC acknowledged the substantial reductions made by Israel and USA in the 2010 round, however the US indicated that it had reclassified further quantities into QPS for the forest nursery sector. Israel indicated an intention to no longer seek CUNs beyond the 2010 round (ie. from 2011 onwards) and in previous rounds Japan indicated it would no longer seek any nominations beyond 2012 according to its action plan submitted in 2008.

TABLE 10 SUMMARY OF MBTOC SOILS FINAL RECOMMENDATIONS FOR 2011 AND 2012 BY COUNTRY FOR CUNS RECEIVED IN 2010 FOR PREPLANT SOIL USE OF MB (TONNES)

Country	CUE approved at 21st MOP		CUN for 2011 and 2012		Parties Approved Amounts	
	2010	2011	2011	2012	2011	2012
Australia		23.840	5.950	29.790	5.950	29.760
Canada		5.261		5.261		5.261
Israel	290.878		232.247		224.497	
Japan		224.451		216.120		216.120
USA		1977.830		1020.478		913.311
Total	**290.878**		**238.197**	**1271.649**	**230.447**	**1164.452**

3.5.5.2 Trends in postharvest and structure uses

Five Parties submitted eight CUNs for the use of MB in structures and commodities in 2010 for use in 2011 and 2012 as shown in Table 11.

TABLE 11. POST-HARVEST STRUCTURAL AND COMMODITY CUE 2010 - 2012

Party	Industry	2010	2011	2012
Australia	Rice consumer packs	6.650	4.870	3.653
Canada	Flour mills	22.878	14.107	11.020
Canada	Pasta manufacturing facilities	3.529	2.084	
Israel	Dates (post harvest)	1.04		
Japan	Chestnuts	5.400	5.350	3.489
USA	Dried fruit and nuts (walnuts, pistachios, dried fruit and dates and dried beans)	19.242	5.000	2.419
USA	Dry commodities/ structures (processed foods, herbs and spices, dried milk and cheese processing facilities) NPMA	37.778	17.365	0.2
USA	Smokehouse hams (building and product)	4.465	3.730	3.730
USA	Mills and Processors	173.023	135.299	74.510
TOTAL		**274.005**	**187.805**	**99.021**

Source: Critical Use Nominations and MOP Decisions on Critical Use Exemptions

The total MB volume nominated in 2010 for non-QPS post-harvest uses was 182.175, following some reductions in CUNs by Parties during the year. MBTOC recommended 2.084 tonnes for 2011 and 101.105 tonnes for 2012 for a total recommendation of 103.189 tonnes. In contrast, in 2006, seventeen Parties had submitted 59 postharvest CUNs for structures and commodities. In 2006, MBTOC recommended 781.076 tonnes of MB for CUN use for structures and commodities.

3.5.6. Number and source of critical use exemptions

Table 12 illustrates progress made in the number of CUNs submitted by non-Article 5 Parties since the 2005 round. Phase-out of MB in non-Article 5 countries has made very significant progress since the 2006 MBTOC Assessment report. When the EU stopped submissions in 2008, the number of Parties requesting CUEs was reduced to five.

TABLE 12. NUMBER OF CRITICAL USE EXEMPTIONS AUTHORISED BY MOP, 2005-2011.

Party	Number of CUEs authorised by MOP Decisions (brackets indicate number authorised by party at licensing phase)							
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2011**
Australia	7	5	3	2	2	2	2	2
Canada	3	3	5	3	4	3	3	2
EU	77 (76)	86 (46)	35 (19)		0	0	0	0
Israel	12	11	12	11	11	9	9	
Japan	13	8	7	7	7	7	7	7
New Zealand	2	2	2	00	0	0	0	0
Switzerland	1	1	0	00	0	0	0	0
US	19	17	16	16	16	16	16	16
Total	**134 (133)**	**133 (93)**	**80 (64)**	**39**	40	37	37	27

Source: Critical Use nominations and MOP Decisions until end of 2010

3.6. MB consumption trends (and phase-out) in Article 5 Parties for controlled uses

The information about MB consumption in this section has been compiled primarily from the Ozone Secretariat database available in late December 2010. Some countries have revised or corrected their historical consumption data on occasion, and in consequence the reported figures and baselines change slightly in each MBTOC report. At the time of making this analysis all Article 5 parties had submitted national consumption data for 2009, which allows for a thorough analysis. The database relating to MB consumption is much more complete than in the past.

3.6.1. Total consumption and general trends

Figure 6 shows the trend in MB consumption in Article 5 countries for the period between 1991 and 2009. Overall trends can be described as follows:

- The Article 5 baseline was 15,867 tonnes (average of 1995-98), rising to a peak consumption of more than 18,125 tonnes in 1998. Article5 consumption was reduced to 44% of baseline in 2006 (6,935 tonnes) and 28% of baseline in 2009 (4,405 tonnes).

- Most Article 5 Parties have continued to make substantial progress in achieving reductions in MB consumption at a national level, as illustrated by the following information. Further details are presented in Figure 6 and Table 13 below.

Trends at the national level can be described as follows:

- At the time of preparing this report all Article 5 parties had reported MB comsumption for 2009. One party, Brazil, reported export of MB (5 tonnes), which was imported previously into the country (i.e. negative consumption).

- The vast majority of Article 5 parties achieved the national freeze level in 2002.

- By 2004, 87% of Article 5 parties (125 out of 144) had achieved the 20% reduction step earlier than the scheduled date of 2005. Only 19 remaining Parties needed to take action to meet the 20% reduction step in 2005.

- In 2009, 90% of Article 5 Parties (133 of 147 Parties) reported national consumption of <u>less than 50%</u> of the national baseline. Only fourteen Article 5 Parties consumed more than 50% of their national baseline in 2009.

- 78% of Article 5 Parties (115 Parties) reported <u>zero</u> MB consumption in 2009. This shows large progress since 2002 when 50% of Article 5 Parties reported zero MB consumption.

- According to latest reported consumption data only one Article 5 country (Iraq) was in non-compliance in 2008 with the 20% reduction step of 2005. This Party has returned to compliance in 2009, reporting zero consumption of MB.

TABLE 13. NATIONAL A 5 MB CONSUMPTION AS PERCENTAGE OF NATIONAL BASELINE, 2003-2007

	Number of Article 5 countries						
Status of national MB consumption	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
MB consumption was 0% of national baseline	87	91	96	101	107	112	115
MB consumption was 1 – 50% of national baseline	19	22	19	29	22	18	18
MB consumption was 51 – 80% of national baseline	11	10	21	10	13	13	14
MB consumption was more than 80% of national baseline	25	19	8	4	2	1	0
Total number of Article 5 parties examined	142	144	144	144	144	144	147

Sources: Analysis of zone Secretariat Data, December, 2010.Data for 2003, 2004 and 2005 were taken from Table 3.10 of MBTOC 2006 Assessment Report.

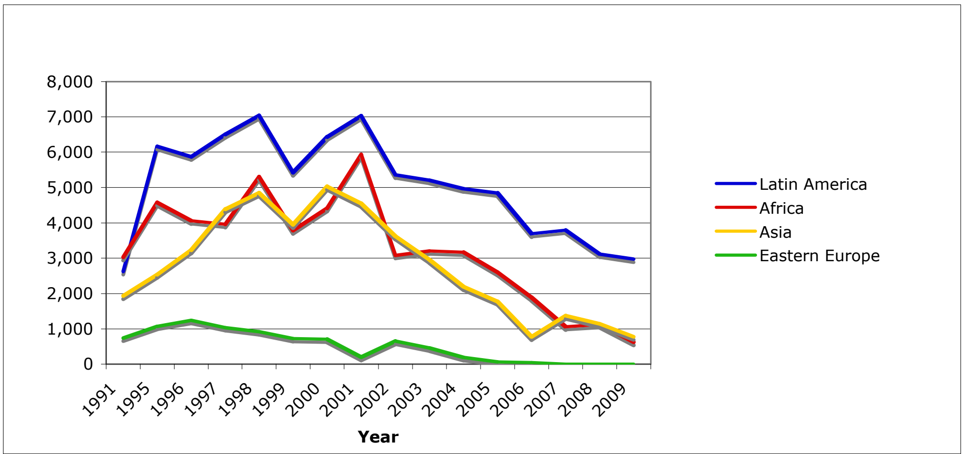
3.6.2. Article 5 consumption trends by geographic region

At regional level, the decrease in consumption has been greatest in CEIT countries (now reporting zero consumption), followed by Asia and Africa, while Latin America is the region with smaller relative reductions, All Article 5 regions except Latin America consume substantially less MB now than in 1991 (Figure 6). Some agricultural sectors in Latin America are still reporting significant use of methyl bromide, including melons in Central America, strawberries in Chile and Argentina, and cut flowers in Ecuador, but progress in reduction was made in these countries in 2009 as compared to 2007.

The status of MB phase-out in A 5 regions in 2009, compared to the regional baselines (1995-98 average) is as follows:

- Latin America has phased-out 54% of its regional baseline
- Africa has phased-out 86% of its regional baseline
- Asia has phased-out 80% of its regional baseline
- CEIT region has phased-out 100% of its regional baseline

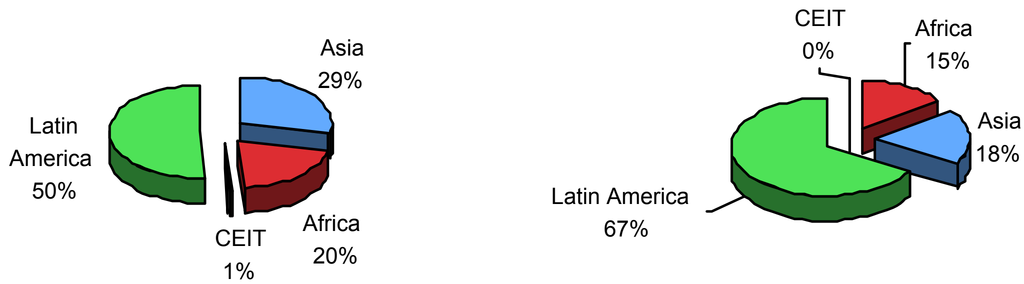
FIGURE 6. MB CONSUMPTION TRENDS IN ARTICLE 5 COUNTRIES 1991 – 2009



Source: Ozone Secretariat database, 2010

Figure 7 illustrates the proportional changes that occurred among the Article 5 regions from 2006 to 2009. In 2009, the relative consumption was proportionately much higher in Latin America at 67% of the total, followed by Africa at 14%, Asia at 18%, and CEIT is at 0% of the total reported in Article 5 regions. This was a substantial change from the proportions of 2006, when Latin America accounted for 52% and Africa 28% of the total MB consumption in Article 5 regions. The shift, which is evident since 2006, is mainly attributed to remaining and new uses of MB in certain sectors such as melons and strawberries (MLF, 2006; Implementation Committee, 2006; MBTOC, 2007).

FIGURE 7. RELATIVE MB CONSUMPTION (BY REGION) IN ARTICLE 5 COUNTRIES IN 2006 C.F. 2009



2006 **2009**

Table 14 summarises the status of consumption with respect to regional baselines of 1995-98 in the major Article 5 regions in 2009. The regions reduced their consumption by 54 – 100% compared to the regional baselines, showing a significant progress compared to the previously reported reductions of 24 – 90% (MBTOC, 2007):

TABLE 14. MB CONSUMPTION BY ARTICLE 5 REGIONS IN 2009.

Region	2009 consumption	Regional baseline	% Reduction from baseline	Number of Parties
Latin America	2,971	6,389	54%	33
Africa	629	4,471	86%	53
Asia	805	4,104	80%	51
CEIT	0	900	100%	10
TOTAL	4,405	15,864	72%	147

Source: Database of Ozone Secretariat, December 2010.

3.6.3. Article 5 national consumption as percentage of national baseline

Most Article 5 countries have achieved considerable MB reductions at national level. With respect to compliance, the vast majority of Article 5 countries achieved the MP freeze as scheduled in 2002. By 2003, 82% of Article 5 Parties (117 out of 142 Parties) had achieved the 20% reduction step earlier than the scheduled date of 2005, as indicated in Table 15. For further details see Table 13. In 2003 only 25 Parties needed to take action to meet the 20% reduction step of 2005.

The consumption data reported for 2005 indicates that only 8 parties failed to comply: 3 countries in Latin America, 3 countries in Africa, 1 country in the Pacific and one CEIT country. In 2008 only one Article 5 Party out of 145 (Iraq) had not complied with the 20% reduction step. However, all Article 5 parties complied with the 20% reduction step in 2009 as shown in Table 15.

Many Article 5 countries have achieved MB reductions far greater than those required by the Protocol schedule. In 2005, 80% of Article 5 countries (115 countries) had reduced national MB consumption to less than 50% of national baseline; this figure increased to 133 Parties (90%) in 2009. In 2009, only 14 Article 5 parties consumed more than 50% of their national baseline.

A number of Article 5 countries have implemented measures to promote and maintain MB phase out; further information can be found in Chapter 7 of this Assessment Report.

TABLE 15. STATUS OF COMPLIANCE IN ARTICLE 5 COUNTRIES, 2005 - 2009.

MB consumption as % of national baseline, and status of compliance with 20% reduction step	Number of Article 5 countries			
	2003	2005	2008	2009
MB consumption was 0 - 80% of national baseline	117	136	146	147
MB consumption was more than 80% of national baseline	25	8[a]	1[b]	0
Total	142	144	146[c]	147

Source: Database of Ozone Secretariat in November, 2006. For additional details refer to Table 13
a. Ecuador, Fiji, Guatemala, Honduras, Libya, Tunisia, Turkmenistan, Uganda.
Source: Database of Ozone Secretariat in November 2006.
b. Iraq
c. One Party Timor L'Este did not report 2008 consumption to the Ozone Secretariat.

3.6.4. Number of Article 5 countries consuming methyl bromide for controlled uses

As in other sections of this chapter, this analysis of MB consumption covers controlled uses only, not exempted QPS uses. Fifty-six Article 5 parties (38%) have never used MB or reported zero MB consumption since 1991, as summarised in Table 16 below. The total number of Article 5 parties that have consumed MB (currently or in the past) is 91, which is 62% of the total 147 Article 5 parties. Of the 91 MB-user countries, 59 (65%) have phased out MB, and 32 remained as consumers in 2009 as shown below.

This indicates that many Article 5 countries have made substantial progress by completing their national phase-out of MB consumption. In total, 78% of Article 5 countries did not consume MB in 2009. Note that this analysis refers only to the controlled uses of MB, and that some of these countries may still use MB for QPS.

A regional comparison reveals that CEIT Article 5 countries have made the greatest progress in ceasing MB consumption (100% of countries that used MB), followed by Africa (86% of countries), Asia (80% of countries) and Latin America (54% of countries that used MB).

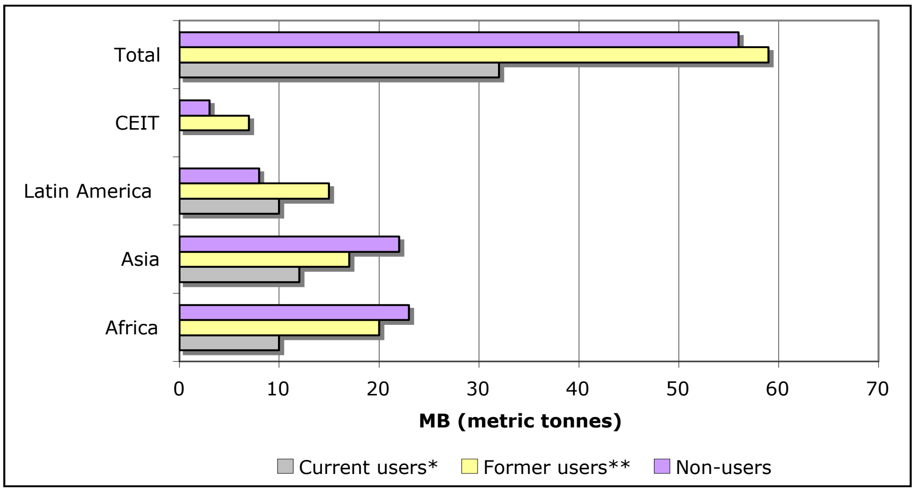
TABLE 16. NUMBER OF ARTICLE 5 COUNTRIES THAT CONSUME MB (CURRENT AND FORMER CONSUMERS) BY REGION, IN 2009 (EXCLUDING QPS).

National MB consumption status [a]	Number of countries, by region				
	Africa	**Asia**	**Latin America[b]**	**CEIT**	**Total**
Current users: countries using MB in 2009	10	12	10	0	32 (22%)
Former users: countries that used MB in past and have zero consumption in 2009	20	17	15	7	59 (40%)
Sub-total: Current users and former MB users	**30**	**29**	**25**	**7**	**91** (62%)
Non-users: countries that have not consumed MB since 1991 [c]	23	22	8	3	56 (38%)
Total	**53**	**51**	**33**	**10**	**147** (100%)

a. MB consumption reported in database of Ozone Secretariat in December 2010.
b. Latin American and Caribbean region.
c. Parties that have not reported any MB consumption for controlled uses in the period 1991-2009, exc. QPS.

Figure 8 provides a graphic illustration of **Table 16** above, showing the status of MB users (current and former) and non-users in each Article 5 region in 2009, excluding QPS. Hence in Africa of the 30 countries that have used MB 20 (67%) phased it out by 2009, in Asia 17 (59%) of 29 user countries, and in Latin America and the Caribbean 15 (60%) of 25 user countries have also phased out MB by 2009.

FIGURE 8. NUMBER OF ARTICLE 5 COUNTRIES THAT ARE MB CONSUMERS (CURRENT AND FORMER) AND NON-USERS, BY REGION, IN 2009 (CONTROLLED MB USES ONLY).



Source: Database of Ozone Secretariat in December 2010. * Using MB in 2009. ** Using MB before but reporting zero consumption in 2009

3.6.5. Small, medium and large Article 5 consumers

Table 17 shows the diversity of MB consumption patterns in Article 5 countries. In 2005 the distribution of small, medium and large consumers was as follows: 87% of Article 5 countries consumed 0-100 tonnes, while 9% consumed 101-500 tonnes, and only 4% consumed more than 500 tonnes. In 2009, the proportions changes as follows: 93% of Article 5 countries consumed 0-100 tonnes, 6% consumed 101 – 500 tonnes and <1% (only

1 country) consumed ¡500 tonnes. The number of large consumers (>500 tonnes) decreased from 11 countries in 2001 to 6 countries in 2005, and one country in 2009.

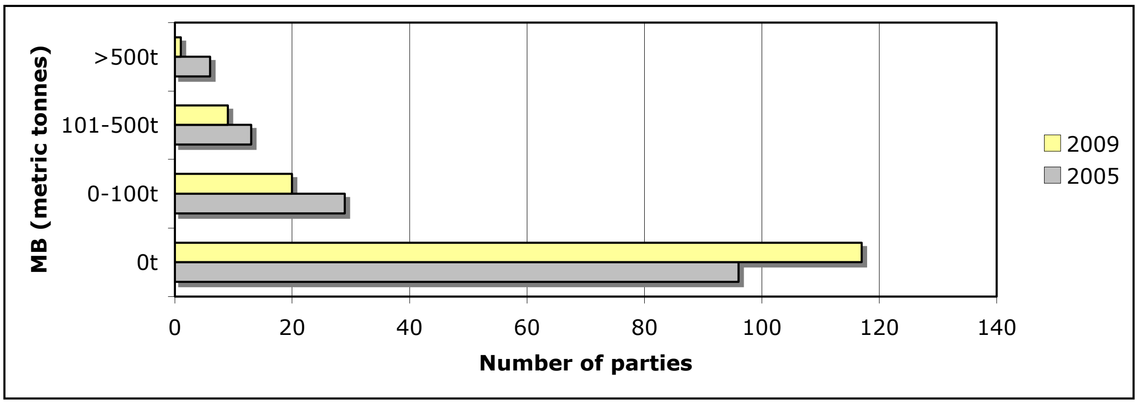
TABLE 17. NUMBER OF SMALL, MEDIUM AND LARGE VOLUME CONSUMER COUNTRIES, 2005 VS. 2009

MB consumption per country	Number of Article 5 countries	
	2005	2009
0 tonnes	96	117
Small: > 0 – 100 tonnes	29	20
Medium: 101 – 500 tonnes	13	9
Large: > 500 tonnes	6	1
Total number of countries	144	147

Source: Database of Ozone Secretariat in December 2010

The data in Table 17 is graphically illustrated in Figure 9 and compares the number of large, medium and small consumer countries in 2005 (pale bars) and 2009 (dark bars). It shows that a number of Article 5 countries changed from being small volume consumers (consuming up to 100 tonnes) to non-consumers (consuming 0 tonnes MB), and that most large consumers became medium sized consumers in this 4-year period. Only one Article 5 Party presently consumes more than 500 tonnes of MB per year for controlled uses and three more consume 400 tonnes or higher.

FIGURE 9. NUMBER OF SMALL, MEDIUM AND LARGE VOLUME CONSUMER COUNTRIES, 2005 COMPARED TO 2009.



Source: Database of Ozone Secretariat in December 2010.

3.6.6. Major consumer Article 5 Parties

Substantial progress has been achieved in Article 5 countries that consumed the greatest quantities of MB. In 2009, only 8 of these countries still reported consumption between 100 and 500 tonnes (down from 12 countries in 2006) and only one county (Mexico) remains in the usage category above 500 tonnes. The top 15 MB consuming countries together accounted for 80% of the Article 5 baseline in the past, and about 86% of total Article 5 consumption in 2000-1. National details are provided in Table 18 below. The top 15 countries reduced MB consumption by 68% from 2001 to 2009 (from 14,932 tonnes in 2001 to 3,901 tonnes in 2009). An increase was noted in South Africa in 2008 (where consumption increased from 100 tonnes in 2007 to 376.5 in 2008), but consumption reported for 2009 was only 17.5 tonnes.

- From 2001 to 2009, the top 15 countries reduced MB consumption from about 15,087 tonnes to 3,901 tonnes, a reduction of 74%. In the last 4 years alone, the top 15 countries have reduced MB by 20% , from 4,830 tonnes in 2004 to 3,901 tonnes in 2009.

- In 2009, MB consumption in the top 15 countries was only 31% of the baseline on average. These countries have phased-out 69% of their aggregate baseline consumption (**Table 18** column 4).

- By 2009 these large consumers phased out 80% of their historical peak use of MB.

Many Article 5 countries are finishing or have finished implementing MLF projects to reduce or totally phase-out MB. This includes 14 of the historical 15 largest MB consuming countries (i.e. countries that consumed more than 470 metric tonnes in the past, which together accounted for 80% of the Article 5 baseline consumption). The exception is South Africa, which did not have a MLF or GEF project[3] for MB phase-out, but nevertheless reported a greatly reduced consumption in 2009.

Two Parties in this top 15 group, Brazil and Turkey, which reported consumption larger than 500 tonnes in the past, phased out MB completely and reported zero consumption in 2007. In 2008, Lebanon also completed its phase out, and Zimbabwe, with a baseline of 928 metric tones, has recently reported zero consumption for 2009 (complete phase-out).

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[3] South Africa was not eligible for a MLF project. This country was eligible for a GEF project, but did not submit a project proposal

TABLE 18. FIFTEEN LARGEST ARTICLE 5 CONSUMERS OF MB IN THE PAST, AND PRESENT PROGRESS IN PHASE OUT

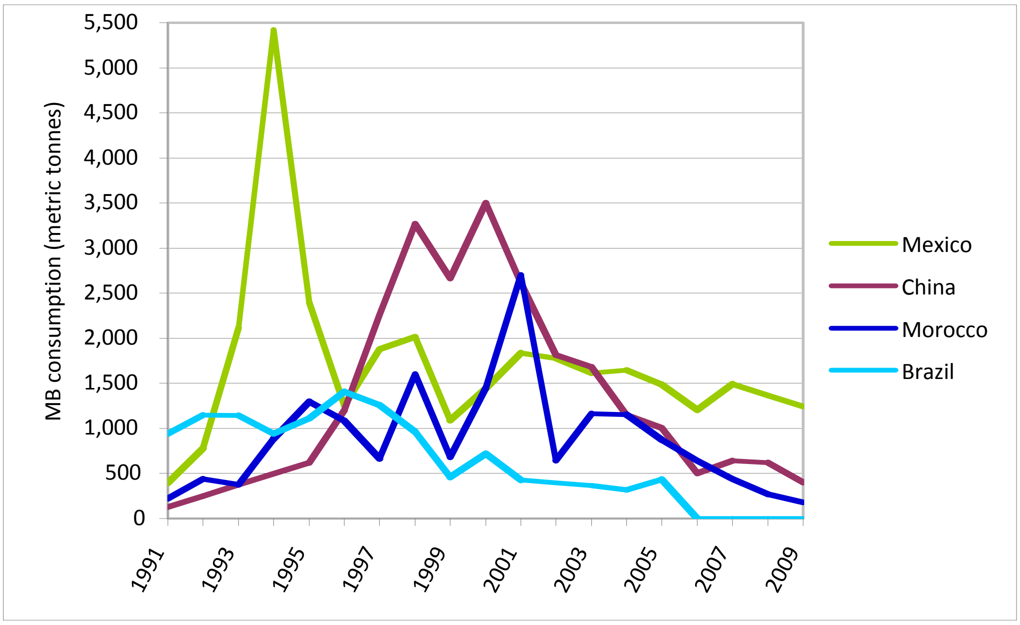
Country	National MB consumption (tonnes)			MB eliminated from peak year to 2009	MB eliminated from baseline year in 2009	MLF project
	In peak year a	Baseline (1995 – 98)	2009 consumption and (% baseline)			
China	3,501	1,837	403 (22%)	88%	78%	Yes
Morocco	2,702	1,162	180 (16%)	93%	84%	Yes
Mexico	2,397	1,885	1,242 (66%)	48%	34%	Yes
Brazil	1,408	1,186	0 (0%)	100%	100%	Yes
Zimbabwe	1,365	928	36 (4%)	96%	96%	Yes
Guatemala [b]	1,311	668	400 (60%)	69%	40%	Yes
South Africa	1,265	1,005	17 (2%)	98%	83%	No [c]
Turkey	964	800	0 (0%)	100%	100%	Yes
Honduras [b]	852	432	227 (53%)	73%	47%	Yes
Argentina	841	686	438 (64%)	48%	36%	Yes
Thailand	784	305	74 (24%)	91%	26%	Yes
Costa Rica [b]	757	571	318 (56%)	58%	44%	Yes
Egypt	720	397	317 (80%)	56%	20%	Yes
Chile	497	354	249 (70%)	50%	30%	Yes
Lebanon	476	394	0 (0%)	100%	100%	Yes
Total of top 15 countries	19,840	12,610	3901 (31% av.)	78% average	69% average	

[a] Maximum level of national MB consumption in the past
[b] Melon producers in these countries increased consumption greatly in recent years. Guatemala and Honduras are implementing projects designed to bring compliance and are now showing significant progress in phase-out
[c] South Africa was not considered eligible for a MLF project and was invited to prepare a GEF project

Figure 10 illustrates the trends in consumption in the four countries that in the past consumed the largest volumes of MB, in the range of 1,400 – 3,500 tonnes per annum historically (China, Brazil, Mexico and Morocco). Of these, only Mexico still consumes more than 500 tonnes.

Consumption in Mexico and Brazil peaked in the 1990's, while consumption in China and Morocco peaked in the early 2000's. Brazil has made the greatest progress in reducing MB, reporting zero consumption (complete phase-out) in 2007 (baseline 1,186 tonnes). In 2009, the four largest consuming countries showed an overall downward trend, although sometimes with peaks. All four Parties have implemented or are currently implementing investment projects funded by the MLF, aimed at MB phase-out before de 2015 deadline.

FIGURE 10. TRENDS IN MB CONSUMPTION IN FOUR ARTICLE 5 PARTIES THAT HAVE CONSUMED THE LARGEST VOLUME OF MB (>1400 TONNES PER ANNUM), 1991 – 2009



Source: Database of Ozone Secretariat in December 2010.

3.6.7. Assessment of progress in phase-out in Article 5 countries

The trends and indicators analysed above lead to the conclusion that Article 5 countries have achieved highly significant progress in reducing and phasing out MB, as illustrated by the following summary of the situation in 2009:

- Many Article 5 countries have implemented MLF projects and other activities that have led to MB reductions and phase out;
- 72% of the Article 5 production baseline for controlled uses has been phased out;
- 78% of the Article 5 consumption baseline has been phased out;
- 90% of countries consumed less than 50% of their national baseline in 2009;
- Of the 91 countries that have used MB, 56 (62%) reached zero consumption by 2009;
- Latin American countries phased out 54% of the regional baseline and 58% of their peak level of consumption (7,030 tonnes) and is the region with the smallest relative reductions, still consuming more MB now than in 1991;
- African countries phased out 86% of the regional baseline and 91% of their peak level of consumption (5,931 tonnes);
- Asian countries phased out 80% of the regional baseline and 84% of their peak level of consumption (5,025 tonnes);
- CEIT Article 5 countries phased out 100% of the regional baseline and 100% of their peak consumption (1,245 tonnes);

Large consumption (>500 tonnes) remains in only one Article 5 country (in Latin America).

3.6.7.1. Article 5 consumption with respect to compliance

The vast majority of Article 5 countries achieved the freeze in consumption in 2002;

94% or 136 of 144 countries complied with the 20% reduction step in 2005; only 8 countries did not comply; in 2008 only one country had not complied with this required reduction, but it returned to compliance in 2009.

87% of Article 5 countries achieved the 20% reduction step earlier than the scheduled date of 2005.

The present status in 2009 of the 15 Article 5 countries that have historically consumed the largest volumes of MB (470 - 3,500 tonnes per annum) is:

- The top 15 countries phased out on average 78% of their national baselines (up from 34% in 2005);
- These 15 countries eliminated a combined total of 15,939 tonnes of MB since their peak level of consumption;
- They eliminated consumption of 3,948 tonnes in the 4-year period from 2005 to 2009.

3.7. Methyl Bromide use by sector – controlled uses

The data reported in this section was compiled from several sources. MBTOC estimated the relative proportion of MB use in the soil and postharvest sectors in non-Article 5 countries by examining CUEs that have been authorised by the MOP Decisions and, where available, by national authorisation or licensing procedures.

MBTOC also carried out a survey of Article 5 ozone offices and national experts in about twenty key countries that reported consumption larger than 30 tonnes of MB in 2009 or reported large reductions in MB consumption for controlled uses. (The survey was also sent to countries reporting use higher than 100 tonnes of MB for QPS purposes (results of this analysis can be found in Chapter 6 of the Assessment Report). The survey sample covered over 90% of the Article 5 MB consumption for non-QPS purposes.

Most Article 5 countries are implementing or have completed MLF projects and therefore carried out national surveys to identify MB use categories. As a result the quality of information on MB uses in Article 5 countries is now more reliable than it was in the past. However, some countries were able to provide only estimates rather than national survey data, and some countries did not submit a reply, so the MBTOC survey results in this chapter should be regarded as estimates rather than precise data. MBTOC also contacted UNEP-DTIE CAP offices in the three Article 5 regions where these operate (Latin America, Asia/ Pacific and Africa), national experts and NOU's and implementing agencies and is very grateful for the valuable information and help provided.

3.7.1. Global overview of fumigant uses

MB has been used commercially as a fumigant since the 1930's (MBGC, 1994). It is a versatile product, used in many different applications. MB is mainly used for the control of soilborne pests (such as nematodes, fungi, weeds, insects) in high-value crops, and to a lesser extent for the control of insects, rodents and other pests in structures, transport and commodities.

Historically methyl bromide has been used for a wide range of pest and dieases control activities. Many of these have now been phased out or replaced by alternative processes. Others are in process of replacement.

TABLE 19. MAIN TYPES OF MB FUMIGATION

In soil:	As a preplant treatment to control soil borne pests (nematodes, fungi and insects) and weeds of high-value crops such as cut flowers, tomatoes, strawberry fruit, cucurbits (melon, cucumber, squash), peppers and eggplant.
	As a treatment to control 'replant disease' in some vines, deciduous fruit trees or nut trees;
	As a treatment of seed beds, principally against fungi, for production of a wide range of seedlings, notably ornamentals, some vegetables and formerly tobacco;
	As a treatment to control soilborne pests in the production of propagation stock of high plant health status, e.g. strawberry runners and nursery propagation materials. In some cases treatment is required tomeet certification requirements;
In durables:	As a treatment to control quarantine pests in import-export commodities or restrict damage caused by cosmopolitan insect pests in low moisture content products such as cereal grains, dried fruit, nuts, cocoa beans, coffee beans, dried herbs, spices, also cultural artefacts and museum items;
	As an import-export treatment to control quarantine pests and in some cases fungal pests in durable commodities such as logs, timber and wooden pallets, artefacts and other products;
In perishables	As an import-export treatment to control quarantine insects, other pests and mites in some types of fresh fruit, vegetables, tubers and cut flowers in export or import trade;
In "semi-perishables"	To prevent fermentation or inhibit sprouting and fungal development in products that have high or very high moisture contents, for example high moisture dates and fresh chestnuts, and also some stored vegetables, e.g. yams and ginger;
In structures and transport	As a treatment to control insects and rodents in flour mills, pasta mills, food processing facilities and other buildings;
	As a treatment to control cosmopolitan or quarantine insect pest and rodents in ships and freight containers, either empty or containing durable cargo.

These categories of use can also be divided into two major groups:

- Quarantine and pre-shipment (QPS) uses, which were estimated to account for about 48% of MB fumigant use in 2009 (as controlled uses are phased out, QPS use has become proportionally higher; it was reported at about 38% of total uses in 2005). These uses are not subject to Protocol reduction schedules. QPS uses include wooden pallets, durable commodities in the import/export trade, transport and some perishable commodities. Detailed information on QPS is provided in Chapter 6 of this Assessment Report.

- Non-QPS uses, which were estimated to account for approximately 52% of MB fumigant usage in 2009. These uses are controlled under the Protocol and as such are subject to phase-out schedules. Non-QPS uses include soil fumigation, structures (mills and food processing) durable stored products, semi-perishables and some transport.

The non-QPS tonnage was calculated on the basis of the tonnage of CUE uses authorised by the MOP and by parties during the licensing phase for non- Article 5 Parties and the results of the MBTOC survey of MB uses in Article 5 countries. Using this data, MBTOC estimated that of the global MB use (not consumption) in 2009 (18,945 tonnes including both QPS and controlled uses) an estimated 47% for soil fumigation and about 5% for postharvest (durable commodities and structures) as indicated in **Table 20**.

TABLE 20. ESTIMATED GLOBAL USE OF MB FOR QPS AND NON-QPS IN 2009.

Major sectors	Reported uses in 2009*	% of total
QPS	8,486	48%
Non-QPS comprising:-	9,081	52%
Soil	8,083	47%
Postharvest (durables and commodities)	896	5%
Total QPS & non-QPS	**17,567**	**100%**

* Actual use, not consumption. Data QPS consumption in non-A5 parties are for 2007. An unidentified difference in use of about 2,128 tonnes remains for QPS.
Sources: Reported MB consumption for QPS in database of Ozone Secretariat of December 2010. CUE uses authorised by MOP Decisions. MBTOC survey of MB uses for controlled and exempted uses in Article 5 countries carried out in 2010.

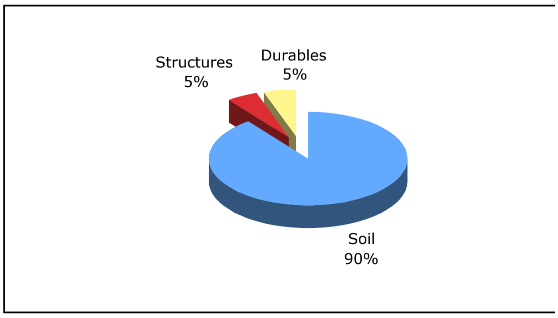
3.7.2. Quarantine and pre-shipment

In 2009 the reported MB production for QPS was 8921 tonnes. This represented about 44% of total global MB production for all purposes. Reported QPS consumption for 2009 was 10,614 tonnes, however "use" was determined at 8,486 tonnes, which leaves an unidentified or unallocated amount of about 1,824 . Detailed discussion on production, consumption and use of MB for QPS purposes can be found in Chapter 6 of this Assessment Report.

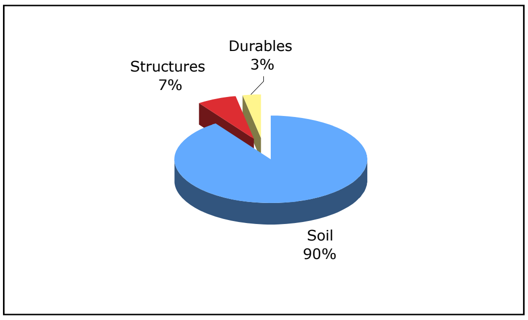
3.7.3. Non-QPS sectors

MBTOC has estimated that the total non-QPS use can currently be allocated to major sectors as follows: approximately 90% for soil fumigation, about 6% for structures and about 4% for durable commodities in 2009. In non-Article 5 countries the estimated proportions in 2009 were approximately 91% for soil uses, about 6% for structures and about 3% for durables as illustrated in Figure 11. The results of the MBTOC survey indicated that Article 5 countries in 2009 used approximately 90% of MB for soil fumigation, 5% for structures and about 5% for durable commodities, excluding QPS.

FIGURE 11. ESTIMATES OF GLOBAL METHYL BROMIDE FUMIGANT USE BY MAJOR SECTOR IN 2009, EXCLUDING QPS



Article 5 countries (2009)



Non-Article 5 countries (2009)

Sources: Estimates derived from database of Ozone Secretariat December 2010, MBTOC survey of MB uses in Article 5 countries in 2010 and CUEs authorised by 19th and 20th MOP Decisions and authorised by national authorities.

3.7.4. Non-QPS uses in non-Article 5 countries

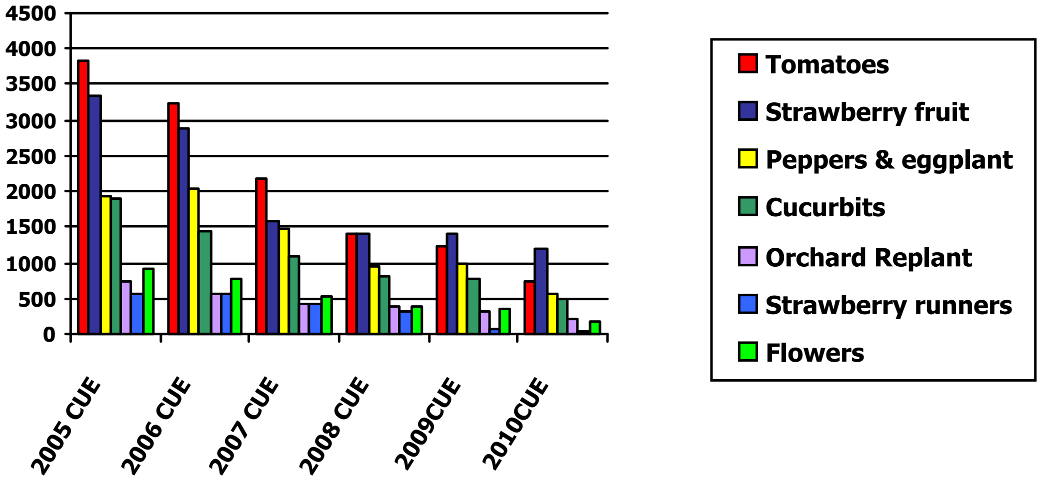
The remaining controlled uses of MB in non-Article 5 countries are presently allowed as critical use exemptions only. CUEs have been authorised by the Meetings of the Parties for the following crops in specific circumstances: tomatoes, strawberry fruit, peppers, eggplant, cucurbits, ornamentals (cut flowers and bulbs), orchard replant, nurseries, strawberry runners, and several miscellaneous crops.

The postharvest uses of MB comprise specific circumstances in food processing structures such as flour mills, pasta mills, durable commodities such as dried fruits, nuts, rice, and other products such as cheese in storage, cured pork products in storage and fresh market chestnuts.**Figure** 12 illustrates the trends in the CUE tonnage authorised by MOP decisions for individual major crops (soil fumigation) and postharvest uses, from 2006 to 2010. (Some parties made further reductions in the CUE tonnages during the licensing procedures, but these reductions are not taken into account in Figure 12)

Substantial reductions in the MOP-authorised tonnage can be seen for all crops since 2005. Most reductions are due to uptake of alternatives, although in the nursery sectors some recategorization to QPS has occurred. The data indicate consistent downward trends for all other crops and uses, although reductions for strawberry fruit in California have slowed.

The chart indicates metric tonnes authorised for CUEs by MOP Decisions. Some parties made further tonnage reductions (not shown in this chart) during the licensing procedures.

FIGURE 12 MAJOR USES OF MB CUES AUTHORISED BY MOP, 2005–2010.

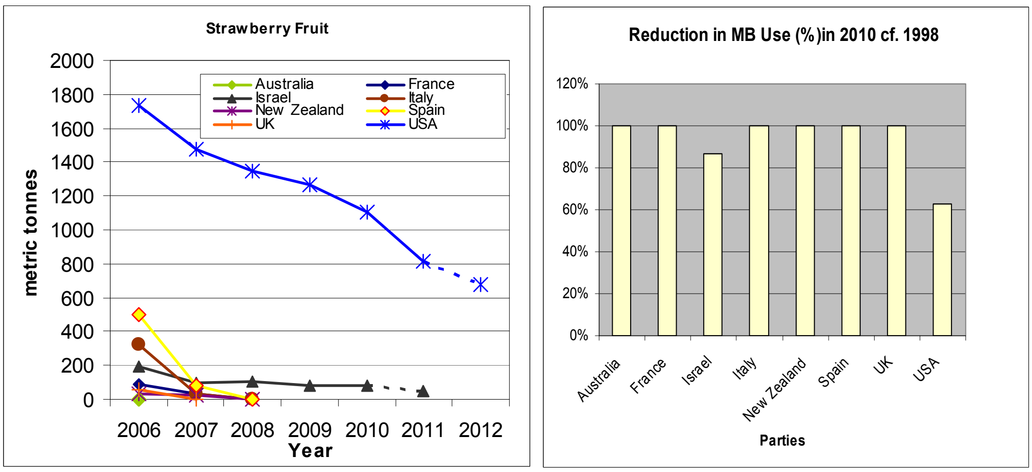


Source: Authorised lists of CUEs in Decisions published in the reports of the meetings of the Parties to the Montreal Protocol 2004-2010.

3.7.5. Major soil uses in non-Article 5 countries

This section examines the trends in the soil uses for major crops in the period 2005-2011. In Figure 13, the left-hand chart shows the quantity of MB authorised by MOP Decisions for strawberry fruit CUEs in individual parties. (Some parties made further reductions in CUEs at the licensing phase but these reductions are not shown in the Figures in this section). The number of countries using CUEs for strawberry fruit was 8 in 2005 and only 2 in 2010 (Israel and US). The total CUE tonnage authorised by MOP Decisions for strawberry fruit was reduced by 75% since 2005. Additional reductions were also made at national level during the licensing phase, but are not shown in these graphs.

FIGURE 13. LEFT: STRAWBERRY FRUIT CUE TONNES AUTHORISED BY MOP, 2005-2010. RIGHT: PERCENTAGE OF MB PHASED-OUT IN STRAWBERRY FRUIT, BY PARTY, 2010 C.F. 1998.



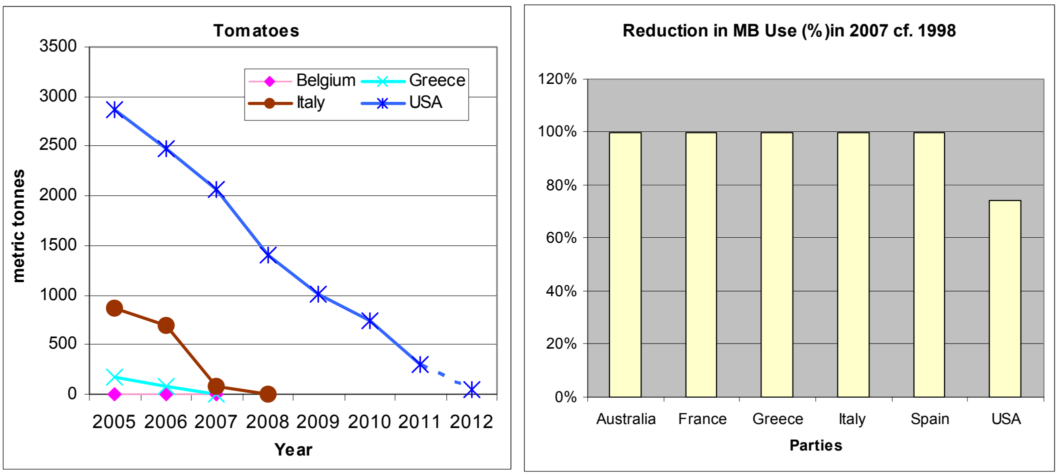
EU countries included are France, Italy, Spain and the UK.

Source: Decisions on CUEs in the reports of the Meetings of the Parties to the Montreal Protocol, and 1998 data of historical MB use from critical use nomination documents.

The chart on the right side of Figure 13 shows some of the countries that used MB for strawberry fruit in 1998, and the percentage of MB that was phased-out in strawberry fruit in these countries in 2010.

Figure 14 shows similar data for tomato CUEs authorised by MOP Decisions. The total CUE tonnage authorised by the MOP for tomato was reduced by 83% since 2005. Additional reductions were also made a national level during the licensing phase, but are not shown in these graphs. The number of countries that had a CUE for tomato was 5 in 2005, and 2 in 2010 (Israel and US). The chart on the right side shows some of the countries that used MB for tomato production in 1998, and the percentage of MB that was phased-out in tomato in these countries in 2010.

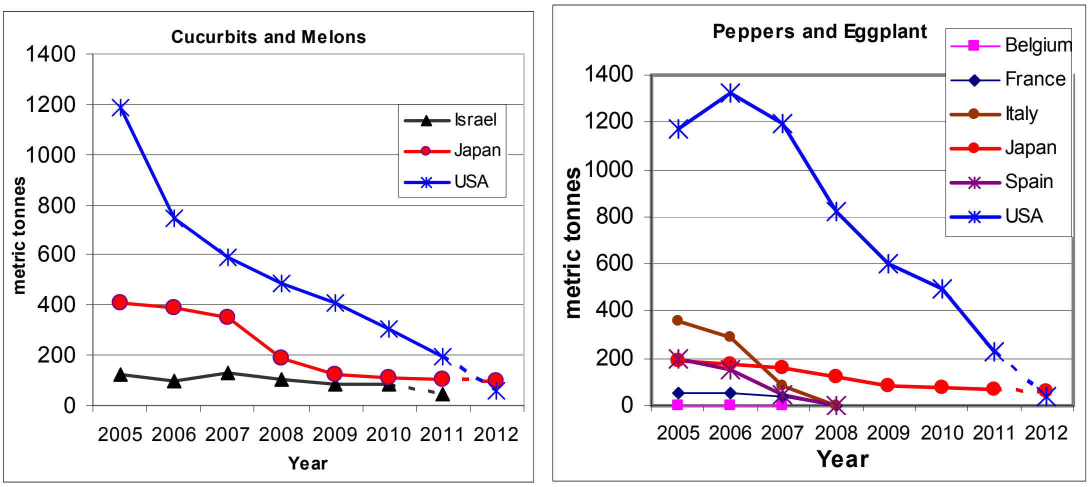
FIGURE 14. LEFT: TOMATO CUE TONNES AUTHORISED BY THE MOP, 2005-2010. RIGHT: PERCENTAGE OF MB PHASED-OUT IN TOMATO, BY PARTY, 2010 C.F. 1998.



The EU countries were Belgium, France, Greece and Italy.
Source: Decisions on CUEs in the reports of the Meetings of the Parties to the Montreal Protocol, and 1998 data of historical MB use from critical use nomination documents.

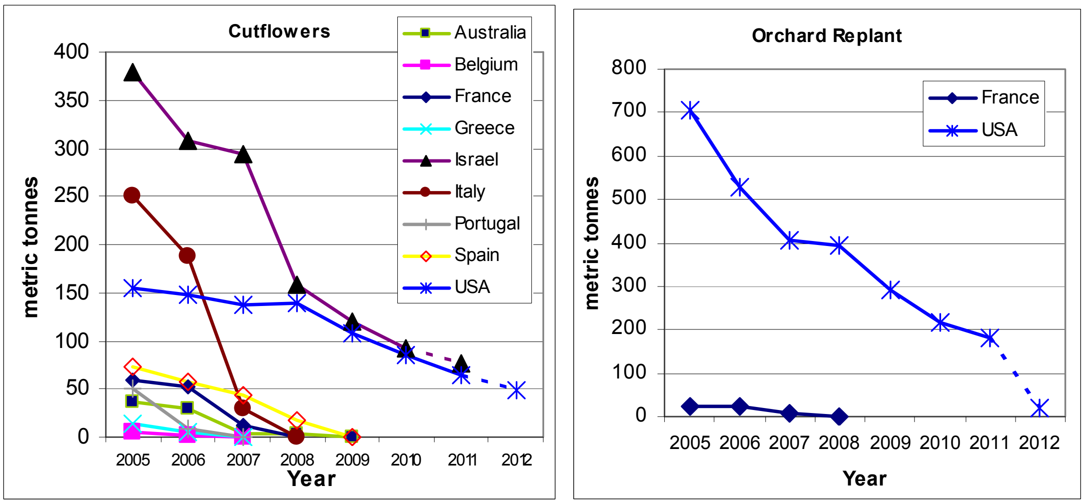
Figure 15 provides a series of charts illustrating the trends in the CUE tonnage authorised by MOP Decisions for other individual crops in 2005-2010, namely cucurbits, Figure 16 describes the phase-out status for peppers and eggplant, ornamentals (cut flowers and bulbs) and orchard replant.

FIGURE 15. CUCURBITS (LEFT), PEPPERS AND EGGPLANT (RIGHT) CUE TONNES AUTHORISED BY MOP, 2005-2010.



Source: Decisions on CUEs in the reports of the Meetings of the Parties to the Montreal Protocol.

FIGURE 16. CUT FLOWERS (LEFT), ORCHARD REPLANT (RIGHT) CUE TONNES AUTHORISED BY MOP, 2005-2010.



Source: Decisions on CUEs in the reports of the Meetings of the Parties to the Montreal Protocol.

3.7.6. Postharvest uses in non-Article 5 countries

Postharvest uses can be divided into structures and commodities. Structures comprised more than 70% of the postharvest CUE tonnage authorised in 2005 to 2010.

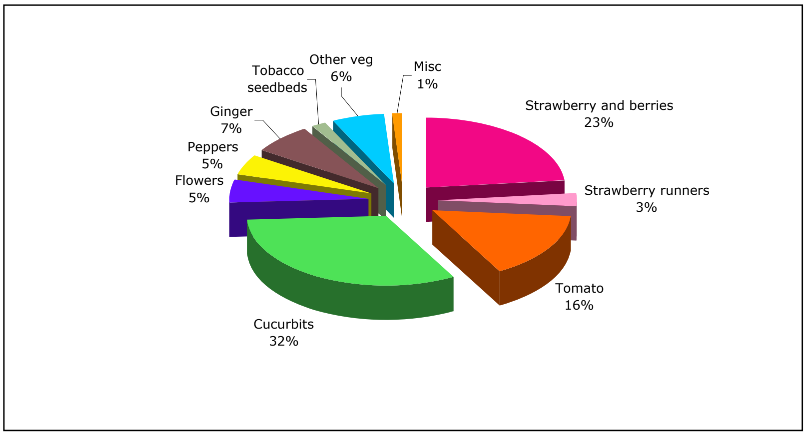
Trends in the CUE tonnes authorised by MOP Decisions (Decisions Ex.I/3, XVI/2, Ex.II/1, XVII/9 and XVIII/13) for structures and for commodities for 2005 to 2012 show that MB consumption in these sectors have been reduced from about 275 tonnes in 2010 to approximately 100 tonnes (see Table 11). Presently, five Parties seek CUEs in small amounts for this sector: USA, Israel, Japan and Australia.

3.7.7. Major controlled uses in Article 5 countries

The recent MBTOC survey carried out in 2010, as described in section 3.2.1, identified the major MB uses in 2009 as follows: approximately 90% was used for soil fumigation (i.e. for treatment of soil before planting crops), approximately 5% for durable commodities and about 5% for structures (excluding QPS). These survey results should be regarded as estimates rather than precise data. Percentage variations between results obtained in 2005 and 2009 are not directly comparable, since in that period large MB users have phased out completely and others have significantly reduced consumption. This may result in sectors that were small in the past now occupying a larger proportion of the total.

Figure 17 presents the survey results for the soil sector in Article 5 countries, indicating that the major crops using MB in 2008 were cucurbits (i.e. melon, cucumber and similar crops) (32%), followed by tomatoes (16%) strawberry fruit and other berries (raspberries, blueberries, blackberries; this use particularly reported in Mexico) (23%), cut flowers (5%) peppers and eggplant (5%), tobacco seedbeds (2%), ginger (7%, from China), strawberry runners (3%), other vegetables 6% (green beans, lettuce, asparagus) and other miscellaneous uses (medicinal herbs, turf, (1%). A previous MBTOC survey (MBTOC, 2007) identified the largest Article 5 uses in 2005 to be cucurbits (29%), tomato (20%), strawberry (18%) cut flowers (12%) and tobacco seedbeds (5%).

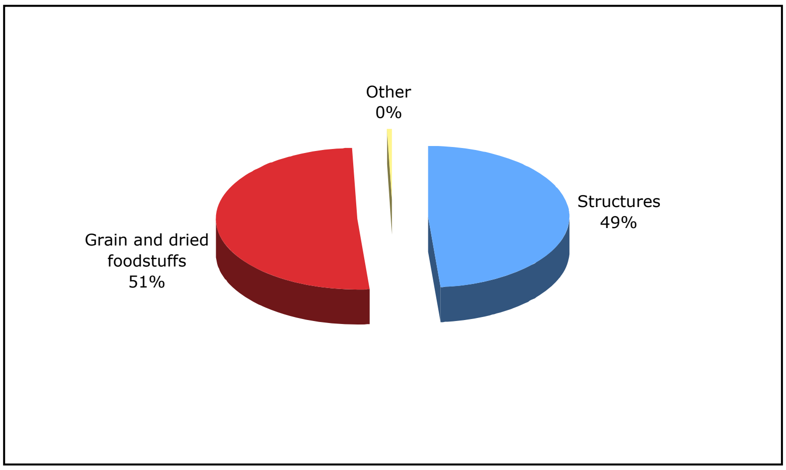
FIGURE 17. SOIL SECTOR SURVEY RESULTS: MAJOR CROPS USING MB IN ARTICLE 5 COUNTRIES IN 2009.



Source: MBTOC survey of MB uses in Article 5 countries, 2010

Figure 18 presents results of the survey with respect to postharvest uses of MB for controlled uses in Article 5 regions in 2009. The results indicate that the major uses were stored grains and dried foodstuffs including cassava chips and dried fruit and nuts (about 51%), buildings and structures including mills (about 49%), and other uses 1% (timber and wood products, coffee and cocoa beans) A previous MBTOC survey in 2005 (MBTOC, 2007) estimated that about 40% was used for stored grains, 34% for buildings and structures, 18% for stored food (unspecified) and other or unidentified uses (7-8%). However, it should be noted that the survey results are estimates and do not provide precise data.

FIGURE 18. POSTHARVEST SECTOR SURVEY RESULTS: MAJOR MB USES FOR DURABLE PRODUCTS AND STRUCTURES IN ARTICLE 5 COUNTRIES IN 2008 (EXCLUDING QPS USES).



Source: MBTOC survey of MB uses in Article 5 countries, 2010

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4

Alternatives to Methyl Bromide for soil fumigation

4.1 Introduction

Historically since 1991 about 91% of MB used in non-Article 5 and Article 5 regions has been used for pre-plant soil fumigation. In 2010, less than 10,000 tonnes of the 56,083 tonnes baseline is being used for soil uses in both Article 5 and non- Article 5 countries and by 2012 the amount used in non-Article 5 countries will be reduced to less than 2,000 tonnes. In addition, Article 5 countries have reduced their MB consumption by over 50%. Since the 2006 report, there has been widespread adoption of alternatives in many countries previously using MB or applying for critical uses of preplant soil fumigation with MB. For instance, the 16,000 tonnes of MB applied for critical use in non-Article 5 countries in 2005 has fallen to less than 2,600 tonnes in 2011. There are alternatives for almost all uses, however regulatory barriers and cost prevent their current adoption across all sectors worldwide. In non-Article 5 countries, these specific uses (e.g. nursery production), require less than 1,000 tonnes of MB.

This chapter focuses on alternatives adopted to achieve this success, in particular on alternatives that provide the same short term outcomes as MB and some which are suitable to replace MB over the long term. MBTOC identified several key alternatives that perform consistently across regions and sectors (eg methyl iodide (MI), 1,3-D/Pic, Pic alone, 3 way treatment with 1,3,D, Pic and metham sodium and others which are more specific to certain target pests (eg grafting, dimethyl disulphide DMDS). Since 2005, several chemical and non-chemical alternatives have been accepted widely for uses where MB had been sort under 'Critical Use' provisions. Many agricultural sectors have fully adopted these alternatives in a wide range of cropping practices and no longer submit nominations to continue use of MB under critical use provisions of the Montreal Protocol. The fact that MB cannot generally be replaced by one in-kind alternative has been re-confirmed in non-Article 5 and Article 5 regions. This implies that growers and other stakeholders may need to change their approach to crop production, which often involves new skills, training and change in time management. Management change is often a major barrier to adoption of alternatives, often more so than economic issues.

This update to our previous reports focuses primarily on the methodologies that have been adopted by a significant number of users. However, we also describe soil treatments that are effective for managing soilborne pests but may be limited to specific areas by availability of active ingredients, by climatic factors, by cultural practices, by regulations and by economics. Lastly, we briefly detail some emerging technologies that in the future may be available for reducing crop losses originating from soils and substrates. A number of review articles have been published on alternatives to MB use and a meta-analysis of over 200 international studies (Porter *et al.* 2006) provide the Parties with information on the relative effectiveness of alternatives in many sectors.

4.2 Chemical alternatives

4.2.1 Chemical alternatives adopted commercially

Since the 2002 and 2006 MBTOC assessment reports, there have been some major advances in the registration and commercial adoption of chemical alternatives to MB. Actually, at least within EU countries, all chemicals commonly considered as MB alternatives (Chloropicrin, 1,3-D, MITC generators) are subject to increasing regulations which either prevent or retrict use under their pestcide reviews Since 2008, two emerging chemical i.e. iodomethane (methyl iodide) and dimethyl disulfide (DMDS) have been registered in several countries . On the other hand, some initially promising chemicals included in the 2002 and 2006 MBTOC reports have seen little further development, e.g. propargyl bromide sodium azide, propylene oxide and are no longer regarded as potential alternatives to MB. The following alternative fumigants are currently available:

- Chloropicrin (trichloronitromethane) (Pic) is effective for the control of soilborne fungi and some insects but has limited activity against weeds (Ajwa *et al.* 2003). Pic has provided a satisfactory and consistent control of Fusarium wilt on melon, Verticillium wilt on eggplant, and Fusarium wilt and Fusarium collar rot on tomato (Gullino *et al* 2002). Similar results were observed for other pathogens as well. Combination with virtually or totally impermeable films (VIF, TIF) have been an effective strategy to reduce application rates keeping satisfactory efficacy (Chow 2009). However, the increase in use of Pic in strawberry production in the USA and Israel following the phaseout of MB has resulted in increase in infestation with *Macrophomina phaseolina*. It is anticipated that other fungal pathogens may emerge as well. In addition, regulatory constraints continue to limit Pic use in some countries.
- 1,3-Dichloropropene (1,3-D) is used as a nematicide and also provides effective control of insects and suppresses some weeds and pathogenic fungi (Ajwa *et al* 2003). 1,3,-D as a single application has no effect in controlling fungi or bacteria. As with Pic, 1,3 D can achieve similar efficacy when combined with virtually or totally impermeable films (VIF, TIF) at reduced dosages (Chow 2009).
- Fumigants based on the generation of methyl isothiocyanate (MITC), e.g. dazomet, metham sodium and metham potassium, are highly effective at controlling a wide range of arthropods, soilborne fungi, nematodes and weeds, but are less effective against bacteria and root-knot nematodes. Their use to replace MB has usually been when they are combined with Pic or 1,3-D. For example the very effective 3 way system developed and used in the SE USA (Culpepper, 2008).
- Iodomethane or methyl iodide (MI) is a liquid fumigant which has been tested on a wide range of crops by drip and shank-injected and found to be highly effective at controlling a wide range of soilborne pathogenic fungi, nematodes, and weeds (Browne *et al.* 2006, Fennimore *et al.* 2008, Schneider *et al.* 2008, 2009, Yakabe *et al*. 2010). Methyl iodide is considered the closest one to one replacement to methyl bromide, however , the longer resident time in soil means that for some cropping situations , longer plant pack times may be required.
- Formaldehyde, has been shown to provide effective broad-spectrum control of

soilborne pathogens, especially bacteria, fungi and ectoparasitic nematodes (Kritzman *et al.* 1999). This fumigant, not widely registered, is highly soluble in water. Formalin is not effective against *Fusarium oxysporum* at the commercial rates; however, when combined with metham sodium (MS) it provides effective disease reduction. (Gamliel *et al* 2005b)

- Dimethyl disulfide (DMDS), which has been registered in some countries, including the US, appears to be highly efficient against various nematodes. (García-Méndez *et al.* 2009, Heller *et al* 2009, López-Aranda *et al* 2009a, 2009b, Santos *et al* 2009). The toxicity of DMDS varies among soil fungi (Gamliel, unpublished data). DMDS efficacy can be enhanced when combined with VIF or TIF films (Chow 2009).

Currently, most single chemical alternatives target specific groups of organisms and therefore combinations of fumigant chemicals are generally used to give broadscale treatment comparable to MB. With the exception of methyl iodide, it is clear that none of the currently available fumigants, used alone, offer a completely satisfactory alternative compared to MB (Wharton and Matthiessen 2000, Di Primo *et al.* 2003, Triky-Dotan *et al* 2007, 2009). Obviously, the future of soil disinfestation lies in combining available fumigants with other chemical and non chemical alternatives .

4.2.2 Application methods

4.2.2.1 Mechanical Injection

4.2.2.1.1. Shallow injection (Shank injection)

The main method of application has been the use of mechanized injection rigs, which apply MB at depths of 15 to 30 cm in soil (called ‘shallow injection’), followed immediately by tarps applied in strips or broad acre to seal in the fumigant. The process is either carried out as broad-acre fumigation where one sheet is glued to the previous one, or under strips of plastic with both edges of the strips buried by the machinery during application to soil. Strip fumigation involves injection of MB/Pic mixtures into strips generally ranging from 0.8 – 1.8 m wide. The injection may be made into pre-formed beds or beds may be formed as part of the application process at the time of injection. The beds are also covered with plastic mulch as part of the operation. Strip application generally results in the application of less fumigant per hectare than broad-acre application, but leaves the system open to recolonization due to the untreated furrows. A variety of mixtures of MB and Pic are used in this type of fumigation. Historically the predominant mixture used was 98% MB containing 2% Pic. Pic was added as a warning agent, and these low levels were not effective against pests and diseases. With the phase out of MB under the Montreal Protocol the use of MB formulations with higher concentrations of Pic has increased. For example MB/Pic 67:33, 70:30, 57:43, or 50:50, with the Pic being used as the effective active agent for the control of fungi and diseases, are replacing the 98:2 formulations. The use of higher concentrations of Pic has been an important factor in the reduction in the use of MB.

4.2.2.1.2. Deep injection

Another injection method for MB is called ‘deep injection’ (approximately 80 cm depth). In this case MB is applied without covering the area with plastic mulch. Deep injection of MB is carried out mainly as strip fumigation, or as an auger application to individual tree or vine holes prior to planting and replanting in deciduous orchards, vineyards and other plantations, mainly in the USA (Browne *et al* 2009).

4.2.2.1.3. Manual application

MB and other fumigants can also be applied manually using simple equipment and application methods. This can be either by pre-vapourising the gas in a 'hot gas' method or using it directly from a punctured can as a cold gas. This involves treating soils, which have been pre-tarped with plastic mulch. Use of this latter method has been limited in many countries due to concerns over safety.

4.2.2.1.4. Hot gas

This method is particularly suited for small-scale areas or enclosed spaces where machinery is difficult to operate. The main manual method is the so-called 'hot gas' method where liquid MB from cylinders under pressure is vaporized in a heat exchanger and then dispersed under plastic covers over the top of the soil. As MB is a heavy gas, it permeates into soil to give control of pathogens and weeds. Worldwide, this is the principal method of application in Article 5 countries and the predominant method used for fumigating soil in greenhouses (glass and plastic covered). In many Article 5 countries, this method is also widely used for outdoor fumigation. When applied manually, MB is often supplied as a mixture containing 2%Pic, added as a warning agent in many instances to comply with national safety regulations.

4.2.2.1.5. Cold gas (cans)

The cold gas method is the easiest but can be the most inefficient of the methods discussed to apply MB. In this method, small steel cans of less than 1 kg capacity are placed beneath thick plastic sheets and then punctured -in the best case- with a specialised device to release the gas into soil. This must be done carefully so as not to damage the plastic barrier and increase risk to the user from MB. Can's use is registered only in few non-article 5 countries e.g. Japan and Article 5 countries e.g. Jordan, Lebanon, Egypt. as their use is considered to be dangerous. Cans continue to be permitted arguing they provide small land holders with an easy application method and the ability to apply targeted amounts of MB to small areas where injection machinery may be difficult to use.

4.2.2.1.6. Drip irrigation

Fumigants can also be applied through drip irrigation lines. This method is used for MB application in greenhouses in some countries. However, the widest use of drip application is for MB chemical alternatives. In some countries, such as the US, drip application has become an important method for using 1.3-D/Pic mixtures and emulsifiable formulations of Pic and 1,3-D followed sequentially by metham sodium.. The main advantages of applying fumigants via drip irrigation are improved distribution of the fumigants in soil, the ability to reduce dosages and better control of emissions, especially in combination with barrier films (Ajwa *et al*., 2001,2009).

4.2.3 Combination of chemicals

A combination of fumigants can extend the spectrum of controlled pests with a performance that matches, or even surpasses that of MB. A well-known commercial product consists of a mixture of Pic with 1,3-D. This product (under the brand names of Telopic™, Telodrip™, Inline™) is widely used to control soil nematodes and fungal diseases (Ajwa *et al* 2003, Gamliel *et al* 2005, Minuto *et al* 2006.)

Combinations of fumigants can help to decrease the susceptibility of each fumigant to accelerated degradation in soils in which this phenomenon has been shown to occur. For example, in soil in which accelerated degradation and loss of activity of metham sodium was observed, the use of a formalin-metham sodium mixture resulted in effective control of Verticillium wilt and other diseases (Triky-Dotan *et al* 2009). However, application of combinations of fumigants may also have negative attributes and present challenges. Combination of metham sodium and certain halogenated fumigants (i.e. 1,3-D,Pic), for instance, can lead to rapid loss of the latter and thus, reduce effectiveness (Zheng *et al* 2004). Such combinations should therefore be applied sequentially to avoid problems. Further research is needed to explore additional effective fumigant combinations.

Mixtures of fumigants or sequential applications of these chemicals integrated with or without other non chemical IPM techniques can provide pest control and yield increases which are equivalent to those obtained with MB. A recent statistical analysis of more than 160 studies in strawberry fruit and tomato crops has shown that, even across a wide variety of countries, climates, soil conditions and different pest pressures, there are still a number of chemical combinations that have been consistently proven to be as effective as MB and therefore should be considered for the remaining uses of MB (Porter *et al* 2006).

4.2.3.1. 1,3-D and Pic

1,3-D/Pic is a key alternative to MB, which has been widely accepted commercially for the control of soil nematodes and fungal diseases. A large number of studies and a recent review of over 160 trials undertaken internationally have shown that these formulations consistently gave yields equivalent to MB (Ajwa *et al.* 2002, 2004,;, Minuto *et al.* 2006, Porter *et al.* 2006). Formulations of 1,3-D mixed with Pic are registered in many Article 5 and non Article 5 countries. Nevertheless, decisions taken by EU in 2010 regarding 1,3- D and soon expected for Pic may significantly change the availability of these chemicals.. In 2006, the majority of the industries in Australia and Spain had switched to these formulations as the key alternative to MB (Porter *et al* 2006a). Application costs are similar or less than those compared to MB.

Where registered, the TC-35 formulation is the main fumigant combination presently replacing MB. However, regulatory requirements limit the utility of this combination in some geographic regions. Present regulations on 1,3-D relating to regional quotas (e.g. township caps), buffer zones, restrictions in zones with Karst topography and personal protective equipment are regularly under review in USA and this has partly restricted its uptake as an alternative for MB in California and Florida. Also, application to heavy soils in cold climates (<10°C) has shown phytotoxicity issues of this combination in strawberry runner crops.

4.2.3.2. 1,3-D and MITC

Combinations of 1,3-D and MITC are used in Europe, Canada and other countries (Thomson, 1992). Their future availability in EU countries is uncertain. Combination of 1,3-D and metham (also known as metham sodium or methyl isothiocyanate generator) were shown to increase weed and pest control (Ajwa *et al,* 2003), Ajwa *et al.* (2005) have demonstrated that sequential application of metham sodium after reduced rates of 1,3-D/Pic EC or Pic controlled soil pests and produced strawberry yields equivalent to standard MB/Pic fumigation, without negative effects (Ajwa *et al.* 2004a,b). 1,3-D and metham sodium application have shown some limitations due to longer plant back periods, enhanced degradation in some sandy soils and compatibility issues with some fumigants.

Repeated use of this combination over a number of seasons led to a reduced disinfestation effect.

4.2.3.3. MITC, 1,3-D and Pic

The combination of the three fumigants has gained interest in the last five years. This combination is highly effective against nematodes, fungi, weeds and soil insects (Thomson 1992), but it can be phytotoxic and has long plant back periods (Porter *et al.* 1999; 2002). The product was withdrawn from registration in the USA in 1992, but is still registered in Canada and has outperformed MB for control of pathogens in trials on strawberries in Australia (Mattner *et al.,* 2001). There has been renewed interest of this combination as an alternative to MB where it still has registration (e.g. Canada, Mexico). This combination enhanced fungal, nematode and weed control over the use of 1,3-D/Pic alone (Ajwa *et al* 2006, Porter *et al.* 2006b, Candole *et al* 2007).

4.2.3.4. Formalin and metham sodium

A mixture of formalin and metham can extends the spectrum of pathogen control and can result in a synergistic effect particularly on fungal pathogens. The toxic effect of the mixture was seen at greater depths in soil compared with the application of each chemical alone. The formalin-MS mixture controlled *Fusarium oxysporum* f.sp. *radicis-lycopersici, Monosporoascus cannonballus*, and *Rhizoctonia solani*, pathogens often difficult to control by many chemical treatments. The synergistic effect was also evident when reduced dosages were applied (Di-Primo *et al.* 2003; Gamliel *et al.,* 2005). The importance of Formalin-MS mixture is significant in soils where the phenomenon of accelerated degradation of MS occurs. For example, this combination resulted in effective control of Verticillium wilt and other diseases in soil where accelerated degradation and loss of activity of MS was observed (Di-Primo *et al.,* 2003; Gamliel *et al.* 2005; Tricky-Dotan *et al.* 2006). As Formalin and MS react strongly when they are mixed together (Zheng *et al.* 2004) application of these two fumigants must be done from separated containers (Gamliel *et al.* 2005).

4.2.4 Registration issues

The development of new application methods and several new fumigants as discussed above has led to registration of alternatives or new methods for existing alternatives in many non-Article 5 countries where methyl bromide is still being used. For example in Canada, a Pic product, Pic-100, has been registered by the Pest Management Regulatory Agency (PMRA) for use by a strawberry nursery grower. However, the product has not received clearance by the Prince Edward Island authorities where the nursery is located due to groundwater contamination concerns. In Israel, initial procedures are under way for chloropicrin in cucurbits.

Methyl iodide (MI), a major chemical alternative to MB, is now registered in all but two states (Washington and New York) in the United States, including the southeast region, Florida and California for field-grown ornamentals, peppers, strawberries , tomatoes, stone fruits, nut crops, vine crops (including table and wine grapes), turf, conifer trees and nursery crops. Requirements for large buffer zones will limit the areas where MI can be adopted in California. Trials with MI continue being conducted in many Article and non Article 5 countries. The registration process is going in countries applying for CUEs, including Australia, Israel and Japan. To ensure that the mitigation measures for MI will be consistent with the measures being required for the other fumigants, the label requirements are presently being reexamined in the USA. 1,3-D, may be subject to similar provisions when the soil fumigants are evaluated together again in 2013.

The EU has further reported that registration for 1,3-D and other alternatives including Pic, dazomet and MS are under review. A grace period for the registration of 1,3-D became due on 20 March 2009 and was extended, but in 2010, 1,3-D has been definitively out of annex I of the 91/414/CEE regulation, Its future re-registration is still uncertain. As of 18 March 2010, MB is no longer registered or authorized in the EU for all uses, including QPS.

A number of other chemicals, which are possible alternatives to MB, are being considered for impending registration in specific countries recently. They include dimethyl disulphide (DMDS) in Europe and the USA and MI/Pic in Australia respectively.

1,3-D/Pic has restricted availability in Israel. It is registered for potato, tomato eggplant, pepper, strawberry and some cucurbits (watermelon and melon), while dazomet is only registered for melon, watermelon and tomato. Methyl iodide is currently under registration experiments.

4.3 Non Chemical alternatives

4.3.1. Resistant cultivars

The use of resistant cultivars to control soilborne pathogens (fungi, bacteria, viruses, nematodes and parasitic higher plants) is considered as the best alternative to MB. However, development of resistant varieties, if genes are available, requires substantial research (Danailov 2009; Quesada-Ocampo and Hausbeck 2010; Takken and Rep 2010; Tanyolaç and Akkale 2010) and may take 5 to 15 years depending on crop species and genetic resources. There are however, continuing efforts to develop new resistant vegetables (Stamova 2006,2008, Danailov 2009, Mimura *et al.* 2009, Quesada-Ocampo and Hausbeck 2010, Tanyolaç and Akkale 2010), fruit trees (Liu 2007; Ye *et al*., 2009) and ornamentals varieties (Norman *et al*., 2009). The major limitations to using resistant varieties as an alternative to MB to control diseases include the appearance of new races that overcome resistance genes, the presence of high population levels of pathogens that can override resistance, and environmental conditions, which may limit the level of resistance (Besri *et al*., 1984; Besri 1993; Cap *et al*., 1993; Stamova. 2008; Devran and Sogut, 2010; Takken and Rep 2010; Tanyolaç and Akkale 2010).

Cultivars with resistance to diseases such as Fusarium and Verticillium wilts, Fusarium crown rot, Phytophthora crown rot (Morra and Bilotto 2006; Stamova 2006; Crino *et al*., 2007; Quesada-Ocampo and Hausbeck 2010; Takken and Rep 2010), root-knot nematodes (Dickson 2007; Thies *et al*., 2008; Wu *et al*., 2009; Devran and Sogut 2010), bacteria (Stamova 2008; Wimer *et al*., 2009) and viruses (Sasaki *et al.,* 2006) have been developed or are in development. There is also a major effort to breed plants with resistance to *Orobanche* spp. (Dor *et al*. 2009) , a target for MB use in Israel and under quarantine in other countries (eg Australia).

4.3.2. Grafting

4.3.2.1. General overview

Grafting has been used with great success to control a wide spectrum of vegetable diseases such as *Fusarium*, *Verticilium* and bacterial wilts, *Phytopthora* spp., gummy stem and southern blights, black root rot, corky root, vine decline, root-knot nematodes and some viruses (CMV, ZYMV, PRSV, WMV-II,TYLCV) (Bausher *et al*., 2007; Crino *et al*., 2007; Paroussi *et al*., 2007; King *et al*., 2008; Louws, 2009). In addition to reductions in disease severity, grafting also provides yield increases, improved fruit quality, growth promotion, extended production periods and crop longevity, more efficient fertilizer use, reductions in the number of plants required per hectare, tolerances to soil salinity, low temperature and flooding (Bausher *et al*., 2008; Chen and Wang, 2008; Davis *et al*., 2008; Hamdi *et al*., 2009; Maršić and Jakše 2010).

Grafting is most widely used in greenhouse production systems, in soil or substrates (Sakata *et al.* 2007; Davis *et al.* 2008; Maršić and Jakše 2010), as an effective alternative to MB. In the USA, grafting is still mostly limited to greenhouses and organic producers, but many research projects are underway to establish the technology on a wider scale, particularly in the open fields (Bausher 2008, 2009; Kubota *et al*., 2008b; Rivard *et al.* 2008, 2009; Freeman *et al.* 2009; Louws 2009). In 2008, over 40 million grafted tomato seedlings were used annually in US greenhouses and several commercial trials have been conducted for promoting the use of grafted melon and tomato seedlings in open fields (Kubota 2008; Kubota *et al.*, 2008 a,b). However, many constraints that limit adoption of grafted seedlings in the USA still exist with the most important being availability of the very large number of seedlings required for large-scale open-field production systems. To overcome this problem, high-speed vegetable semi- or fully-automated grafting machines (grafting robots) were introduced in the country (Kobayashi 2008; Kokalis-Burelle *et al*., 2008; Yang *et al*., 2009). The best performance seen with grafted plants has been obtained when they are used as a component of an IPM program combining non- chemical and chemical alternatives (Besri 2008; Davis *et al.*, 2008; Kokalis-Burelle *et al*., 2008; Lin *et al*., 2008; Rivard *et al.*, 2008). Many rootstocks are now available to improve plant production with solanaceous crops (tomato, eggplants, peppers) and cucurbits (melon, water melon, cucumber) under different stressed conditions, such as soil borne pathogens, low soil temperature, poor fertility, as well as soil salinity and flooding (Bausher, 2008; Hamdi *et al*,. 2009; Louws 2009; Palada and Wu 2009; Maršić and Jakše 2010).

In watermelon, recent findings demonstrated that control of *Monosporascus cannonballus* by grafting onto *Cucurbita* seems to be related primarily to the increased resistance of its root system to infection by the fungus and provided further evidence on the use of grafting as a disease management measure for this disease (Beltran *et al.*, 2008). In addition recently wild watermelon germplasm lines derived from *C. lanatus* var. *citroides* were identified that may be useful as resistant rootstocks for managing root-knot nematodes in watermelon (Thies *et al.*, 2010). On the contrary disappointing results were collected in China were grafted cucumber were found to be infected by *Fusarium solani* (Li *et al.* 2010).

If the planted area devoted to grafting increases in the future, it is likely that there will be a shift in the soil microbial ecology that could lead to development of new diseases or changes in the pathogen population of current diseases. This shift in pathogen populations may result in the re-emergence of previously controlled diseases. Although grafting was shown to control many common plant diseases, the ultimate success will likely depend on how well changes in pathogen populations and other unexpected consequences are monitored (King *et al.*, 2008). Grafting does not always increase yield particularly if selection of the root stock is not correctly made (Ricardez *et al.*, 2008).

4.3.2.2. Grafting combined with other alternatives

Resistance of rootstocks to pathogens can break down with high pathogen population pressure, new pathogens and under some environmental conditions e.g. high temperature, salinity (Besri 2007, 2008a,b, 2009; Minuto *et al.* 2005). Some pathogens, such as *Colletotrichum coccodes* can affect resistant rootstocks, particularly when soil fumigants are not used in combination with this technology . Minuto *et al*., 2005; Garibaldi *et al.* 2008 reported that in the presence of medium to high disease incidence, the best results were obtained by combining the use of a resistant tomato rootstock with soil fumigation with DMDS, metham sodium. Pic. Eggplant cultivars grafted on rootstocks resistant to root-knot nematodes (*Meloidogyne* spp.) are increasingly grown in Sicily (Southern Italy) to reduce nematode infection. Verticillium wilt disease was observed on grafted eggplants (scion cv Black Bell on *S. torvum*) indicating that grafting needs to be associated with alternative control methods (Garibaldi *et al*., 2005).

In commercial sweet pepper greenhouses in Southeast Spain, the use of rootstocks resistant to *P. capsici* and *M. incognita* in soils treated with MB alternatives has resulted in the selection of virulent populations of *M. incognita*, but not to *P. capsici.* Therefore, the use of resistant rootstocks in soils is combined with 1,3-D/Pic, metham sodium or biofumigation (fresh sheep manure plus chicken manure) plus solarization (Ros *et al.*, 2005).

In Greece, combining grafting with soil sterilization with calcium cyanamide effectively controls *Verticillium* wilt and significantly increased plant growth and yield of eggplant (Bletsos 2006). To control root knot nematodes in Turkey, Yilmaz *et al.* (2008) used grafted eggplants and soil solarization combined with 1,3-D. In Italy Morra *et al*. (2007) found no differences in plant productivity when they used grafted pepper combined or not with MB or 1,3-D/Pic. In Guatemala, grafted melon and grafted melon in combination with MS, 1,3-D, and MB produced similar yields (Diaz-Perez *et al*., 2009). Burelle *et al*. (2008) in the USA also reported that there were no differences in tomato and melon rootstocks galling in soil treated with MB, MI, or DMDS.

Combination of grafting with non-chemical alternatives is now being used in many countries. Growth and yield of grafted cucumber were significantly higher in grafted plants grown in perlite than in expanded clay pellets (Marsic and Jakse, 2010). Biofumigation with broccoli and grafting efficiently controlled *M. incognita* and produced significantly higher yields in organic tomato production in Turkey (Kaskavaci *et al*. 2009). Combining effects of soil solarization and cucumber grafting increases plant height and yield (Ulukapi and Onus 2007,Yilmaz *et al*., 2009).

4.3.3. Substrates

4.3.3.1 General overview

Substrates are widely employed for growing healthy and high-quality plants, particularly in protected agriculture and offer an excellent means to avoid the use of methyl bromide. Generally, substrates are free of pathogens or can be readily and cheaply decontaminated (Koohakan *et al*., 2004). Substrates used include inorganic materials, such as rock wool, solid foams (e.g. polyurethane), glass wool, vermiculite, perlite, zeolite, volcanic gravel (lapilli), tuff, clay granules, sand etc, and organic materials such as peat, pine bark, coconut plant waste, almond shell, and diverse other materials (Urrestarazu *et al*., 2005; Pizano, 2006; Rubio *et al*., 2010), and each with its own specific physicochemical properties that fulfill plant cultural requirements (Kilinc *et al*., 2007; Gül *et al*., 2007; Ao *et al*., 2008).

Adoption of crops grown in substrates showed the greatest increase in protected, intensive agriculture (e.g. cut flowers, nursery plants, vegetables) both in Article 5 and non-Article 5 countries. In China for example, soilless culture increased from 1 ha in 1985 to 3,150 ha in 2000 (Jiang *et al.,* 2000). Soilless culture is used in production of tomatoes, peppers, strawberries, cut flowers, melons, cucurbits, nursery-grown vegetable transplants, strawberry plants and tobacco seedlings (Kazaz and Yilmaz, 2009). Although initial investment is generally high, increased productivity and yield due to higher planting densities and often better quality of produce, offsets any extra costs (Caballero and De Miguel 2002; Savas and Passam, 2002; Kwin 2003). An economic study comparing soil cultivation with substrate systems in Greece concluded that substrates could substantially improve farmers' incomes (Grafiadellis *et al*., 2000). Similar conclusions were reported in other countries (Engindeniz, 2004). When the Netherlands phased out MB in the early 1980s, growers initially adopted simple and cheap substrate systems (e.g. bucket containers) but now have switched to much more sophisticated production methods that still employ substrates (Lieten, 2004). A number of countries have now developed substrate systems that are cost effective because they employ materials that are locally available e.g. vegetable production in Kenya, Hungary and New Zealand, and in strawberry production in parts of France (Hunt 2000, Budai, 2002, Lieten, 2004, Mutitu et al. 2006ab).

The float bed is a simple hydroponic system that was developed by the tobacco industry for transplant production. It involves germination of seed in substrates such as vermiculite or peat mix in polystyrene plug-trays floating on a shallow bed of nutrient solution. Modifications of this technique have been adapted for the production of various types of vegetable seedlings. Float systems, based on substrates and hydroponics, have replaced the majority of the MB for tobacco seedling production worldwide (Wite *et al*., 2009). The number of nurseries using substrates for seedling production has increased significantly in many countries, particularly forest nurseries. The adoption of this technique is currently expanded into vegetable production (tomato, cucumber, pepper, and eggplant), strawberry and ornamentals crops (Minuto *et al*., 2009).

Constraints on soilless culture may include lack of identification of suitable local substrates, potential ground water pollution from systems that do not recycle the nutrient solutions and the vulnerability of the system to pathogen attack. These constraints can normally be addressed by training and good management practices. The use of substrates has less potential to replace MB for large-scale open field operations because of limited availability of suitable local materials.

4.3.3.2 Substrates and biological agents

The incorporation of beneficial fungi and bacteria into the substrates has improved the use of soilless culture as an alternative to MB (Canovas-Martinez, 1997; Singh *et al*., 2007). The development of disease suppressive substrates (no disease even when pathogens are present) has been shown to result from the presence of both biotic and abiotic factors and a diverse and complex set of mechanisms is involved. Some substrates have natural suppressiveness to plant pathogens (Clematis *et al*., 2009). Different biological agents can be used to control soilborne plant pathogens and a wide number of biological commercial products are now available (Singh *et al*., 2007).

Substrate mixed with the fungus *Muscodor albus* was found to eradicate a wide range of microorganisms due to the production of volatile compounds (Strobel *et al*., 2001). Biological control with these volatile-producing fungi has been considered to be an interesting alternative method to control root diseases in greenhouse and nursery situations, resulting in a possible biological fumigation of the soil with the antimicrobial volatile compounds (Mercier and Manker, 2005).

4.3.4. Heat treatment

4.3.4.1. Steam

Soil disinfestation by steam is an ecological technique used in intensive agriculture, especially in greenhouse industry with vegetables and ornamental crops to reduce soil borne pathogens (fungi, bacteria, nematodes) and weed seeds (Gelsomino *et al*., 2010). It is widely used in developed and developing countries (MBTOC, 2007). The most common and simple steam application technique is sheet steaming, which involves covering the soil with a thermo-resistant sheet sealed at the edges, then pumping the steam under the sheet (Van Loenen *et al*., 2003). The usual recommended treatment is to maintain a temperature of 70ºC for at least half an hour to control plant diseases and weeds (Runia 2000), although some treatments may be applied at 60-80ºC for about one hour. The high temperatures achieved can eradicate pathogens (Sosnowski *et al*., 2009), but could also lead to injurious effects on key components of the soil ecosystem (Minuto *et al*., 2005, Lu *et al*., 2009, Roux-Michollet *et al*., 2008, 2010).

Use of steam pasteurisation has continued to increase as an alternative to MB in intensive, protected, high-value cropping systems such as flowers and vegetables. This is largely due to new and more efficient equipment and techniques being available, such as negative pressure steaming, hood steaming (for seed beds) and improved, more flexible equipment for sheet steaming (Runia 2000; O'Neill and Green 2009). Negative pressure steaming allows treatment at much deeper soil depths than sheet steaming and uses almost half the fuel of sheet methods (Runia 2000). Different fuel options for operating the boilers, for example gas in Argentina and Bolivia, and wood in Brazil (Barel 2005, UNIDO 2005;) are helping growers reduce costs, and making the treatment more viable as an alternative to MB. Improvements in terms of machinery were achieved by the introduction of metal hoods. Steam is applied to the soil surface beneath the hoods and forced into the soil. This technique is suitable both in greenhouse and in field application, thus a number of self-propelled machines and greenhouse equipment have been developed.

Steaming is also comparable to MB for sterilizing plugs or seedling trays (Wite *et al*., 2010). Steam has replaced the use of MB for sterilization of substrates in a number of areas. For example, Chile adopted steam as a MB alternative for substrates in the tree nursery sector.Bolivia has adopted small steam boilers for sterilizing substrates (new and re-used) for seed potato, vegetables and ornamentals, as part of a UNDP MB phase-out project (Barel 2005).

As steaming is generally more expensive than treatment with MB, it is normally used for high value crops (Fennimore and Goodhue, 2009) .Treatment time is slower than MB fumigation, but the replant time is negligible, providing a faster treatment overall than MB fumigation in smaller areas like greenhouses and tunnels. Traditional steaming methods require high amounts of water, power, and fuel (Crump 2001). The newer improved steam application methods utilize less water and fuel (Runia 2000; Barel 2004). Water and fuel can also be reduced by using steam as a component of an IPM program (Dabbene *et al.*, 2003, Bennett *et al.,* 2005 Gay *et al.*, 2006).

A self-propelled soil-steaming machine has been designed and tested for the release of steam after incorporation in the soil of compounds such as potassium hydroxide (KOH) and calcium oxide (CaO) that result in an exothermic reaction (Gelsomino *et al.*, 2010). This machine can be equipped with rubber tracks to reduce soil compaction and is also able to operate in a reduced space (Peruzzi *et al.*, 2005; Bàrberi *et al.* (2009).

4.3.4.2. Steaming and other alternatives

Since the most important limitation of steam application is related to the "boomerang effect" caused by the biological vacuum, the combination with subsequent application of antagonist microorganisms selected for their colonization ability is recommended. Steam combined with *Coniothyrium minitans* considerably reduced sclerotia numbers of *S. sclerotiorum* in the soil (Bennett *et al.,* 2005). Gilbert *et al.* (2008) combined solarization and steam for field-grown cut flowers and strawberry.

4.3.4.3 Hot water

Hot water treatment is widely used in Japan to control soilborne pathogens (Uematsu *et al.*, 2003). Hot water is applied for the cultivation of tomato, melon, strawberry, spinach, sweet pea and carnation (Kita *et al.,* 2003; 2007, 2010, Nishi 2000, 2002). The quantity of hot water applied depends on the depth of root penetration expected for the crop to be planted. Hot water treatments improve soil properties (Kita *et al.*, 2007). The use of a boiler and fuel can be costly but in Japan the yield increases and the revenues generated invariably benefit the growers.

4.3.4.4 Solarization

Soil solarization is a non-chemical approach to soil disinfestation which makes use of solar heating. Pathogen control is accomplished by covering the soil surface with a clear plastic film to trap solar radiation and accumulate heat. Soil temperatures can be raised to levels that are lethal to many, but not all plant pathogens. Under suitable climatic conditions, solarization can effectively control a wide range of soilborne pests, including fungi, bacteria, weeds, nematodes and insects. Solarization is usually conducted for 30 days or more, in order to achieve pathogen control down to a depth of 40 cm or more. Temperatures in field soils during solarization are relatively low compared with artificial heating methods such as steaming, although in containerized systems, soil temperature can reach 70^{o}C. Thus, the effect of soil solarization on living and non-living soil components is likely to be less drastic. Indeed, negative side effects observed in several cases with soil steaming and fumigation, e.g. phytotoxicity and pathogen reinfestation due to the creation of a biological vacuum, have been rarely reported with solarization. A very important feature of soil solarization is the induced suppressiveness phenomenon that frequently occurs in solarized soils, in which pathogen reestablishment is suppressed after treatment (Gamliel and Katan 1993). The effectiveness of soil solarization in controlling many diseases in a variety of annual crops has been shown under a variety of conditions, soils and agricultural systems in many countries. These solarization studies are reviewed and discussed in Katan (1981), Katan and DeVay (1991), Stapleton (2000) and Gamliel and Katan (2009).

The mode of action of solarization is complex, involving direct thermal inactivation of pathogen propagules, shifts in microbial populations and activities that favor antagonists, and changes in soil physical and chemical properties (DeVay and Katan 1991). As with any control method, solarization has both advantages (e.g. being a non-chemical strategy) and limitations (e.g. occupation of the soil for 4 to 6 weeks and a dependence on climate). Moreover, solarization does not control all pathogens. Improved control by solarization might enable its use under a wider range of conditions, and might even shorten the solarization period necessary for pathogen and pest control. Since solarization is a passive, weather-dependent process, integration with other physical, chemical, and biological control methods is desirable to maximize the efficacy and predictability of pathogen control. Control of certain soil pathogens in solarized soil was improved by combining this method with reduced dosages of fumigants .This was especially evident in the control of soilborne diseases not controlled by solarization alone. Solarization also improved the performance of fungicides such as carbendazim and others when applied to soil (Gamliel and Katan 2009).

4.3.4.5. Solarization and other alternatives

Several benefits are expected from combining solarization with other alternatives such as other pesticides: activity of the heated pesticide and propagule sensitivity to that pesticide are increased; the spectrum of controlled pests can be expanded and the improved pest control may consequently lead to reduced pesticide dosages and treatment cost. When solarization is combined with fumigants, the fumigant is captured under a plastic tarp, resulting in longer exposure; the use of solarization combined with effective chemicals can increase the former's effectiveness in pest control under certain limiting conditions. Furthermore, such a combination can shorten the required duration of solarization. The sequence and timing of application are crucial when a combination of treatments is being used . Eshel *et al* (2000) showed that control efficacy of a reduced dose of MB or MS is strongly increased when applied after a short solarization period of 8 days, i.e., after mulching. Thus it was recommended to apply solarization for a short period and then introduce the desired fumigant (or biocontrol agent) via the drip-irrigation system or other means. Chellemi and Mirusso (2006) extended this concept by applying soil solarization for a short period of 7 days followed by injection of a mixture of 1,3-D plus Pic under the plastic with a special injection rig. Survival of *F. oxysporum* f. sp. *lycopersici* in soil declined significantly with this combination. Significant reductions in populations of yellow nutsedge, purple nutsedge, and root-knot nematodes were achieved with a reduced dosage of fumigant when it was applied 7 days after the planting beds had been covered with plastic film. These results demonstrated that chemical and non-chemical soil-disinfestation methods can be combined using novel application technologies and procedures to improve their spectrum of controlled pests and reduce fumigant application rates.

The sequence of first applying solarization and then fumigant should be carefully considered. If too long a period elapses between soil tarping and fumigant injection, the plastic tarp may be damaged and the fumigation efficacy reduced. In addition, an adverse effect can result from applying fumigant at the end of solarization, especially when full rates of the fumigant are used, since some of the beneficial microorganisms remaining in the solarized plot may be adversely affected (Gamliel *et al*. 1997). Hence, such combinations should be avoided. The reason why a sequence of soil solarization and then fumigant application results in better pathogen control than the opposite sequence has not been studied. It can be hypothesized that this phenomenon is connected with an enhanced weakening effect when the propagules are first heated.

The combined solarization-fumigant treatment can be applied with commonly available machinery and technologies. Originally this was carried out by applying the fumigants to the soil and immediately covering it with transparent polyethylene. However, the discovered optimal sequence for application, i.e. first solarization followed by fumigant application, also required adjustment of the application procedure. Application on row crops and raised beds using drip irrigation is common and simple. In this method, the soil is lined with the drip-irrigation system followed by tarping with plastic mulch and performing the solarization. The fumigant is applied through drip irrigation at the indicated time. The drip system should be designed and set up for fumigant application with regard to the material used, and the spacing of the drip emitters within and between the drip lines. When drip lines are used for application, additional equipment for fumigant injection is not needed. A challenging technology is to inject the fumigant under a plastic tarp, which has already been laid over the soil in order to retain the optimal sequence of application. This type of application is required in a wide-scale open field or in agricultural practices where application through drip irrigation is not available or registered. This challenging application method was successfully accomplished by Chellemi and Mirusso (2004), who designed a machine for injecting soil fumigants underneath raised planting beds covered by plastic mulch without disturbing the integrity of the beds or tearing the plastic tarp. Using an impermeable plastic mulch, they were able to achieve uniform concentrations of a fumigant mixture of 1,3-D and Pic across the beds. Successful fumigant application and effective control of soilborne pests were obtained when solarization was combined with fumigants. The machine also eliminates the concern of worker exposure to fumigants by separating land-preparation activities from the fumigant-application process. The machine was tested in Israel with similar results for the control of onion diseases with a combination of solarization and MS (A. Gamliel, unpublished data).

4.3.5. Organic amendments

Specific organic amendments can create changes in the microbial, chemical and physical factors of soil so they become suppressive to disease. Whilst these by themselves are unlikelt to replace MB, as part of a soil system they can give suppression of dieases.Goicoechea (2009), Bonanomi *et al.* (2010), Oka (2010), Abbasi *et al*., (2008) reported that an organic matter (OM) is pathogen-specific. An OM suppressive to one pathogen could be ineffective, or even conducive, to other pathogens.

New uses of byproducts derived from the production of bio-ethanol were detailed by Abbasi *et al.* (2009). They showed that condensed distiller's solubles can suppress *V. dahliae* populations and reduce microsclerotia germination.

4.3.6 Biofumigation (Biodisinfestation)

Biofumigation (biodisinfestation) at commercial level is widely used in many developing and developed countries to control soil borne pathogens (Fan *et al*., 2008, Mattner *et al*. 2008, Bensen *et al*. 2009, Njoroge *et al*. 2009, Zurera *et al*. 2009,). There are several patents for commercial manufacturing of biofumigants for pest control using *Brassica* seed products. Bello *et al*. (2007) reviewed how Spain, switched to biofumigation and biosolarization as the main non-chemical alternative, followed by soilless cultivation, crop rotation, resistant varieties and grafting. These alternatives are more effective when combined in Integrated Crop Management (ICM) systems.

4.3.6.1. Biofumigation and solarization:

The combination of biofumigation and soil solarisation (biosolarisation) has generally been found to be synergistic in improving the efficacy of both procedures and thereby reducing the time required for solarization and the rates of amendment needed for biofumigation (Chellemi 2006, Ndiaye *et al*., 2007, Iapichino *et al*. 2008,, Medina *et al*. 2009, Porras *et al*., 2009,) .

4.3.6.2. Reducing redox potential

In Japan This new technology is known as "soil reduction redox potential" " reductive soil disinfestation (RSD)", "biological soil disinfestations (BSD)", "or anaerobic soil disinfestations (ASD)". Rice or wheat bran are mixed into the soil, followed by flooding the soil and covering it with plastic sheets for at least three weeks to allow the microorganisms to degrade the organic materials. During this period, the oxygen becomes depleted in the soil because of the multiplication of microorganisms, creating anaerobic and thereby reductive conditions (Katase *et al*., 2009). Soil temperatures also increases to 30– 40^{o} C due to heat of solarization and bran fermentation. Volatile organic acids such as acetic acid and n-butyric acid are generated to sufficient levels to kill nematodes and pathogens (Chiba Prefecture 2002, Shinmura 2004; Takeuchi 2004; Momma 2008;; Katase *et al*., 2009). This method is effective for the control of *Meloidogyne* spp.and *Pratylenchus* spp. as well as soilborne fungal pathogens such as *Pyrenochaeta* spp., *Fusarium* spp, *Phomopsisi* spp. (Kubo et al., 2004; Katase *et al*., 2005; Kubo and Katase 2007). The process is used in Japan for greenhouse cultivation of tomato, cucumber, watermelon, melon, strawberry, kidney beans, peas, and spinach (Kubo *et al*., 2007). Adding organic material such as molasses (Shinmura 2003) and low concentrations of ethanol (Uematsu *et al*., 2008) have also been tested instead of rice and wheat bran. Soil reduction technology has been also tested in the Netherlands (Lamers *et al*., 2009).

4.3.6.3. Biological control and biofertilizers

Biological control for soilborne diseases remains an important area of study. The most promising new area being investigated is the combination of amendments with biological control agents to improve the activity of both processes. Zhang *et al*. (2008) tested organic fertilizer application with and without added biocontrol agents (*B. subtilis* SQR-5 and *Paenibacillus polymyxa* SQR-21) for the control of wilt disease in cucumber caused by *F. oxysporum f. sp. cucumerinum* under field conditions. With the organic fertilizer wilt incidence was 30-51%, but in the presence of the biocontrol agents (termed bioorganic fertilizer, BOF) the incidence was reduced to 5-14%. The populations of Foc in BOF-treated soils were significantly decreased compared with control. Ling *et al*. (2009) and Wu *et al*. (2009) tested the same formulations for control of Fusarium wilt of watermelon caused by *F. oxysporum* f. sp. *niveum*. They found that the best control was attained with BOF added at the nursery with a second application to the soil at transplant time. Wilt incidence was 0% with these treatments whereas it was 100% in the control.The antagonistic bacteria were shown to produce several antifungal compounds identified to be fusaricidin A, B, C, and D (Raza *et al*., 2009). Ha *et al*., (2008) tested the efficacy of shrimp and crab shell powder as soil amendments (SCSP) and *B. subtilis* strain PMB-034 on control of Fusarium wilt of asparagus bean caused by *F. o*. f. sp. *tracheiphilum*. Soils treated with SCSP and *B. subtilis* had much lower incidence of Fusarium wilt and the plants showed improved growth and uptake of mineral nutrients. Compared to untreated control disease severity was reduced by about 50-60% and shoot dry weight increased by 39%-58%.

The antagonistic capacity of a combination of 2 compatible microorganisms, a bacterium (*Burkholderia cepacia*) and a fungus (*T. harzianum*), against *P. capsici*, the causal agent of rot in pepper, was examined by Ezziyyani *et al*. (2009). *B. cepacia* reduced fungal survival by antibiosis while *T. harzianum* showed greater competition for space and nutrients and a tendency to mycoparasitism and enzyme lysis. Biomass production of the antagonists was optimized in an oat-vermiculite medium, which proved to be efficient, cheap, and rapid. Treatment with *B. cepacia* + *T. harzianum* reduced *P. capsici* induced wilt incidence of pepper by up to 71%. One of the reasons for this success was that the 2 antagonists used were compatible and had a wide antifungal spectrum.

Compost in combination with compost extract and application of beneficial bacteria overcame some of the effects of apple replant disease (ARD) (Schoor *et al*., 2008). However the organics provided inconsistent results from ARD trials whereas MB fumigation provided the best growth.

4.4. Crop specific strategies

4.4.1 Strawberries

4.4.1.1. Strawberry fruit

4.4.1.1.1 Chemical alternatives

Formulations of 1,3-D/Pic, Pic alone and metham sodium combined with other fumigants have been adopted widely throughout industries applying ´Nominating for Critical Use´ (CUN's). Of the Parties previously applying for CUN's, most have completely implemented these alternatives. Australia and France phased out MB by 2006, France and the United Kingdom by 2006 and Italy, New Zealand and Spain by 2008 (EU 2008). Since 2009, USA and Israel are the only non- A5 countries continuing use MB for this crop.

Recent trials on strawberry fruit in Australia, Spain and the US confirm that MI/Pic and DMDS/Pic performed as well as MB/Pic (Porter *et al,* 2006, Santos *et al*, 2007, López-Aranda *et al*., 2007, Mann *et al* 2007, Noling 2008), and others. Dazomet + 1,3-D and Pic alone were also very effective (López-Aranda *et al*, 2008). In the USA, iodomethane has recently been registered in all of the strawberry production states. Fumigant trials indicate comparable results to MB, but the maximum registered rates in California (100 kg/ha; http://www.cdpr.ca.gov/docs/registration/MI_pdfs/MI_table_label.pdf) are below the rate tested in many trials. In Florida, MI use has expanded rapidly since its registration there in 2008. In late 2006, a review article on alternatives researched in southeast USA, concluded that the majority of available MB alternatives provide effective control against most soil-borne diseases and nematodes, as long as appropriate application methods and rates were used. In situations where *Cyperus* infestations are severe, alternative fumigants may be combined with herbicides to minimize weed interference (Santos and Gilreath, 2006). In California, weed management research showed that the herbicide, oxyfluorfen, can be applied safely to strawberry for control of common weed species in annual plasticulture strawberry production, thereby reducing time required for hand weeding (Daugovish *et al*., 2008). In Florida, field studies were conducted to compare the performance of several chemical alternatives on the control of sting nematode (*Belonolaimus* spp.) and marketable

yield of 'Camarosa' strawberry (Gilreath *et a*l., 2008). 1,3-D/Pic and dazomet, 1,3-D/Pic, Pic and MS, and fosthiazate/ Pic all proved equally effective as MB/Pic for strawberry plant vigor, sting nematode control, and early and total marketable yields.
In the EU, a range of chemical alternatives have been adopted to fully replace MB, including 1,3/D, MS, dazomet and Pic although their registration is under revision. In the EU, MB is no longer authorized at the national level (the grace period for MB expired on 18 March 2010). Requests for revision of registration of 1,3-D, Pic, dazomet and MS have been submitted.

In China, a new formulation of Pic, 1,3-D, 1,3-D/Pic, MI, and MI/Pic in capsules has been developed. Initial results showed that there was no significant different between Pic application by capsule compared to the standard injection method. (Cao *et al.*, 2008, Wang *et al,* 2009.).

4.4.1.1.2 Non-chemical alternatives

Strawberry production in substrates occurs mainly in greenhouses and in cool climates with short cropping cycles, targeting early season markets or niche markets. Soilless systems are widely adopted in Europe (used on about 400 ha in Belgium, on about 300 ha strawberries in 2004 in France and increasing, on 35 ha in Ireland, on 150 - 500 ha in Italy, on 130 ha in Spain in 2005, and used in Austria, Denmark, Finland, Germany, Greece, Hungary, Netherlands, Poland, Portugal and Sweden). Efforts to reduce initial set up costs for substrate systems are expected to increase their adoption as a MB alternative worldwide for this crop.

In Europe, several other non-chemical alternatives are applied in commercial strawberry fruit production, such as crop rotation (used widely in Denmark, Germany, Netherlands, Poland), steam (used for protected strawberry in Belgium, France and Germany), solarisation (used in Cyprus when nematodes are not present), mulches (against weeds, used in Estonia, Germany, Slovenia), biofumigation (small-scale use in the Netherlands and Slovenia).

In addition, growing *Tagetes patula* as a non-chemical alternative to MB is a success story in the Netherlands (and is now also applied in some locations in Germany and Poland). In this system, *Tagetes* is grown as a catch crop for root lesion nematodes (*Pratylenchus penetrans*) and a green manure. This crop eradicates root lesion nematodes effectively and reduces the incidence of the fungal pathogens *Verticillium* and *Rhizoctonia*. The rootknot nematode *Meloidogyne hapla* is reduced. Estimations are that at least 70% of the Dutch strawberry growers (both for runners and fruit) use this method (Runia, Molendijk and Evenhuis, 2007)

In California, the influence of crop rotation on soilborne diseases and yield of strawberry (*Fragaria x ananassa*) was determined at a site infested with *Verticillium dahliae* microsclerotia and at another with no known history of V. dahliae infestation during 1997 to 2000 (Subbarao *et al*., 2007). The effects of rotation on *V. dahliae* and Pythium populations, strawberry vigour, Verticillium wilt severity, and strawberry fruit yield were compared with a standard MB+Pic fumigated control treatment at both sites. *V. dahliae* microsclerotia were significantly reduced with broccoli and Brussels sprouts rotations compared with lettuce rotations at the *V. dahliae*-infested site. In the absence of fumigation, rotation with broccoli and Brussels sprouts is an effective cultural practice for managing Verticillium wilt in strawberry production; whereas, in fields with no detectable *V. dahliae*, broccoli is also a feasible rotational crop that enhances strawberry growth and yield. According to a cost-benefit analysis, the broccoli-strawberry rotation system could be an economically viable option provided growers are able to alternate years for strawberry cultivation.

In California also, adoption of organic strawberry production has expanded to over 700 ha in 2009 (California strawberry commission acreage survey, 2010).

4.4.1.2. Strawberry nurseries

MB is used for the production of strawberry runners to meet strict certification standards for virtually pest-free strawberry runner stock. Since a single strawberry runner grown in year one can expand to several million runners by year five, the adverse impacts of pests is of particular importance and mean an alternative should give the same level of risk as MB or better. For this reason only a few alternatives are suitable. MI/Pic mixtures, 1,3-D/Pic in some situations and substrate production of plug plants are the alternatives being adopted. In particular, MI/Pic is becoming accepted as a one to one replacement for this industry and trials continue to prove effective in Australia, China, Spain and the USA. However the high rates necessary to achieve certification for strawberry runners in California, the largest runner producer in the world, are not yet registered for use in the US (Mann *et al*., 2007; Cao, pers comm., 2008).

In other studies, a range of alternative fumigant combinations (MI/Pic, and 1,3-D/ Pic followed by dazomet, Pic followed by dazomet) controlled weeds at levels comparable to MB/Pic (Fennimore *et al*., 2008 ab).

In Japan, a simple, economically feasible system using trays filled with substrate is proving particularly useful for the production of strawberry runners. Various materials are used as substrates (e.g. rock wool, peat moss, rice hulls, coconuts husk and bark) and can be reused after sterilising with solar heat treatment or hot water (Nishi and Tateya, 2006b).

4.4.2 Orchard and vineyard replant

Replant disease remains a serious economic threat to certain orchards of perennial fruit trees and grapevines. The economic implications are exacerbated by the long production life of orchards and vineyards. Replant disease is poorly understood as it is often caused by an undefined pathogen complex that can be complicated by abiotic factors such as soil type and nutrition. An essential element in disease control is the killing or removal of deep-seated established roots from the previous crop. These roots can act as a reservoir and inoculum source of disease for the new trees/vines. Fumigation or other methods are thus not only needed against the pathogens, but also to kill the old roots. Producers are reluctant to adopt alternatives unless proven to be effective over a reasonable time span. In spite of this, the global request for MB for replant by non-A5 countries has declined from more than 800t in 2005 to less than 20t for 2012 as evidenced by the 2005 and 2010 CUNs. 1,3-D and Pic, both alone or with MS can also used (Caprile and McKenry, 2006; Browne *et al*., 2007; 2008; 2009, Beede *et al*., 2009, Wang *et al*., 2009). Preliminary results with site-specific fumigation using Pic alone (where nematodes are not present as part of the pathogen complex) or in combination with 1,3-D show this could be a solution (Upadhyaya *et al.,* 2008). Spot treatments administered through GPS-controlled shanks or through a spot drip application system are nearly as effective as strip or broadcast treatments for almond and stone fruit replant (Browne *et al*., 2008).

A number of non-fumigant alternatives to MB are in use in many countries and are under further investigation with the grace period ending in March 2010. These include agronomic practices such as rotation and nutrient depletion where possible (McKenry *et al.,* 2009), resistant rootstocks (McKenry, 2006), organic soil amendments (Mazzola *et al.,* 2009), and biofumigation (Nyczepir *et al.,* 2007). Partially replacing old soil with fresh soil has led to limited success in South Africa, (Van Schoor *et al.,* 2009). Steam is presently under investigation (Fenimore *et al.,* 2009) but found to be uneconomic in the Netherlands (EC Management Strategy, 2009).

The EU completed the phase-out of critical uses of MB by the end of 2008. The alternatives used by the EU Member States are targeted at the specific group of pathogens in replant situations and summarized as follows: For fungal pathogens; Pic, MS, Dazomet, MS + Pic (not mixed), Dazomet + MS (not mixed) and steam. For nematodes; 1,3-D, MS, Dazomet, Dazomet + MS (not mixed), steam and carbofuran. These alternatives combined with mulches and resistant varieties are used where the problem encompasses nematodes, fungi and weeds (EC Management Strategy, 2009).

The preferred treatment in the USA is based on 1,3-D used singly or with Pic where the required dosage rates are allowed under prevailing local regulations. It is successfully used in light sandy soils but the dosage needed for heavy soils exceeds the maximum of 370 kg/ha allowed under California regulations.

Research under the USDA Pacific Area-wide Pest Management Program continues to study the use of reduced fumigant rates and reduced fumigated areas, targeted fumigant methods (minimizing non-targeted emissions), non-chemical approaches and risk-based management.

4.4.3 Open-field woody crop nurseries

Propagation materials of many types (bulbs, cuttings, seedlings, young plants, sweetpotato slips, strawberry runners, and trees) are subject to high health standards. For many uses of MB, alternatives need to provide a level of pest and pathogen control sufficient to achieve an acceptable yield and quality. For propagative material, or nursery stock, a clean root system (or clean bulbs) is essential. This is critical to prevent the spread of economically important pests and pathogens from the nursery fields to the fruiting or production fields. Nursery crops can remain in the ground anywhere from 9 to 26 months before being transplanted to fruiting fields. The required level of pest and pathogen control for propagative material must remain effective over this entire growing cycle, as contrasted with annual fruits or vegetables produced over a much shorter time. Nursery stock used for planting into organic production systems often comes from MB treated nursery fields.

For certified nursery stock, regulations can either specify a level of control that must be achieved or use of approved soil treatments that are accepted as insuring a high level of control based on the review of available data by the regulatory body. For non-certified stock, the market sets the standard that must be met. In either case, lack of a clean root system could mean a 100% loss in marketable product for the grower. MB has commonly been used to meet clean propagative material standards. In some cases, sufficient data and grower experience have allowed growers to transition from the 98:2 formulations of MB that were commonly used to 67:33 or 50:50 formulations depending on the pest or pathogen to be controlled and level of severity of the infestation (De Cal *et al.,* 2004; Porter *et al.,* 2007). Research trials indicate some alternative fumigants (such asMI) and some combinations (such as 1,3-D +Pic) provide control comparable to MB under specific circumstances (Hanson *et.* al, 2010; Schneider *et. al*, 2008; Schneider *et. al*, 2009a; Schneider *et. al*, 2009b; Stoddard *et. al*, 2010;Walters *et. al*, 2009).

Nursery soil treatments require broadacre, or broadcast, application in order to insure adequate protection against colonization by pests and pathogens from adjacent untreated soil. Strip treatment does not insure this level of protection. The requirement for broadacre treatment has hindered adoption of LPBF (which might allow lower rates of MB and alternative fumigants) in some areas where gluing of LPBF for broadacre treatment has not been commercially available.

Soil texture, soil temperature, and soil moisture can affect performance of MB alternatives so as to render them either suitable or unsuitable for specific conditions. Equally important to efficacy is consistency of performance of MB alternatives. Inadequate performance risks a 100% loss. As materials, or combinations of materials, meet the requirement for efficacy and consistency (as established by research results over multiple years and locations), the body of data can be reviewed by regulatory entities for incorporation into the lists of approved certified nursery soil treatments. An example of this would be the approval by California Dept of Food and Agriculture of the use of 1,3-D as a certified nursery stock soil treatment for certain crops under specific conditions, as well as MI, although at rates much higher than the maximum rate registered for use in California (CDFA, 2009).

An alternate approach to the use of soil treatments is the use of containerized, or soil-less substrate, production systems where this is economically feasible and is able to produce a product, i.e, root system, of acceptable size and quality to the marketplace.

Production of high health propagative materials remains a significant challenge as Parties transition away from methyl bromide (Zasada *et al*, 2010). The consequences of failed treatment not only impact the propagative material, but also jeopardize the performance of MB alternatives in the fruiting fields.

EU member states phased out use of MB for nursery production between 1992 and 2007 (EC Management Strategy, 2009). Chemical alternatives in commercial use in the EU for control of combinations of fungi, nematodes, and weeds in nursery production systems include dazomet, MS, and 1,3-D. Non-chemical alternatives include substrates, grafting, resistance, steam, and rotations. DMDS is still under development.

Japan phased out use of MB for nurseries in 2005. Alternatives in commercial use include dazomet, Pic, 1,3-D, and MITC (pers. comm.Tateya, 2010).

MB is used in the USA where necessary to meet certified nursery regulations. Alternatives in commercial use in the U.S. for nurseries include both chemical (1,3-D, MS, Pic) and non-chemical (containerized production, substrates, resistant varieties, and steam) alternatives (US CUN). Additionally MI has been added by CDFA to list of certified nursery treatments, but the rate required by CDFA certification program is higher than currently allowed on either the US or California label.

In Article 5 countries, substrates are used for certified citrus and banana propagative materials in Brazil (pers. comm. Ghini, 2010). Grape, pear, apple, and citrus propagative materials are produced in Argentina without MB, but information was not available on what alternatives are in commercial use (pers. comm. Valeiro, 2010). In China, MB is used for production of certified nursery material. Pic and MI are being tested as alternatives (pers. comm. Cao, 2010).

4.4.4 Vegetables

4.4.4.1. Solanaceous crops

Substantial number of chemical alternatives is presently available for controlling soilborne pathogens, nematodes and weeds in Solanaceous crops. The most common are 1,3-D/Pic, Pic, metham sodium and metham potassium used alone and/or in combination with each other. These alternatives continue to prove as effective as MB (MBTOC 2007, TEAP 2007, Culpepper *et al*. 2008, Noling *et al*. 2009, Porter *et al*. 2010). The registration of MI for tomato, pepper and some other crops in USA (except New York and Washington) (Culpepper *et al*., 2008), Japan, New Zealand, and Turkey (Allan and Brilleman, 2010) have offered further alternatives to MB in these countries. However, some phytotoxicity problems concerning MI on ornamentals and vegetables under specific conditions still need further clarification (Rosskopf *et al*. 2009, Spadafora 2009). A new fumigant, dimethyl disulfide (DMDS), has proven to be effective against a wide range of phytopathogenic nematodes in a number of countries (Ajwa *et al*. 2010); however, it is less effective against fungi and weeds (Garcia-Mendez *et al*. 2009, Owens *et al*. 2009). A new development was reported in China for tomato production by formulating 1,3-D and Pic in gelatin capsules. This could be a promising technology for reducing environmental emissions and potential human exposure combined with good field efficacy (Wang *et al*. 2009ab).

Adoption of non-chemical alternatives such as substrates, grafting, resistant varieties, steam, solarization, biofumigation, biosolarization, biofumigation and biodisinfection has been increasing. These alternatives are used extensively as MB alternatives in *Solanaceous* crops in Mediterranean Countries and other areas of world (Besri 2004, Yilmaz *et al*. 2007, Bello *et al*. 2008, Fennimore *et al.* 2008, Louws 2009, Bello *et al.* 2010ab, Díez Rojo *et al.,* 2010). Soilless culture, often used with other alternatives such as resistant cultivars and grafting, is the main alternative to MB in tomato, pepper and eggplant production in Northern Europe (Besri 2004, Schnitzler 2007). Another key transitional strategy to reduce MB usage is the adoption of grafting. Grafting not only protects plants from soilborne pests but also increases the yield and quality of Solanaceous crops. As a MB alternative, soil solarization combined with chemical and non-chemical alternatives has been successfully used to control soilborne pathogens in Solanaceous crops in more than 50 countries having hot climates, long sunlight hours and high solar radiation values (Katan 1996, Besri 2004, Kaskavalci 2007, Candido *et al*. 2008**)**. Soil solarization and organic amendment treatments are effective to control *Meloidogyne incognita* in tomato production in Turkey (Kaskavalci, 2007). It has been demonstrated that consecutive two- and three-year solarization increased the tomato yield significantly and weed emergence was suppressed (Candido *et al*. 2008). Although weed densities in hot pepper production were significantly reduced, root knot nematode populations were suppressed in Costa Rica (Santos *et al*., 2008). Solarization combined with biofumigation resulted in significant tomato yields and decreased densities of certain pathogens and nematodes (Gomes *et al*. 2008, Iapichino *et al*. 2008). Anaerobic soil disinfestation applied by flooding, soil solarization and adding organic soil amendment was as effective as MB to control *P. capcisi* and plant parasitic nematodes (Butler *et al*. 2009).

Many resistant cultivars have been developed for soilborne diseases affecting tomato such as Fusarium wilt (races 1, 2, and 3), Verticillium wilt (race 1), Alternaria stem canker, *Phytophthora* spp., Fusarium crown rot, root-knot nematodes and some bacteria (Fery and Dukes 1996, Scott 2005, Sorribas *et al.*, 2005). In China, three tomato breeding lines were determined to have heat-stable resistance to southern root-knot nematode and are considered as good sources for breeding resistance in tomato (Wu *et al*. 2009).

Substantial reduction of MB use has been achieved in the Southern States of the USA in tomato, pepper and eggplant production. The Georgia 3-way fumigant system (1,3-D/Pic /MS) employed in these crops has provided an alternative for many of the difficult situations proven to be hard to control with other alternatives (Noling, 2009). Grafting is mainly used in greenhouses and small organic tomato farms but new research is in progress to help establish grafting in the USA (Kubota *et al.*, 2008, Rivard and Louws 2008). Treatment with organic mulch infested with saprophytic fungus *Trichoderma* sp. provided the highest levels of nutsedge suppression. Black and infra-red transmissible plastics and *Trichoderma* infested cogongrass treatment enhanced tomato fruit size and yields (Shabana *et al*. 2009). This work is still experimental.

Grafting, mostly employed to control Fusarium, Verticilium, bacterial wilts, corky root and root-knot nematodes, is now widely used in Europe, East Asia, North Africa and Central America (King *et al*. 2008). Grafting has been rapidly adopted in Turkey where MB use was completely phased out in 2007. Yields of grafted tomato and eggplants have significantly increased (Yilmaz *et al.* 2007) and use of grafted seedlings has reached up to 65.5 million in 2009 in Turkey (Yilmaz 2010, personnel communication.) In Morocco, grafting has become widely accepted and is used in100 % of the protected tomato producing area (Besri 2008b). In Japan, 60% of the regular tomatoes and 90% of the cherry tomatoes were produced by grafting in combination with alternative chemicals for nematode control (1,3-D, Pic, MS and fosthiazate) in the Kumamoto region (Nishi and Tateya 2006). Further progress was achieved in grafting technology in Japan by developing a grafting robot containing an automatic seedling feeder system, which reduces labor and increases efficiency and accuracy (Kobayashi 2008). In Italy, grafting alone provided acceptable yields and gross returns in pepper and was sufficient to prevent plant damages from *P. capsici* (Morra *et al.* 2007).

In Spain, biofumigation and biosolarization (biodisinfestation) are the main non-chemical alternatives that are increasingly used in pepper and tomato productions (Bello *et al.* 2008, 2010ab; Ros *et al*. 2008, Díez Rojo *et al.* 2010).). Biosolarization, currently used in 12% of the pepper production areas in Spain is effective in controlling *Phytophthora* when applied in the middle of September (Guerrero *et al*. 2008). An integration of soil solarization with organic amendments and seed treatment with *Trichoderma viride* as biological control agent was found to be the most effective approach for reducing pre- and post-emergence damping-off disease in tomato in India (Joshi *et al.* 2009).

4.4.4.2. Cucurbits

Rootstocks resistant or tolerant to soilborne pathogens (*Fusarium oxysporum, Monosporascus cannonballus, Didymella bryoniae, Phomopsis sclerotiodes* are available for most of the cucurbits (King, 2008). Production of grafted cucurbits continues to expand in Mediterranean countries (Atasayar, 2006, Jebari, 2008; Besri*,* 2007, 2008), and Mexico (Ricárdez- Salinas *et al.;* 2010). In Japan, China and Korea, most of the cucurbits grown are grafted (Davis *et al*., 2008). In Israel, cucurbits grafting is increasing (Cohen *et al.*, 2007).

In Spain, grafted cucumber showed a 100% resistance to *Fusarium oxysporum f. sp. radicis-cucumerinum* (Añaños Bedriñana, *et al*., 2009). In Italy, since 2006 sudden and heavy melon collapses have been observed and consistently correlated both to the scion/rootstock combination and the use of exogenous auxins basically adopted to increase the yield (Minuto *et al*., 2009). Grafting is used as a component of IPM programmes (Besri, 2008). International trade of grafted plants is increasing. (Kubota, 2008; Lee, 2008)

Cucurbit grafting is still rare in the United States (Davis *et al*.; 2008, King, 2008). Issues that currently limit the further promotion of grafted seedlings in the U.S. are: limited number of propagators and rootstock varieties, long distance transportation, high market price of seeds and grafted seedlings, and the relatively large amount of seedlings needed for open field production. (Kubota, 2008.) The perceived cost may be the major factor limiting grafting in the United States. However, the cost of grafting vegetables has decreased dramatically since the mid-1990s. While in the past the costs of grafted vegetables were ranging between US$1.80 and US$2.28 per plant, estimates now run about US$1.00 or less per plant, for example, for watermelon (King, 2008).

In many countries and particularly in the USA, chemical alternatives combined with herbicides, when additional weed control is necessary, are still very popular. Methyl iodide, a new fumigant, applied under metalized tarps has shown to be efficacious but it is not yet registered for cucurbits. In Georgia, fumigant combinations using 1,3-D, Pic and MS were as effective as MB for controlling *Meloidogyne incognita*, *Pythium irregulare*, *Rhizoctonia solani* and *Cyperus esculentus* in squash crops (Desaeger *et al.*, 2008). Managing weeds in cucurbit production is still challenging in open field crops in the U.S. Although halosulfuron is a key herbicide in curcurbit production, there is a controversy about its potential phytotoxic effects (Norsworthy and MIster, 2007; Trader *et al*. 2008, Kammler *et al.* 2010). However, some studies show that, even though this could be partially true, some windows could be found to use halosulfuron in a way and timing to control weeds while minimizing impacts on yields and quality of fruits. (Brandenberger *et al*., 2005; Norsworthy *et al*., 2007; Trader *et al*., 2007; 2008; Macrae *et al*., 2008; Kammler *et al.*, 2010; Shrefler *et al*., 2007; Rosskopf *et al*; 2009).

4.4.5. Ornamentals

Floriculture containing hundreds of flower types, different production cycles and cropping systems is a worldwide complex industry. Most of the ornamental crops are produced annually, but some are grown as perennial crops over several seasons (e.g. roses and some carnation crops). This complex structure of floriculture requires implementing different MB alternatives and integrating pest management programs in the production systems. Fortunately, some chemical and non-chemical alternatives are currently available for controlling soilborne pathogens, nematodes and weeds in ornamental crops. Major chemical alternatives used increasingly in ornamental production include dazomet, metham sodium, metham potassium,1,3-D, Pic, MI and DMDS (Reuven *et al.* 2005, Yilmaz *et al*. 2007, 2009, Klose *et al*. 2007ab, Klose *et al*. 2008, Rosskopf *et al.* (2008) , Gerik *et al*. 2009, Noling and Botts 2009, Rosskopf *et al*. 2009ab, Schneider *et al*. 2009, Yakabe and MacDonald, 2010).

Combination of chemicals or biocontrol agents with solarization further increased the effectiveness of alternative applications in ornamental crops (Rosskopf *et al*. 2007, Yilmaz *et al*. 2007, 2009, McSorley *et al.* 2009). In Turkey, solarization + 1,3-D for nematodes control and solarization + MS or dazomet for soil-borne diseases control was very effective in carnation and gerbera production (Yilmaz *et al.* 2007,2009). Combining steam application with formaldehyde successfully controlled *Fusarium* in column stock (*Matthiola incana*) grown in heavily infested soils in the UK (O'Neill *et al.,* 2005). In California, Gilbert *et al.* (2009) combined solarization and steam to develop a cost-effective soil disinfestation system for flowers and strawberry. In this study, steam with and without solarization controlled pests equal or better than MB+Pic.

Soilless culture systems have been one of the best and increasingly used MB alternatives for protected ornamentals in many countries (Savvas 2003, Pizano 2004, 2006, Amor *et al.* 2007, Kazaz, *et al.* 2009, Zazirska *et al.* 2009, Vallance *et al.* 2010). Substrates generally provide better yields and quality that result from higher planting density, optimum plant nutrition and better pest and disease control, and are able to offset the extra initial set up cost of these systems (Akkaya *et al.* 2004; Engindeniz 2004, Pizano 2004, 2005, 2006, Minuto *et al.* 2007). The flowers most commonly grown in substrates are roses, carnations and gerberas, but other flower types are also being produced with this cropping system (Nucifora, 2001, Savvas, 2003, Pizano, 2004, 2006, Kazaz *et al.*, 2007)

4.4.6. Ginger

The most serious disease in ginger production is a root rot caused by *Pythium*. Once ginger in the field is infected, it does not satisfactorily meet market value. A single infected plant in the field, very quickly spreads to other plants causing damage in the whole field. The USA had a CUE for ginger production in 2005, but completely phased use of MB for ginger production in the 2006 production year.

In Japan, several pesticides are registered and provide good efficacy for control of *Pythium.* Alternatives, including Pic, Pic + 1,3 D, MITC+1,3-D, dazomet, and MS have a much longer plant back time to avoid phytotoxicity, resulting in a shorter growing time with less yield. Additionally, many fields in Japan are located close to residential areas which make the use of Pic difficult. Despite these limitations, these alternatives are now in use with some yield loss due to insufficient supply of MB. In Japan, a large national project is underway to develop a manual describing ways to use these alternatives and to insure compliance with Japan's commitment to complete phase out of MB in 2013.

In addition, several alternatives are under registration review including MI and a mixture of azoxystrobin and metalaxyl M. Several chemical for seed rhizome treatments are evaluated for registration.

In China, ginger is grown either in open field, plastic tunnels or greenhouses. The main soil-borne pests are root-knot nematodes and bacterial wilt (*Ralstonia solanacearum).* Currently MB is used for soil fumigation treatment in March before transplanting or in late October just after harvest. Pic is the only alternative to MB at present in China. Dazomet and sulfuryl fluoride are not registered at present. However, Dazomet is now prepared for registration.

4.5. Conclusion

In the last decade, there has been a large increase in the knowledge and use of products and methods for soil disinfestation to control pathogens, insects and weed seeds. Tighter restrictions on MB and all fumigant alternatives has meant that industries once reliant on fumigation are seeking alternatives integrating pest management options which provide greater protection of the host because of greater resilience of the soil system. In the short term, however there are a number of fumigant alternatives that can replace MB for almost all uses. Except for few remaining situations (eg strawberry runners in Australia, Canada and strawberry fruit and nursery plants in the USA), there are enough fumigant alternatives to control pests in non A5 countries and their adoption is increasing in A5 countries. This has and will continue to decrease the amounts of MB used in A5 countries before phase out in 2015 (see chapter 9). In the longer term, Integrated Croping Management technologies need continual development to ensure sufficient protection for key soilborne pathogens and some weeds. One of the key remaining challenges to further MB reduction includes identification of alternatives, which provide clean propagative material with the same risk afforded by MB. This means studies are required which not only assess the relative level of disease on the crop but also the depth of control of the pathogen/pest problem in soil. This will ensure that the risk of use of the alternative can be objectively evaluated and appropriate regulations developed to support the development of clean propagation material.

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5

5. Structures and Commodities - Methyl Bromide uses and alternatives for pest control

5.1. Introduction

The world population has experienced steady growth with the expectation that it will reach 8 to 10 billion in a few years. Unfortunately, annual food losses of 50% or even more have on occasion been reported in some countries especially when storage is done by subsistence farmers. Effective pest management strategies must be made available to farmers to improve existing traditional storage methods or use new storage systems, otherwise poor pest control may lead to over reliance on chemical insecticides.

Moreover, expected climate change may impact pest infestation of food commodities and the structures involved in food processing and storage because of possible changes in the complex of pest species and the special distribution of pests present in the different continents. Climate change impacts are expected to require the adaptation of pest management methods to prevent the spread of new or emerging pest species.

Storage is an artificial ecosystem. To maintain pest control in this artificial environment it is necessary to take into account biotic (pests) and abiotic (temperature, humidity) components and operational practices (sanitation, inspection, sampling). In the absence of deliberate protection efforts organic materials naturally deteriorate and serve as food and shelter for various living organisms. Storage can slow or limit deterioration and contol pest losses.

5.1.1. Information Sources

An extensive search of published scientific and technical online journals was conducted by librarians at Agriculture Agri-Food Canada in London Ontario, specifically for MBTOC. Additionally, MBTOC members supplied information from their reference data bases, national libraries, research and commercial contacts. Information about effectiveness and adoption of alternatives in food processing and for commodities is not always available as research; the information is often found in commercial experience. Therefore, we did not limit our search for information to the research literature, noting, however, that the commercial experience and views of industry do not always arrive in citable format.

MBTOC also obtained information from Parties. Information included in the CUNs also contributed to MBTOC's evaluation. Since there are now only two Parties with CUNs for 2013 in the field of food processing, the Governments of Canada and United States were contacted to request information pertaining to technical efficacy and cost implications of alternatives for flour milling, as well as views and experienced of the industry sector. The

Government of Canada sent a prepared response and additional supporting research reports. Researchers for the US Department of Agriculture sent summaries of supporting research.

5.2. Current MB Uses in Non-Article 5 Parties for structures and commodities

All non-QPS MB uses in non-A (5) Parties were to be phased out under the Montreal Protocol as of 2005. Since that time, use of MB for non-QPS applications requires that a Party make a determination that the use is critical and that no technically effective and economically feasible alternatives can replace MB at the current time and for the particular circumstances of that use. Having done so, the Party nominates the use through the critical use process. The UNEP Ozone Secretariat receives Party nominations and sends them for evaluation through to the Methyl Bromide Technical Options Committee (MBTOC) of the Technical and Economics Assessment Panel (TEAP). When received by MBTOC, the CUNs are either evaluated by the Structures and Commodities sub-committee or the Soils sub-committee depending on use.

Since 2003 when the CUN process began, (to allow readiness for the 2005 phase out) the amount of MB requested for critical use nominations (CUNs) for structures and commodities often decreased each year or every couple of years. In virtually all cases, the actual amount of MB exempted for use through CUN process decreased, often as a result of MBTOC recommendations.

For the 2010 round of CUNs, the following MB structural and commodity uses remain for non-A(5) Parties:

Australia – One CUN for packaged rice,
Canada – One CUN for flour mills and one CUN for pasta facilities,
Japan – One CUN for fresh chestnuts,
United states – Four CUNs in total: one for structures which includes flour mills, rice mills and pet food facilities; one for food processing facilities and related equipment (including facilities that produce cookies, crackers, pet food and pasta, spice milling equipment and cheese held in cheese storages); one CUN for commodities (including dried fruits and nuts and dates), and one CUN for dry-cure pork in storages.

5.3. Reasons for lack of adoption of alternatives in some structural and commodity CUNs

Of these CUNs listed above, at time of writing, the following have not, to date, adopted alternatives to MB:

- Australia Rice
- Japan fresh chestnuts
- US cheese in storages (included in the CUN titled National Pest Management Association (NPMA))
- US dry-cured pork in storages

In the case of Australia rice, a fumigant (phosphine) has been proven effective and registered for many years. The applicant company, however, has considered the logistical changes required to adopt them to be too expensive, particularly because drought has reduced harvests and therefore the ability of the applicant company to invest. Controlled atmosphere storage has also been proven effective and in various methods is in widespread commercial use worldwide for rice. Additionally, there are several other proven methods used commercially in other countries to ensure that packaged rice remains pest free through marketing.

The Australia rice nomination has decreased over the years mostly because the rice harvest has decreased due to drought; the nominated amounts also decreased as the applicant adopted MB dosage rates more in keeping with standard dosage rates. In September 2010, the Government of Australia released a new plan to phase out of the use of MB for rice with significant decreases in planned MB nominations until 2014. They indicated they would not nominate MB for rice in 2015.

The Government of Japan conducted an extensive research program to search for an effective alternative for many years. Eventually methyl iodide (MI) was determined to be effective, and further work was conducted to achieve registration. MI was registered for use on fresh chestnuts in 2009, but commercial distribution and farmer training in safe use of the fumigant is taking several years to achieve. In the meanwhile, small decreases in the nominated amount of MB have been achieved through improvements in on-farm logistics pertaining to MB fumigation practices. It is believed that farmer training and adoption of MI for fresh chestnuts in Japan will begin in 2011, but recent meetings with Government of Japan indicate commercial distribution and farmer training are proceeding more slowly than expected.

In the United States there is no registered alternative for the pests of cheese and dry cure pork when these products are in storage. In fact, no alternative to MB has been shown to be technically effective for the pests of concern in the circumstances of these nominations. Cheese infested with pests is considered adulterated and can not enter commerce without effective treatment, and at this time MB is the only treatment allowed.

The dry cure pork included in the CUN is a regional food of several Southern United States having only some similarity to the dry cure pork products found in Spain or Italy for example. The processing, storage methods, salt and water content of Southern US cured pork are different, which, it is believed, gives rise to the pests of concern. For several years now, the Government of the United States has sponsored a multi-state, multi-university research project testing potential alternatives for pest treatments for dry cure pork and cheese. It has not found an effective alternative, but has demonstrated IPM methods which have been adopted and which have decreased MB use.

5.4. Regulatory considerations and the impact on registration on adoption of alternatives for structures and commodities

Product registration is required in many countries. If a fumigant or a treatment claims to, or is intended to, control pests it is regulated as a pesticide under one or more domestic legislations and regulations. The exception is that some physical treatments, such as treatment by cold or heat or by modifying the atmosphere of storage (controlled atmosphere) may not require registration; on the other hand, the physical treatment by ionizing radiation (irradiation) does require regulatory approval.

Significant efforts have been undertaken by many commercial companies and Parties to research, apply for registration and register alternatives to optimize their legal use. The registration process is very costly with lengthy delays and requires that companies who own the fumigants (registrants) to have a high level of technically-qualified regulatory personnel. The outcome after this expense and lengthy time expenditure is uncertain. Where the company that owns the fumigant foresees a small market in a particular country or application, the company often determines the financial reward does not justify the commercial risk and investment involved. This can result in one Party having access to a technically effective alternative that is not available to other Parties.

Most fumigant registrations are highly restrictive because of the fumigant's toxic nature. Conditions of registration in reducing hazard from use may include provision of training/stewardship program for certified applicators using criteria agreed with the agency, submission of additional data and additional risk mitigation and label amendments.

Regulatory agencies in various countries have adopted risk mitigation measures for the use of fumigants and these are described on the label. As an example, some labels require varying buffer zones depending on application rate, structure size, application method, type of tarp or airtightness of structure and closeness to neighbors. Some mitigation measures require the registrant to train applicators and certify them as stated on the label before the product is used. As a further example, in the United States, personnel involved in fumigation must wear protected gear and, depending on the circumstances, respirators that meets the standard of the US Occupational Safety and Health Standard Agency (OSHA). An aeration period is required until the fumigator determines the fumigant has decreased to safe levels. Fumigation mitigation measures are intended to protect handlers and bystanders.

Although an alternative may be technically appropriate as an MB replacement for a given situation, it may not be available in practice; lack of registration is often a constraint. The varying pesticide registration process in different state/countries, the situational needs for their uses and the potential problems with import/export regulations impact the speed of uptake of alternatives.

Regulatory problems associated with MB alternatives have to be viewed in context of possible upcoming regulatory events with MB as well. Currently, the US EPA is in re-registration process for MB, and it has published the intention to reduce worker exposure limits. Currently the re-registration eligibility decision calls for worker exposure limits of 1ppm for an 8 hr time-weighted average, but since there were concerns about that limit it is under review. Currently, the 'clearance level' is 5ppm. (The term 'clearance level' refers to that level after a facility fumigation aeration which allows re-entry of personnel.) Industry users of MB in the US have supplied the worker exposure data for facilities but now the worker exposure data for QPS use is being generated. All MB users are trying to work out if it will be possible to mitigate worker exposure rates through new labor practices.

As an added precaution to over-reliance on one or more chemical fumigants to the exclusion of other methods, it should be noted that chemical fumigant alternatives in general, have issues related to their long-term suitability for use. In both the European

Community and the United States, MB and most other fumigants are involved in a rigorous (re-) review that could affect future regulations over their use. The long-term sustainability of treatments adopted as alternatives to MB is an important consideration; both chemical and non-chemical alternatives should be used responsibly and sustainably as part of an IPM program. For further information on IPM in flour mills, the reader is referred to the IPM Section of this Chapter.

5.4.1. Regulatory issues affecting the use of ethyl formate

Ethyl formate is registered in Australia and New Zealand as Vapourmate® for cereal grains and oilseeds, grain storage premises and equipment, some horticultural produce for various pests with application rates between 10-420g/m3 of the ethyl formate CO2 mix. Current price is about twice that of methyl bromide but where methyl is not available for non QPS use it provides an option.

5.4.2. Regulatory issues affecting the use of propylene oxide

Propylene oxide (PPO) is not registered for use on dried fruits in California which is the location of US production of dried fruits. PPO label limits fumigations in chamber no greater than 10,000 cubic feet (http://www.epa.gov/oppsrrd 1/REDs/propylene-oxide-red-addendum.pdf). According to the industry, chambers for dried fruit are much larger, nearly 1 million cubic feet. Moreover, most of the dried plums are fumigated in storage warehouses that are part of the processing facilities. (United States correspondence to MBTOC, May 2010)

5.4.3. Regulatory and environmental issues affecting the use of sulfuryl fluoride

Where sulfuryl fluoride (SF) is an approved methyl bromide alternative for several post-harvest applications in food processing structures and commodities, it is in very widespread use. For example, in recent years in the United States, the approval of SF to treat flour mills and food processing facilities and numerous food commodities has very significantly contributed to reductions in methyl bromide use. In fact, in locations where MB users are interested in adopting SF as an alternative treatment, the slow progress in regulatory approvals has been a cited in ongoing requests for MB for critical use.

In Australia, SF is registered for rice, polished rice and wild rice against all stages of stored product pests in silos, food handling and processing facilities, mills, warehouses, temporary and permanent fumigation chambers (Dow Profume Label Australia, 2008). Significantly however, SF is not registered for use on packaged rice in Australia. Packaged rice is the subject of the Australian postharvest CUN and this lack of regulatory approval has been cited as a continuing barrier to adoption of alternatives by the applicant.

Additionally, where the extent of approvals for the use of sulfuryl fluoride is less than the extent of approval of methyl bromide, problems adopting SF have been cited by CUN applicants. In the US, *currently*, there is registration for the use of SF in structures and tolerances for many food products, although the list of foods on the SF label is not as inclusive as is the list of foods on the methyl bromide label. This has been the main reason for the ongoing CUN for pet food facilities and for the requested use of MB in food processing facilities. Food products and ingredients are commonly found in silos, in warehouses and finished product stores in mills, processed food facilities and pet food facilities.

However, in September 2010 the US EPA clarified that "EPA can conceive of circumstances where, despite the fact that all practical steps to minimize the amount of finished product have been taken, some finished product remains in the facility, incidental fumigation of such finished product in this situation would be permissible under the label" and the product will not be considered "adulterated" if the fluoride residue is below 70 ppm on the processed food. As a result, of this clarified interpretation from the US EPA, the US National Pest Management Association was able to notify the US EPA that it would not need to submit a CUN for food processing facilities in 2011. MBTOC assumed that this clarified interpretation should also improve the ability of the millers to use SF in their facilities.

However, in January 2011, the US Environmental Protection Agency (USEPA) proposed a regulation which would eventually eliminate the previous approvals for the use of sulfuryl fluoride (SF) as a pest control measure for foods and in food processing structures, if there will be food contact. EPA's sulfuryl fluoride human health risk assessment shows that aggregate fluoride exposure is too high for certain identifiable subpopulations in the United States, in particular children under the age of 7 who live in areas with higher fluoride concentrations in drinking water resulting from natural background sources. Although sulfuryl fluoride residues in food contribute only a very small portion of total exposure to fluoride, when combined with other fluoride exposure pathways, including drinking water and toothpaste, EPA has concluded that the tolerance (legal residue limits on food) no longer meets the safety standard under the Federal Food, Drug, and Cosmetic Act (FFDCA) and the tolerances for sulfuryl fluoride should be withdrawn.

A March 2006 US National Academy of Science report recommended that the current drinking water standard (MCLG of 4 mg/L) should be reduced. Some American regions have naturally high fluorine in soils which impacts total fluorine intake. The teeth of children are harmed by high fluorine levels; other health effects were also examined as part of the risk assessment.

US EPA took this action as part of an overall proposal to reduce fluorine use in water and other sources. US EPA's proposal includes various phase-in periods for the withdrawal of the use of sulfuryl fluoride. Following this regulatory proposal there is time for the regulator to receive comments, a normal political process, and eventually, a final regulation will be published (Federal Register. January 19, 2011)

MBTOC has noted in previous reports that an action that removes the pesticide tolerance for SF would increase significantly pressure to revert to MB in structural and commodity fumigation.

MBTOC notes that the issue of fluorine levels and health impacts is regional because environmentally occurring fluorine and additions to water vary regionally. For example, in January 2011, Australia responded that fluorine in water and diet in Australia is not injurious to health and therefore approvals of sulfuryl fluoride will not change as a result of the US EPA publication (Australian Pesticide and Veterinary Medicines Authority (APMVA). Jan 14, 2011)

In Canada, although registration for SF was achieved for structures several years ago, a maximum residue levels for the fluorine residue in food resulting from the SF treatment of the food processing structure has not been set; this is cited as a contributing factor to the ongoing CUN for flour milling and pasta facilities. The reason for this is that food products and ingredients are commonly found in silos, in warehouses and finished product stores in mills and pasta processing facilities.

Millers in Canada have report real problems in adopting SF because of the lack of regulatory approval for food contact as well as efficacy problems (Environment Canada, 2010; Canadian National Millers, 2007). In Canada there is no maximum residue level (MRL) established for SF food contact and as a result no food contact is allowed.

5.4.3.1 Sufuryl fluoride - Maximum residue level issues

Additional registration issues arise where treatments will be used on food commodities or where treatments used in food processing buildings might transfer residues to food because the maximum residue limits for the residual chemicals must also be registered in importing countries. In recent years, some large MB-volume consuming countries have both published and revoked maximum residue levels for the residues of some methyl bromide alternatives in food commodities.

As an example, in France, approval of the use of SF on fresh chestnuts has been withdrawn. The SF treatment resulted in a fluoride residue in chestnuts, which exceeded the European Union 25 ppm MRL.

For Europe, there is no MRL for fluoride residues resulting from SF treatment of dried fruit. Similarly to Canada, in the EU there is no food contact registration for SF in flour mills. Large mills containing integral flour bins are experiencing very difficult practical implementation problems with SF fumigation. Other than in the UK, the SF supplier is not advocating the combined use of SF and elevated temperatures, although MBTOC recommends this combined treatment.

5.4.3.2 Sulfuryl Fluoride - additional restrictions

There is an increasing regulatory scrutiny in the US to ensure compliance resulting from new registrants of sulfuryl fluoride. Recently sulfuryl fluoride was included in the Toxic Air Contaminants list. In California, the state occupational, health and safety regulator (Cal/OSHA) expanded the Structural Fumigation Enforcement Program to include Santa Clara and San Diego counties and the California Department of Pesticide Regulation (Cal/DPR) announcement to initiate the reevaluation of sulfuryl fluoride. (United States correspondence to MBTOC in 2010, citing Lee Whitmore, PCOC, Fall 2008)

As methyl bromide was being phased out, and alternative fumigants being phased in, the fumigation industry realized it needed to improve its overall professionalism and conduct its business in a compliant manner. Fumigator training improved and more fumigant registrants required that fumigators be certified to use their materials. More often pest control professionals were used for fumigations than in-house staff, which were seen as less trained or not certified. The need for training and certification resulted in a delay in the adoption of alternatives, but it was necessary.

5.4.3.3 Sulfuryl Fluoride - environmental concerns

MBTOC advises the Parties that environmental concerns about using sulfuryl fluoride amongst milling and food processing companies should not be underestimated as an obstacle to adoption of this MB alternative. All flour milling and food processing CUNs in 2010 noted environmental concern with using SF because of its high global warming potential (GWP). The environmental concern is demonstrated either in the context of regulatory uncertainty or by the demands from milling and food processing customers that companies to reduce their carbon footprint. Dow AgriSciences, the main registrant for sulfuryl fluoride has written it is aware of the global warming challenge and is monitoring developments.

MBTOC notes the following statement from MOP 21, Decision XXI/9 (Hydrochlorfluorocarbons and Environmentally Sound Alternatives) (para 8): "To encourage Parties to consider reviewing and amending as appropriate, policies and standards which constitute barriers to or limit the use and application of products with low- or zero-GWP alternatives to ozone-depleting substances, particularly when phasing out HCFCs." Parties may wish to consider the potential similarity (or not) in its concerns for HCFC's and SF.

According to the US pet food industry, use of SF could easily more than offset any reductions in carbon emissions that pet food makers are able to realize. Pet food sector companies reported that use of SF could potentially expand a company's carbon footprint and that such a situation is likely to be viewed by retailers and consumers with much disapproval.

The rice milling sector reports that their industry is currently being driven by international and some national customers that are designing sustainability plans for their own needs and sending the plans down the food supply chain. One of the most basic requirements is to reduce the carbon footprint in every step of the chain. Rice producing fields are currently at a severe disadvantage for their inability to mass-utilize no-till practices. Adding a climate change contributor (SF) to the same supply chain is counterintuitive and contrary to customer requirements of reducing the carbon footprint and controlling global warming

Of note, Walmart, the largest retailer in the United States, announced on February 25, 2010, that it wants its suppliers to eliminate "20 million metric tons of greenhouse gas emissions by the end of 2015." Millers and food processors have pointed to this as an example of the reasons they must continue to use MB and not switch to SF fumigation.

The Government of Canada reviewed for MBTOC the efficacy of the use of SF in flour mills as reported by Agriculture and Agri-Food Canada scientist Paul Fields. The report noted that, "The lack of efficacy of SF in killing the eggs present in flour mills, even under model fumigations that achieve target concentrations for the required period of time, has resulted in the need for two or more fumigations annually, even in mills with a history of one MBr fumigation annually." As a result, Government of Canada noted, "…a practical necessity of using a greater quantity of an alternative fumigant in gas form in the interest of efficacy may give rise to unforeseen cost implications as well as raise questions about the environmental merit of the alternative in question. SF has been identified as a greenhouse gas." (Environment Canada, 2010)

As background to this issue, in 2009, research was published indicating that SF has a much higher global warming potential than previously considered (Millet et al., 2009). Its atmospheric life time is estimated as 36 years, about 8 times greater than previously thought, with the oceans as the dominant sink. These new reports indicate SF may be 4,800 times more effective at trapping heat in the atmosphere than carbon dioxide (St. John, 2009). The GWP of SF is comparable to that of CFC 11 (Muhle et al., 2009). By comparison GWP of R-134a (a refrigerant) is only 1410 and venting is prohibited under the Clean Air Act. California is currently using 50% of all SF produced. According to Anderson in 2009 the current SF use in California is equal to the CO2 emissions of 1 million vehicles over 1 year (Anderson, 2009).

5.4.3.4 Sulfuryl Fluoride - country registration

Dow AgroSciences, the main supplier of SF in North America and Europe, has successfully obtained the necessary registrations for use of SF, but further information on MRLs is being requested by various authorities for extensions of registration to cover the wide range of commodities on the methyl bromide label. The fumigant label is the legal document which indicates the products allowed to be treated under specific circumstances and conditions.

The following is an excerpt from the critical use nomination for 2012: “SF remains under evaluation by Canada’s Pest Management Regulatory Agency. Due to the lengthy delay in full regulatory approval of SF, Canadian mills have been unable to evaluate SF under what are expected to be the final permitted conditions of use.

Furthermore, provincial regulatory bodies have some authority over pesticide use, whether or not for food-related agricultural purposes or for post-harvest structural use. Therefore, the registration of an alternative federally does not mean that provincial authorities will authorize its use.”

As communicated to MBTOC in past re-nominations for critical use exemption and supplemental information provided, the current registration of SF does not enable mills in Canada to conduct trials under conditions of use already permitted in the US by USEPA. (Environment Canada, 2010)

5.4.4. Regulatory issues affecting alternative adoption in flour mills and food processing facilities

Heat treatment does not usually require approval by pest management regulatory authorities, but insurance companies may become involved. There are additional pest barrier methods recommended for use in heat treatments, and these may require regulatory approval. The use of diatomaceous earth (DE) seems to have widespread regulatory approval, but it is slower acting and ineffective in damp areas. The use of insecticidal spraying in a mill is subject to regulation. The use of food-grade mineral oil resolves many of these issues.

Fire protection and occupational health authorities have and may continue to express concerns and demand hazard management plans and methods that can contribute to costs and delays in adopting heat treatments. Many mills have successfully adopted heat treatments. But, some facilities can not adopt heat due to the design of their sprinkler system, their inadequate electrical capacity and/or the unavailability of adequate footprint for external heater and electrical systems (Canadian National Millers Association, 2007).

The real regulatory issues affecting adoption of alternatives have and will continue to pertain to the chemical fumigants. Since the 2006 Assessment Report there has been widespread expansion of the approval of the use of sulfuryl fluoride at national and state levels, followed by the very widespread training of licensed fumigators. However, regulatory approval of sulfuryl fluoride has not been complete enough to satisfy some mill and facility managers.

Millers in Canada and the United States have reported problems in adopting SF because of lack of regulatory approval for food contact (Bair, 2008; Canadian National Millers Association, 2007; Environment Canada, 2010).

For example, in Canada, no maximum residue levels (MRL) have been set for contact with food (any food or raw agricultural ingredient). As a result, the mill has to be either completely emptied of any grain or finished product or those items have to be completely sealed off. These actions are not always possible, and if possible, have an as-yet-undetermined cost. Millers believe when the MRL is effectively zero, then they could be liable if fluoride residue is found in small amounts of flour left behind when equipment is fumigated.

In the United States, MRLs have been established for grains and processed flour and for many other commodities, but not for all the commodities used in bakery mixes and consumer flour mixes (Bair, 2008). One estimate is that over 40% of US flour mills also produce these items and would have them present in large quantities in the mill.

In May 2010 (TEAP, 2010) MBTOC noted that approval for MB alternatives for structures and commodities had stalled and without further improvements, CUNS may have to continue for many years.

However, during 2010, the US National Pest Management Association (the NPMA CUN applicant), achieved a breakthrough in a key barrier to the use of SF as an alternative for this sector. After what was probably considerable work, the US Environmental Protection Agency agreed to clarify the interpretation of unclear wording in the label for sulfuryl fluoride, a controversy which had started with a letter from EPA (Hazen, 2006). This effort by the industry sector, which involved explaining to the regulator how the sector manages to minimize the presence of food prior to and during a fumigation, resulted in a letter from EPA which the NPMA now says will allow its members to use SF without threat of legal prosecution, as long as the presence of food is minimized in the method outlined in the letter (Rossi, 2010). The letter notes a 70 ppm MRL for processed foods which experience incidental fumigation within the parameters described in the letter.

Commendably, the US NPMA has submitted a letter to the US EPA saying that as a result of the clarification from EPA, the US NPMA does not intend to submit a CUN in 2011 for 2013. This breakthrough should also improve the use of SF in the milling sector.

5.5. Integrated Pest Management – Where pest control begins

5.5.1. Defining IPM and its elements

IPM is a sustainable, pest risk-management approach combining biological, cultural, physical and chemical tools in a way that minimizes economic, health, and environmental risks. It is highly information based, starting with knowledge about the pests, integrated with knowledge about the facility. Within the framework of an advanced and sustainable food production system, IPM is the primary response for the agro-food industry facing consumer demands of high quality products while at the same time addressing environmental, safety and socio-economic issues. The reader is invited to review Phillips and Throne's 2010 review of biorational approaches to managing stored product insects for a more thorough definition and discussion.

IPM targets the entire pest complex and related contaminants (fragments, remains and pesticide residues) of a food processing ecosystem, and generally tries to avoid or minimize the use of conventional neurotoxic pesticides by using non-chemical control methods and reduced-risk insecticides whenever possible. Although registered pesticides are safe when used as directed, one of the aims of IPM is to reduce exposure of pest management professionals, workers in food facilities, and consumers to pesticides and pesticide residues.

An IPM system combines, either concurrently or sequentially, biological, physical and chemical tools to achieve adequate pest control while striving to protect the environment, maintain profitability and fulfill consumer demand for decreased or no pesticide use. Achieving reliable pest control without using methyl bromide requires the use of an intensive IPM program which includes intensive monitoring of infestation levels and regular precisely documented cleaning and pesticide applications (TEAP, 2010). IPM strategies require constant maintenance in order to succeed.

5.5.2. Differences in IPM definitions and practices

There is much interest in alternatives to conventional insecticides for controlling stored-product insects because of insecticide loss due to regulatory action and insect resistance, and because of increasing consumer demand for product that is free of insects and insecticide residues.

Although a reduction in use of pest control chemicals in food processing, and using less toxic chemicals is a goal of most IPM practitioners, MBTOC notes that onward from this point there is a divergence in the definition on IPM.

Some people define IPM more strictly as not including full site chemical treatments, and also only including the very minimal or complete non-use of other pest control chemicals.

Some people define IPM as a means of minimizing chemical use, but also incorporate full-site or curative treatments as part of an IPM programs. These may involve fumigation or other processes. In the context of phasing out methyl bromide, IPM should be considered a required pre-requisite to the use of full site chemical treatments by methyl bromide and other fumigants.

This difference in definitions can give rise to confusion as some researchers will report results about the use of ‘IPM alone”.

Given this divergence of definition, and to avoid confusion, MBTOC has placed information about full site treatments by fumigation or heat in the section on pest control in flour milling and food processing found elsewhere in this Chapter.

5.5.2.1 Examples of the differences in IPM practices and evaluation

Mills in Australia, Croatia, Scandinavian countries, Slovenia and the UK have not used full site methyl bromide treatments for several years, and in many mills there has been no increase in pest problems (Nielsen, 2000; Raynaud, 2002; Trematerra and Gentile, 2010).

There have been some reports that IPM alone (i.e., without a full site pest control treatment such as fumigation or heat treatment), has been sufficient for pest control (European Commission 2008.) The number of mills and food processing facilities adopting IPM as a control strategy and achieving control without methyl bromide is increasing worldwide.

In 2008, researchers in Italy noted that an integrated pest management program, including frequent inspections, and an increase in the number of traps representing an alternative to methyl bromide in a mill. The location of infestation points and critical areas enabled timely localized treatments which avoided the use of methyl bromide (Panzeri, 2008).
This is a good demonstration of the divergence of European versus North American IPM practices and definitions which has led MBTOC to accept both viewpoints.

On the other hand, in commercial practice in North America, it is believed that an intensive IPM program will minimize the possibility of needing a full site treatment, In 2010, Campbell *et al*, analyzing the results of lengthy pest monitoring by various methods in several mills reported that pest management changes allowed one mill to decrease to one full-site fumigation from two full site fumigations needed previously. Campbell’s work showed the importance of pest monitoring as done in an enhanced IPM program, but he noted that while improving IPM had important consequences on pest populations, changing the season of fumigation (one of the outcomes of the pest monitoring) had the biggest single impact in reducing pest rebound after fumigation. He summarized that the rate of pest population increase in a flour mill can be managed by sanitation, use of insecticides, structural modifications, pest exclusion methods and reduced indoor temperature (Campbell et al, 2010)

5.5.3. Implementation of IPM programs

Many local and national governments have promoted IPM through legislation and other means. In private industry, decisions and support from senior executives is almost mandatory for adoption of IPM through investment of resources, employee training and re-direction of resources. In many countries, there are consultants and pest control companies working to design, apply, and manage IPM programs including employee training. They have committed themselves to conduct pest control programs with minimal, and often, no pesticide usage, while monitoring the success of the whole pest management program. Using information from governments and pest control companies, millers and food processors can work towards adopting and adapting IPM for their facilities.

5.5.3.1. Elements of IPM

An IPM program has to provide effective pest prevention, based on an accurate pest monitoring system and provide training for industry staff on the tools employed for maintaining an acceptable level of control. Training of the personnel, however, is an important limitation in some countries where there are few possibilities for formal professional education (Bartosik, 2010). However, in many countries there are established training courses and certification requirements for pesticide applicators and workers in food storage and production premises (Hamel, 2010; Urizo, 2007; Urizio, 2005). This expertise could easily be transferred to countries that have no such procedures, if financing were to be made available.

5.5.3.2. Pest prevention

Sanitation is the first line of defense; sanitation has to be a farm – to – fork preoccupation of everyone involved in growing, processing, storing, and marketing durable commodities. Sanitation generally involves elimination of harborages for pests, cleaning and removal of food residues in which pests could multiply, and regular monitoring for the presence of pests (Mills and Pedersen, 1990).

A correctly implemented IPM program can both improve sanitation (in keeping with HACCP processing), and reduce the frequency of fumigation. In recent years, IPM methods have improved and techniques are used more intensively; companies have invested more in human labour and time to achieve the result. Pest control requirements are not the only driver to incorporate intensive IPM; the need to decrease dust as a threat to employee health has also resulted in more sanitation efforts (TEAP, 2010).

One of the methods used by millers to judge the success of a fumigation is the time between the fumigation and the time when pests have rebound to the levels which require another fumigation. There has been considerable discussion about the relative merits of MB versus alternatives in pest rebound times. Recently, Mason and co-workers indicated that regardless of fumigation type or time of year when fumigation occurred, the facilities that maintained the highest sanitation levels achieved the longest rebound times and thus received the maximum fumigation benefit (Mason et al, 2010)

In developing an IPM plan, consideration may need to be given to building design improvements, the materials present, retrofitting of certain facilities and effects, and exclusion practices aimed at reducing or eliminating infestations in incoming food and ingredients (Imholte and Imholte-Tauscher 1999).

Good warehouse practices, including inspection of incoming goods and packages, stock rotation, and use of insect resistant packaging where practical, reduce the probability of infestation. Once packaged, food can be contaminated by insects penetrating the physical barrier provided by the package film. Several authors have reported on the ability of various insects to penetrate films of various type and thickness (Bowditch 1997, Highland 1991, Riudavets *et al*. 2007). Some species do not make holes in packaging but enter packages by existing openings. For example some packaging systems incorporate holes in packages to allow air to escape, and some packages are sewn closed instead of being glued or heat-sealed and do not provide a barrier to insects.

5.5.3.3. Monitoring

Any integrated pest management (IPM) program begins with identification of existing and potential pests affecting the facility or commodity. Information on insect and mite pests and their identification can be found in various reference books (Gorham 1987, Meaney 1998, Rees and Ransi 2004). There are many on-line websites that provide educational materials and publications from research institutes, universities, and private industry that give detailed and specific information on insect species and their identification.

An important part of IPM use in facilities is to identify the infested area and the density, dispersion and changes in number of pests over time. This is essential to make pest management decisions, to know the effectiveness of a control measure and to avoid unnecessary or late control measures. However, much work still remains to be done in this area, including improvement and development of attractants for some species (i.e. *Tribolium* spp.) and better interpretation of trap catches for pest management decision making (Phillips and Throne, 2010).

Insect populations are typically concentrated in relatively small areas (spatially heterogeneous) rather than evenly distributed within the area of concern. Understanding this distribution pattern is often of considerable importance to the development of sampling procedures and of rational pest-management strategies. Recent research also documents extensive insect infestations in and around storage facilities, which provide a constant source for population immigration, even after control measures have been introduced (Doud and Phillips 2000, Campbell and Mullen 2004, Campbell and Arbogast 2004).

Monitoring for insect infestation can be done either directly, by examining premises and products for insects, or indirectly by monitoring indicators of infestation that include monitoring temperature and carbon dioxide (Neethirajan et al, 2007). Direct methods include visual inspection, examining samples of a product, monitoring known problem areas and trapping with or without pheromones or food attractants.

There has been much research on pheromone traps for monitoring stored-product insects, and detailed reviews can be found in Phillips (1997) and Cox (2004). Mating disruption through the use of mass trapping and releasing large quantities of sex attractants has been studied through field experimentation in the USA and Europe (Ryne *et al.*, 2006, Hassan and Al-Zaidi, 2010; Pease and Storm, 2010; Phillips *et al.*, 2010; Trematerra and Gentile, 2010). When used as part of an integrated pest management (IPM) system in conjunction with deep cleaning and hygiene positive results have been obtained.

One obvious limitation of sex attractants is they only capture males, and it is therefore often difficult to relate trap catch to actual infestation levels (Campbell and Arthur, 2004). New generations of traps, which will count insects electronically as they are captured and GPS technology of data transfer and management are now commercialised for monitoring grain and structural infestations (Shuman *et al.*, 2003).

The latest developments of these technologies have included: near infrared (NIR) analysis of grain (Throne *et al.*, 2003; Pérez-Mendoza *et al.*, 2005; Lazzari *et al.*, 2010), rapid immunoassay methods based on polyclonal antibodies (Atui *et al.*, 2003; Schatzki *et al.*, 1993; Riudavets *et al.*, 2004), specific monoclonal antibodies (Dunn *et al.*, 2003), and molecular diagnostics tools with DNA markers based on the polymerase chain reaction (PCR) (Phillips and Zhao, 2003; Ceruti and Lazzari, 2010; Li *et al.*, 2010). These methods provide precise and consistent measurements of insect contamination, and can be used to assay a variety of foods products.

Although a variety of traps have been developed, research is still needed to relate numbers of insects captured to economic action thresholds. Action thresholds of pests should be determined for the situation, pest and commodity as reviewed by Subramanyam and Hagstrum (1996b). Mathematical modeling provides a unifying framework that ties effects of various environmental factors together and permits us to evaluate their relative importance in determining population behavior (Throne, 1995; Flinn *et al.*, 2010). These models form the backbone of expert systems designed to assess risk and recommend control interventions (Flinn and Muir, 1995; Flinn *et al.*, 2003), and they can be applied to establishing economic thresholds.

5.5.4 Tools used in IPM programs

In addition to sanitation, hygiene and other pest control procedures, numerous tools and techniques are used in IPM programs. As described elsewhere in this chapter, heat treatments, cooling treatments, use of modified atmospheres (including high CO_2 and N_2 applications, vacuum treatments, or hermetic storage) can be an important part of IPM programs.

In this IPM section a review on new information about the use of aerosols, contact or surface treatments, biological control, physical control and new active compounds is covered. However, for information on full site treatments by sulfuryl fluoride or heat, and monitoring the effects of those treatments, the reader is directed to the section on pest control in flour mills and food processing facilities elsewhere in this chapter.

5.5.4.1 Aerosols

Another category of control that is a valid component of IPM programs is targeted/localised application with either aerosols or surface treatments to replace whole-plant fumigations (Arthur, 2010).

Although aerosol insecticide applications are being used more frequently in flour mills and other structures, there are few recent reports on their efficacy. Toews et al. (2006b) monitored insect populations in an operating flour mill and showed insects were almost always captured inside the mill in the first trapping period after an aerosol application of dichlorvos+pyrethrin, but it was not clear if the insects survived treatment or immigrated from outside.

Arthur and Campbell (2008) showed that survival of adult confused flour beetle, *Tribolium confusum* (Jacquelin du Val), increased when food was provided after treatment with a pyrethrin-CO_2 aerosol, emphasizing the importance of sanitation in facility pest management programs.

Arthur (2008) investigated efficacy of synergized pyrethrin aerosol for control of the red flour beetle, *Tribolium castaneum* (Herbst), and adult confused flour beetle in a commercial food storage facility, and found the presence of food increased survival of adult confused flour beetle but not red flour beetle. Few treated larvae or pupae of either species survived to the adult stage. Field trials with pyrethrin combined with either the insect growth regulator (IGR) methoprene or the IGR hydroprene and showed that larvae of the red flour beetle were far more susceptible than larvae of the confused flour beetle to the residual deposits from the aerosol, which was assumed to be due to the persistence of the IGR component (Arthur, 2010). However, there are indications of an additive effect of the pyrethrin on the confused flour beetle. Aerosol studies have also been conducted with late-stage larvae of the Indianmeal moth, *Plodia interpunctella*. In a field trial with methoprene, only 13% of larvae embedded in food media and exposed to methoprene survived to the adult stage.

Studies by Jenson et al. (2009ab, 2010) evaluated methoprene applied alone or in combination with a pyrethroid . A partial budget analysis indicated that the combination treatment of 1% pyrethrins + methoprene represented the lowest risk, lowest cost, and would seem to be the optimum combination for control of Indianmeal moth eggs and larvae. Overall, results of aerosol studies show good efficacy of aerosols and good promise for the use of aerosols to reduce the need for structural fumigations.

5.5.4.2 Contact or surface treatments

Recently new mixtures of Diatomaceous Earth and contact insecticides have been developed as another example of integrated tools to improve control efficacy (Korunic, 2010).

Chlorfenapyr is an insecticidal pyrrole first registered in the USA for control of termites, cockroaches, and nuisance ants under the trade name Phantom®. The product label was recently expanded to include food and feed mills, food handling areas, restaurants, and other areas where food is handled and stored. Results of laboratory tests indicated that chlofenapyr was effective against both the red flour beetle and the confused flour beetle, with the red flour beetle being the more tolerant of the two species (Arthur, 2008). This is similar to results with the pyrethroid cyfluthrin (Tempo®), but the order of susceptibility of the two species is reversed for IGRs and diatomaceous earth (Arthur 2008, Arthur et al. 2009, Arthur 2010) As a result of Arthur's 2008 study, stored-product insects were added to the label for the USA.

In a second study, adult red flour beetles were exposed to different concentrations of chlorfenapyr for selected time intervals, then removed and held either with or without food for 7 days. In the presence of food, survival was high regardless of concentration and the day on which post-treatment survival was assessed, but survival did decrease as the exposure period increased from 4 to 8 h. When the beetles were not given food after exposure, survival at each concentration and exposure period declined during the 1-week post-exposure assessments. Results showed the presence of food material greatly compromised effectiveness of the insecticide, and again emphasized the importance of cleaning and sanitation in conjunction with insecticide treatments.

Targeted/localized treatments using heat or fumigants may also be used. Applications of contact insecticides can reduce insect populations in simulated and actual field sites. Additional research is needed for these products to accurately assess their ability to control insect populations in large-scale milling and production facilities (Arthur, 2010). However, as a result of worker safety and other factors resulting previous uses some residual insecticides have recently lost their registration in many countries and is likely to continue in future.

5.5.4.3 Biological control

In implementing an IPM plan, a combination of biological, physical and chemical controls will most likely be required. Biological control with predators and pathogens (Schöller *et al.*, 2006; Navarro, 2004) remains an option as part of an IPM system. Traditional pest control companies are using insect parasites and predators more and more to control stored-product insects, indicating an adoption of biological control (Schöller, 2010). Natural enemies for stored-product pests are now produced in The Netherlands, Germany and Switzerland. Biological control may be relevant to processing facilities that are not willing to stop production for pest control operations.

TABLE 21. STORED PRODUCT NATURAL ENEMIES (GENUS) ASSESSED (FROM LABORATORY STUDIES OR FIELD STUDIES) WORLDWIDE.

Hymenoptera	Hemiptera	Acaridae
Trichogramma	*Xylocoris*	*Cheyletus*
Bracon	*Lyctocoris*	*Blattisocius*
Venturia	*Dufuriellus*	*Pyemotes*
Mesostenus		
Anisopteromalus		
Pterolamus		
Lariophagus		
Theocolax		
Choetospila		
Dibrachis		
Habrocytus		
Cephalonomia		
Holepyris		
Laelius		

5.5.4.4 Commercial production of natural enemies

The following biological control agents (species) are produced commercially in Germany, The Netherlands and Switzerland:
- *Trichogramma evanescens*, egg parasitoid of moths
- *Habrobracon hebetor*, larva parasitoid of moths
- *Lariophagus distinguendus* or *Anisopteromalus calandrae,* larva parasitoids of weevils
- *Cephalonomia tarsalis*, larva parasitoid of beetles

5.5.4.5 Physical control

Physical processes are responsible for a considerable amount of non-targeted pest control and also show promise for inclusion into IPM programs. For example in the case of rice, during the conventional polishing process high mortality is generated in the weevil population (>95%) (Lucas and Riudavets, 2000; Ducom-Gallerne and Vinghes, 2001).

Other mechanical control methods, including the simple turning of the grain or the “Entoleter” (centrifugation and mechanical shocks) killed a high percentage of insects including weevils inside cereal kernels (Beckett, 2010; Vincent *et al.*, 2003). Creating temperature extremes provides effective control and heat treatment is a technically feasible alternative for mills and food commodities (Dosland *et al.*, 2006; Hulasare *et al.*, 2010; Subramanyam, 2010). In China, the major technology for ecological environmentally friendly grain storage is low temperature storage combined with controlled atmosphere storage in the suitable climatic zones (Wang et al., 2010).

5.5.4.6 New active compounds

New active compounds are sought among plant origin extracts with activity against insects and mites (Lee *et al.*, 2003; Tapondjou *et al.*, 2004; Saraç *et al.*, 2004). Precautions need to be taken with these new compounds to avoid risks to humans, and registration of any new product is a requirement in most countries. Despite the wealth of research on botanicals, however, no new active compounds have commercially arisen during recent years. Fumigant toxicity of essential oils in combination with modified atmospheres (Işikber, 2010) and with diatomaceous earth (Nukenine, 2010) against stored-product insects has been also studied.

5.5.5. Constraints and future considerations

Many IPM strategies would benefit from targeted engineering research in order to be applied efficiently. New methods of application, increased energy efficiency, sealing methods and methods to allow gastightness to be determined for existing or new structures still need to be identified or implemented.

For better pest management decisions research has to focus on new methods for identification of pest populations and detecting internal insect pests, improved attractants and improved interpretation of trap catches (Phillips and Throne, 2010; Throne, 2010).

The *Tribolium* genome project has enabled the identification of genes with important functions in the biology of insects. This resulting improvement in basic knowledge will fuel the next generation of pest control technologies (Beeman, 2010).

The red flour beetle was the first agricultural pest to have its genome sequenced (Tribolium Sequencing Consortium, 2008). Much of the postgenomic work has concentrated on genes involved in cuticle breakdown and synthesis during molting because this is a very vulnerable stage for insects, making it a target for new insect control tools. A number of chitinase genes have been found with varying functions, and these are often specialized to act in a certain part of the body at a certain molt (e.g., Zhu et al., 2008). Another potentially vulnerable process in stored-product insects is water regulation because these insects live in a relatively dry environment, and a number of genes involved in osmoregulation have been identified (Park and Beeman, 2008).

5.6. Cautionary note about pest resistance

Pesticides are still used as a tool for control of pests in raw material and structural pest control. Another objective of IPM is to delay the development of insect resistance common in many systems due to the repetitive use of chemical pesticides. It is also an advantageous approach in the context of increasing restrictions for pesticide use and because reductions continue in the number of biologically active compounds registered as pesticides. Pesticide resistance management strategy should therefore rely as far as is practical and possible on non-chemical methods because of the limited number of chemicals available to the industry.

Therefore, resistance to insecticides has to be managed and taken into account in any pest management program. Future research is aimed at gaining a fundamental understanding of fumigant behaviour in grain storages, the movement and colonisation of grain by insect pests and the mechanisms of selection in insect populations (Collins, 2010).

5.7. Cautionary note – psocids as an emerging pest in North America

Psocids became pests of increasing concern in Australia and China in the 1990's, but were not of concern in the U.S. until the 2000's (Throne 2010).The biology of many psocid species has been poorly studied, so there have been efforts to expand our knowledge of biology of psocid species found in the U.S (Opit and Throne 2008ab).

Results of recent studies give some indications that psocids are more difficult to control compared to stored product beetles. Guedes et al. (2008b) detected heat-inducible proteins only in *Liposcelis entomophila,* which could explain the widespread distribution of this species worldwide because these heat-inducible proteins may have a protective function when the insect is stressed. This result has implications for heat treatments. In a second study, Guedes et al. (2008a) found that the insecticides ß-cyfluthrin and chlorfenapyr, but not pyrethrins, were effective for control of *L. bostrychophila* and *L. entomophila*. *Liposcelis bostrychophila* was slightly more tolerant than *L. entomophila*, and behavioral studies showed that this may have been due to less movement and that *L. bostrychophila* tended to keep their abdomen raised while moving, which may have resulted in less contact with the insecticide.

Wei and co-workers at Southwest University in Chongqing China reviewed the effectiveness of fumigants and controlled atmospheres against psocids, a growing problem pest for food processing companies world wide. Often overlooked because of their small size, psocids have been found in a wide range of mills, food processing and stored product facilities. Psocids can both damage, and contaminate food products. In this review, phosphine and ethyl formate were found to be the most effective and practical control methods, since psocids adapted to controlled atmospheres (Wei et al, 2008)

5.8. Further sources of information about IPM

There are numerous sources of information to assist the implementation of IPM without full site fumigation, in milling, food processing and food storage:

A book edited by Heaps (2006) reviews the present status of IPM for mills and processing facilities. Previous reviews on the concept of IPM in stored products can be found in a number of sources (Subramanyam and Hagstrum 1996a, 2000, Hagstrum *et al*. 1999, Campbell and Arthur 2004).

There is a working group on Integrated Protection of Stored Products of the IOBC (International Organization for Biological and Integrated Control of Noxious Animals and Plants, http://www.iobc-wprs.org/index.html). Topics covered in this conference include biological and physical control of pests and diseases. This group meets once every two years and the proceedings are published as the IOBC / wprs Bulletin (http://www.iobc-wprs.org/pub/index.html).

Every four years there is a meeting of the International Working Conference on Stored Product Protection (IWCSPP, 2006). Topics covered in this conference include biological, chemical and physical control of pests and diseases. The 9th conference was held in Campinhas, Brazil, in October 2006 (Lorini *et al.*, 2006) and the 10th conference in Estoril, Portugal, in June 2010 (Carvalho *et al.*, 2010).

Also, there are a number of international (e.g. International Conference on Controlled Atmosphere and Fumigation in Stored Products, also known as CAF, http://www.ftic.info/CAFsite/CAF.html; the annual MBAO Conference on Alternatives to Methyl Bromide, http://www.mbao.org), national and regional meetings that bring together the scientific community, pest management professionals, food processors and policy-makers/regulators and provide an opportunity to update the knowledge on IPM.

5.9. Current status, technical efficacy and adoption of methyl bromide alternatives in structures -- flour mills and food processing facilities

5.9.1. Introduction

MBTOC's first full review of the use of MB and alternatives in flour mills was presented in the TEAP 2008 Progress Report. At that time, three Parties: Canada, Israel and the United States, nominated flour mills for continued critical use of methyl bromide. Although amounts of methyl bromide requested for flour milling use have declined each year, critical use nominations continue for flour mills in Canada and the United States.

In this Assessment Report we augment the May 2008 report, with new references and analysis to assist North American millers and food processors to adopt alternatives. MBTOC specifically focussed on recent advances in understanding of the technical efficacy, and adaptations made by the sector as MB use decreased each year.

Virtually all the fumigator and research reports reviewed indicated that subsequent treatments with alternatives were much more successful than initial experiences (while mindful that there still are some concerns about the efficacy of alternatives). Mills and food processing facilities still report that methods must be fine-tuned through experience at each facility to maximize effectiveness.

The most likely and most often used alternatives for the milling and food processing sectors are, heat treatment either as a full site treatment or as spot heat (combined with the use of a further pest barrier method) and sulfuryl fluoride (SF), either alone or with the addition of supplemental heat in a combination treatment.

Additionally, in Canada, a pest control company reports that it treats a few mills with the phosphine, CO_2 and heat combination process. There are also reports of cylinderised phosphine being used in mills in Chile and Argentina while protection of electronic equipment is provided through the use of positive pressure (Horn, et al, 2010)

Although concerns were reported with the use of each alternative, there were no reports indicating that any particular mill structure, type or conformation completely lacked a technically effective alternative treatment (Environment Canada, 2010; Canadian National Millers Association 2007; European Commission 2008. Part of the submission from Environment Canada included a review by Agriculture and Agri-Food scientist Paul Fields summarizing heat, SF and MB treatments of mills and pasta processing facilities. That summary notes that evidence from trials still does not indicate ideal efficacy of SF treatments in killing pest eggs, when temperature is not high enough (Fields, 2009). MBTOC also notes that conclusion elsewhere in this section) ().

To resolve the flour mill industry concerns about lack of pest efficacy with the alternatives, while achieving the best possible pest kill efficacy for the environmental impact, MBTOC recommends that for any full site treatment (fumigation or heat treatment) in flour milling, the aim should be to kill all life stages of pests present.

There are still regulatory barriers to the use of effective alternatives, and cost concerns or cost barriers. Regulatory issues pertinent to the use of alternatives in flour mills and in food processing facilities are covered in the regulatory and registration section of this Chapter.

5.9.1.1. Integrated Pest Management – the necessary pre-requisite

Achieving reliable pest control without using methyl bromide requires the use of an intensive IPM program which includes intensive monitoring of infestation levels and regular precisely documented cleaning and pesticide applications (TEAP, 2010). For further information on IPM, the reader is referred to the IPM Section of this Chapter. However, since there is a difference of opinion among IPM practitioners about the extent of inclusion of chemical treatments, and to avoid confusion, information about effectiveness of full site fumigation and heat treatments is included in this section and not in the IPM section.

5.9.2. Technical efficacy of sulfuryl fluoride in flour milling

There had been early questions about the effect of various factors on half loss time for SF fumigations. Efforts have been made to model structural fumigations to try to improve efficacy. The recent research focus on half loss times pertaining to the use of sulfuryl fluoride has indicated that while weather conditions during a fumigation is an important predictor of half loss time, the effect of weather is virtually the same for SF as it is for MB.

After evaluating the effect of weather conditions on half loss times in a flour mill, Kansas State researchers concluded that using past fumigation data as the primary means for evaluating the structural sealing quality of a current fumigation is not adequate. Predictions of fumigant leakage rate and fumigation performance should incorporate quantifiable sealing effectiveness and weather information for the planned fumigation period. Comparisons between SF and MB fumigations indicated that under exactly the same weather conditions and fumigation practices the leakage characteristics of SF and MB do not differ. In practical situations where the dosage requirements for SF and MB are typically not the same, however, the leakage rates of SF and MB fumigations could be different due to the buoyancy effect. Nevertheless, the magnitude of the difference may or may not be significant depending on other factors such as sealing quality, wind speed and direction, and ambient temperature (Chayaprasert, 2009).

In further work comparing MB and SF fumigations in the same mill and with extensive leakage and pressure testing, Chayaprasert and co-workers at Kansas State (2010) determined that MB and SF showed similar gas distribution and leakage. Half loss times were different in the different fumigations but the differences were explained by environmental conditions, primarily wind speed (Chayaprasert et al, 2010)

Maier and co-workers at Purdue University monitored environmental conditions during eight fumigations of three flour mills to create their Computational Fumigation Model. Seven fumigations were with SF; there was one MB fume followed by SF fume in the same facility. Exposure times ≤24 h. Half- loss time was 17 hours. Sealing appeared to prevent heat loss from the fumigated structure. Sealing did not result in pressure build up in the mill. Sealing efficacy, wind speed and direction, mill temperature (and the temperature difference night-versus-day) and circulation fan efficacy were the key contributors to fumigation efficacy. They advised that circulation fans should be left operating during the entire fumigation. Their model can assist mill operators and fumigators what the initial concentration should be under certain wind conditions (Maier et al, 2008).

In another grain-milling modelling analysis, half-loss times (HLT) for sulfuryl fluoride (SF) and methyl bromide (MB) within the structure were simulated. When diffusion dominates (no wind), SF had increased leakage rates of approximately 5.4% over MB. However, simulated HLT due to diffusion are in the order of years for both fumigants. If the wind is blowing at measurable rates, convection-driven losses dominate and leakage from the mill is independent of the fumigant being used. Predicted half-loss times for MB and SF are statistically indistinguishable for external wind velocities from 0.125 to 8 m/ s^{-1}. Therefore, HLTs are insensitive to fumigant physicochemical properties when the wind is blowing. Representative and diverse wind-frequency analysis for California and Texas show limited intervals of calm wind periods, and median wind speeds at or above those investigated in this analysis. Thus, the authors concluded that decisions for product use should be based on efficacy, cost, and environmental impact, since convective-induced leakage rates are similar (Cryer et al, 2008).

In North America, fumigations of grain and flour mills are conducted by licensed pest control applicators under service contracts to the mill. Aside from the satisfaction of mill management, fumigators and research scientists demonstrate success in mill fumigation by the immediate, or delayed, death of insects in test cages. Other measurement methods used by millers include recording pest rebound in the mill structure or equipment. But since mills constantly bring in grains and raw materials, and are often located near significant environmental sources of pests, it is difficult to clearly correlate pest rebound with fumigation efficacy (Subramanyam, 2006).

In the European Union much work has been done to assess and improve the efficacy of sulfuryl fluoride treatments, necessary in view of the ban on the use of methyl bromide.

Working in two UK flour mills, Small (2007) placed traps inside the mill buildings within the areas selected for fumigation. Infestation levels of the insects were monitored for 1-2 weeks prior to fumigation and for a total of 12 weeks post-fumigation. From the calculated percentage reduction in insects trapped per day during the post-fumigation monitoring period it was clear that sulfuryl fluoride fumigations had good efficacy against infestations of *Tribolium confusum* and *E. kuehniella*, and compared very favourably with the efficacy of methyl bromide. The authors noted that the absence of T. castaneum in traps pre-fumigation meant that the efficacy of sulfuryl fluoride against this species could not be assessed in this investigation (Small, 2007).

Buckley and co-workers in four UK mills and two Italian mills used traps to monitor insect populations 3-14 days before and up to 4 months after fumigation using insect traps. Fumigation was very effective in controlling populations of *Tribolium spp*. and maintained it at a low level up to three months or more after application, even with high initial levels of infestation, and there was no difference in terms of efficacy between methyl bromide and sulfuryl fluoride. Rapid reinfestation of *Ephestia kuehniella* in 2 mills and the appearance of *Plodia interpunctella* in 3 situations within the weeks following treatment, illustrated the need to associate fumigation with good sanitation practices, such as disinfestations of adjacent buildings, bins and warehouses, and prevention of insect access through doors and windows (Buckley et al, 2009).

The effect of sulfuryl fluoride fumigations and heat treatments in German flour mills was evaluated by Muck and Boye. Two northern Germany mills were observed; one that milled oats and maize (23,000m^3); and one that milled wheat and rye (volume 40,000m^3). Exposure was 50 h for SF and 40 h for heat (50° C for 24 h). Monitoring was done by dome traps for beetles and delta traps for moths. After SF only three insects were caught in total during three months monitoring. With heat treatment the result was two live beetles in the first month (two floors), and 18 beetles on four floors by the second month. The researchers consider both methods valid since they used to get survivors after MB treatment as well (Muck and Boye, 2008).

Klemenz and co-workers at the Federal Research Center for Cultivated Plants in Berlin Germany looked at the use of sulfuryl fluoride in mills, residue of the gas and efficacy against *Tribolium castaneum* and *Esphestia kuehniella*. Max Concentration/Time (CT) for SF fumigations is 1,200 gh/m^3 and SF can only be used 3x/yr. Klemenz and co-workers asked if the recommended parameters were effective for mills in Germany. A mill of 60,000 m^3 was fumigated for 60 h and with a dosage rate of 1,200gh/m^3. Pest control efficacy against all insects was 98%, and they had some eggs of each species and in one species they only had 92% control rate. Germany demands a 99.9% fumigation success rate (allowed survival of 1 out of 1000 pests). So they have determined that the SF parameters used in Germany are insufficient to meet the German regulation that demands 99.9% efficacy of fumigation. The next research focus of this team will be to look at combination SF and heat treatments plus other methods to improve treatment efficacy (Klemenz et al, 2008).

Reichmuth, from this same institute, reported later in 2008 that German millers indicate that 50% of mills have considerable surviving pests because of egg outgrowth after fumigation. Reichmuth suggested that the reason might be problems of scale up from lab methods to real world milling. For example, he noted that lab measurements suggest a MB dose of 5g/m^3, but the standard structural dosage recommendation for MB fumigation is 20g/m^3. Reichmuth suggested that combination of fumigants, heat and/or other methods be investigated to improve SF treatment efficacy (Reichmuth, 2008).

Also in Germany, the same research team reported on 1-4-day-old eggs, larvae and pupae of the warehouse moth, *Ephestia elutella* (Hubner) (Lepidoptera) that were investigated for their susceptibility to SF under different conditions. Each life stage was exposed for 18 h, 24 h or 48 h, to 11.6 g/m^3 or 21.3 g/m^3 at 15˚C, 20˚C or 25˚C and 65% relative humidity. Within 18 h of exposure, all larvae and pupae of *E.elutella* died at 11.6 g/m^3 at all three temperatures. The 1 and 2- day-old eggs were generally more susceptible, whereas the 3 and 4-day-old eggs were more tolerant to the SF treatment. All eggs of all ages were controlled within 48 h of exposure to the concentration of 21.3 pl 1.3 g/m^3 at temperatures of 20˚C and 25˚C (Baltaci et al., 2009).

Ciesla and co-workers in Bordeaux, France investigated the influence on CT and temperature on Red Flour Beetle (RFB) and Confused Flour Beetle (CFB) eggs. They investigated the use of low dosages of SF, at elevated temperatures and longer fumigation periods in mills of 5000 – 7500 m^3. The intent was to provide treatment guidance in view of the relatively low fluoride residue tolerances in the EU following mill fumigation with SF. Temperature was found to be the most important factor leading to good ovicide kill with RFB eggs; at 30˚C there was 100% mortality. Eggs of CFB are easily killed. Increasing the mill temperature to 30˚C or higher allowed the use of 25% less SF. (Ciesla et al, 2009)

With methyl bromide, older, pre-adult stages are much more likely to survive than eggs, while for sulfuryl fluoride the reverse is true. Insect eggs are more likely to survive the SF treatment than are other life stages.

Some management plans for the use of SF have been designed at dosage levels which will allow some egg survival. This causes concern to millers who believe such a treatment is different than MB, and because a pest control treatment that is designed to allow survival may not meet inspection standards (Adam 2008; Beckett et al 2007; Canadian National Millers 2007 and Reichmuth 2007). Some millers have expressed concerns about the ineffectiveness of SF in killing eggs at low or ambient temperatures, and in some cases, these concerns have discouraged the adoption of SF (Adam 2008; Beckett et al 2007; Bell 2008; Harrison 2008; Reichmuth 2007).

Concern about pest egg survival has delayed acceptance of SF, yet this review indicates that egg survival can be avoided. Additionally, recent research shows even mortality of eggs and large larvae of *T. castaneum* were not significantly different than each other following separate MB and SF fumigations under nearly identical environmental and sealing conditions (Hartzer et al, 2010)

During the SF fumigation egg kill can be achieved by increasing dosage or by increasing temperature. The expense of increasing SF dosage rates or adding supplemental heat to the mill concerns millers. Raising dosage rates may also not be the wisest choice from a total environmental perspective. Based on fumigation and pest kill data submitted for MBTOC's 2008 report and subsequent, in virtually all cases where sulfuryl fluoride was deemed to be most successful, mill temperature was also recorded as ≥ 27°C (80°F) (Bair 2008; Dow AgroSciences 2006; Falvey 2008; Prabhakaran and Williams 2007; Small 2007; Subramanyam 2006, Watson et al 2008). Furthermore, the Kansas State study of two MB fumigations and two SF fumigations on the same site, in matched months in subsequent years, showed the importance of achieving temperature of >27°C. During one SF fumigation temperatures were thought to be above 27°C, but were actually 23-26°C with resulting survival of eggs following the fumigation. At the temperatures actually achieved, there was a 14% underdosing of SF (Hartzer et al, 2010).

The combination treatment, referred to as SF plus supplemental heat by MBTOC, may require additional work and cost. Depending on the weather conditions and mill equipment, raising the mill temperature might be achievable through the use of comfort heating equipment or may require the use of additional heaters. The operation of milling equipment raises the temperature inside the mills; depending on mill location and season it may not take much effort to increase the temperature to >27°C during an SF fumigation. For example, monitoring of 6 US flour mills showed mean mill inside-temperatures during

April – September of 29.6°C. During October – April mean mill inside temperature was 24.0°C (Campbell et al, 2010a and 2010b)

Although some mills have obtained successful SF fumigations without the use of supplemental heat, weighing the full realm of technical, cost, regulatory and environmental issues, leads MBTOC to conclude that the best way to use SF for mill treatment is to use SF at temperatures >27°C.

To resolve the flour mill industry concerns about lack of pest efficacy with the alternatives, while achieving the best possible pest kill efficacy for the environmental impact, MBTOC recommends that for any full site treatment (fumigation or heat treatment) in flour milling, the aim should be to kill all life stages of pests present.

5.9.3. Technical efficacy of heat treatments for flour milling and food processing

There are two types of heat treatments employed in flour mills: full-site (structural) heat treatments and spot heat treatments. This section will first review structural heat treatments, followed by spot heat. Although there are few research papers assessing the effectiveness of structural heat treatments, MBTOC believes the treatment to be in common commercial use in many North American grain and cereal mills. Beckett and co-workers reviewed disinfection of stored products and associated structures with heat in 2007. It is an extensive review and readers of this report are recommended to it for additional detail (Beckett et al, 2007)

Achieving a structural heat treatment involves raising the building temperature to 50-60°C, and, to manage risk of building damage, at a rate of 5°C per hour (and cooling at a rate of 5-10°C) with maximum temperatures not higher than 60°C. Sufficient heaters to ensure that 50°C is reached within 6-10 hours are required (Bartlett et al 2005; Bell 2004; Boina et al 2006; Fields 2006; Subramanyam 2006; Hulasare, 2010).

Careful consideration and planning attention is required to ensuring adequate heat sources are available. When preparing for a structural treatment, pest control professionals use diatomaceous earth (DE), insecticide sprays (and/or insecticidal spraying or oil treatment where allowed by regulation) on basement floors, in floor-wall joints, cracks, crevices and wall voids (Beckett et al 2007; Bell 2004; Canadian National Millers Association 2007; Fields 2006; Fields 2008; Hulasare 2008).

Although the requirements for a successful full-site heat treatment seem clear, a review of the papers cited above and others indicate there is an unexpected degree of complexity to achieve success. Reichmuth noted that the difficulties in achieving a good heat treatment have been underestimated (Reichmuth, 2008). It is important to calculate how much heat energy will be required after accounting for heat losses from, for example, exposed surfaces, equipment and infiltration. Hulasare, noted that in his work with Kansas State researchers, the amount of heat energy should range from 0.074 – 0.102 kW per cubic meter of the facility per hour, although during the 2009 Kansas State heat treatment the energy used was 0.16 kW/m^3 per h. (Hulasare et al, 2010)

The use of air movers or fans is essential to ensure uniform heating. Monitoring temperature during treatments may indicate a need to reposition the heater or air flow to ensure adequate temperature is achieved everywhere. If hot air is pumped into the building, openings for air exchange are needed. The added hot air needs to move to allow temperature to increase and because added hot air increases the air pressure in the building (Hulasare, 2010). Particularly air-tight mills or mill floors overly crowded with equipment may not be as successful in raising temperature during treatments, as was reported at Kansas State mill in 2010 (Brijwanim et al 2010) Using insulated and heated floor mats was found necessary in the UK to raise basement floor and floor-wall joints to temperature (Bartlett et al, 2005 and Bell 2004).

Although stored products pests die in <1 hr at 50°C, achieving a structural heat treatment requires that these temperatures be maintained for 24-36 hours to ensure uniform heat distribution in all portions of the building (Beckett et al 2007; Fields 2006).

Recent research efforts have begun to synthesize these data to provide tools to users for optimizing heat treatments. There are heat calculation models available from US university researchers and others to assist mill managers and fumigators to calculate the required BTUs for a successful heat treatment (Subramanyam 2006; Boina 2008).

Recent research efforts have begun to synthesize these data to provide tools to users for optimizing heat treatments. Boina et al. (2008) developed a model for predicting survival of *T. confusum* during heat treatments. The model was validated with independent data from nine heat treatments in structures, and the model predicted the observed mortality. In a different study, time-mortality relationships were determined for eggs, fifth-instars (wandering-phase larvae), pupae, and adult Indianmeal moths exposed to temperatures between 44 and 52°C. Mortality of each stage increased with increasing temperature and exposure time. In general, fifth-instars were the most heat-tolerant stage at all temperatures tested. Exposure for at least 34 min at 50°C was required to kill 99% of the fifth-instars. Their model was developed to predict survival of mature larvae, which is the most heat-tolerant stage of the confused flour beetle, *Tribolium confusum* (Jacquelin du Val), at elevated temperatures between 46˚ and 60˚C. Their model can be used to predict survival of mature larvae of *T. confusum* during heat treatments of food-processing facilities based on time-dependent temperature profiles obtained at any given location.

Different portions of, or equipment in, the building will heat at different rates. Under some circumstances, some parts of the structure, notably walls or floors in basements of concrete construction, may prove difficult or impossible to heat to the required level because they act as heat sinks. For this reason the use of insulated floor mats, DE and/or insecticidal spraying is needed on these harder-to-heat surfaces. In portions of the building where the temperature is <50°C, insect survival can be expected (Subramanyam, 2006).

Berte worked in the Barilla pasta factory in Italy to study the effect of heat treatment as a disinfestation treatment in the pasta manufacturing structure. In 1994, Barilla decided to stop using MB in favour of alternative techniques. For this reason and for the growing attention that Barilla is paying towards the environment, a mill heat treatment was experimented in 2005, and heat was also applied in a large pasta factory in 2007. Hot-air treatment is based on the principle according to which insects and their eggs, larvae and chrysalids die at temperatures starting from 45˚C due to the result of protein coagulation.

In that study, the gradual heating of the pasta factory (~60,000 m^3), needed to eliminate insect pests, was achieved by using the heat produced by production driers, air-treatment plants and thermal convectors. To check whether all the developmental stages (eggs, adults, larvae) of the pests were dead and to evaluate treatment effectiveness, 30 bioindicator kits were provided each containing the following species: *Plodia interpunctella* (eggs and larvae), *Tribolium castaneum* (eggs, larvae and adults), a mixed population of *Lasioderma serricorne*, and a mixed population of *Sitophilus oryzae*. After having tested heat treatment with success in Barilla mills, it can be confirmed that it is applicable and effective in large pasta factories. The researchers concluded that when the required temperature is maintained for ~40 h, species mortality in all developmental stages could be observed. Treatment with hot air can therefore be used together with other precautionary measures in the fight against pests.

Brijwani and co-workers at Kansas State University looked at heat treatment factors in a cereal plant that has 180 rooms. This facility is now solely heat treated, and heat treatments are done every month. Efficacy improvements now allow for a 17-hr heat treatment, which saves time and money. The study advised to increase the heating rate to kill pests faster and the result will be a shorter heat treatment. Pests will survive in cool spots, below 50˚C. and also in flour residues, so it is important to direct heat to otherwise cool spots and remove flour residues (Brijwani, 2010).

Brijwanim and co-workers at Kansas State (2010) reported that heat treatment can control all life stages of *Tribolium castaneum* in 24 h provided that temperatures of 50°C can be achieved quickly. They recommended that 50°C be achieved by 8-10 hr and held for 14-16 hr. Their work also showed the importance of pre-treatment sanitation to remove flour on surfaces and in equipment where insects can hide. In their two heat treatments, there were survivors on the first (ground) floor level and particularly where insects were placed in cages which also contained flour. On the first floor, it took >17 hours to reach 50°C; the maximum temperature was only 51.95°C and temperature was held for only 6.1 hours. Nevertheless, 50-99% of the test insects were killed. There was about 50% survival of adults hidden in flour versus about 10% survival when flour was minimal (Brijwanim et al, 2010).

Guerra (2009) conducted studies to analyse high temperature treatment of pests in food manufacturing and storing structures. Heat treatment was highly effective and the authors considered it a valid alternative to methyl bromide fumigation. The treatment of 30 h at temperatures ranging from 50 to 59° C was effective against all life stages of *Sitophilus oryzae, Tribolium confusum* and *Oryzaephilus surinamensis*.

Spot heat treatments are also used by some companies as part of a progressively applied pest control program. Spot heat refers to the heating of a piece of equipment, or a zone of a processing facility, with hot air moved by fans or forced hot air (creating a high pressure zone) until the area is heated to above 50˚C for the required time. In Israel the spot heat treatment for mill equipment is 52˚C for 30 minutes (Hazen 2006) Key to the use of spot heat is the additional use of a barrier method to kill pests which will crawl from the heated area in search of cool refuge. Diatomaceous earth, insecticide sprays or food-grade mineral oil applied in a thick drip line can be placed on the floor across routes of escape to kill or trap escaping pests. Spot heat is one alternative available for those processing facilities or situations where a full site treatment is not practicable, or to delay the need for a full site treatment.

Spot heat is considered effective as part of a progressive pest control program where temperature monitoring is done carefully and where additional pest barrier techniques are also used (Beckett et al 2007; Hazen 2006. In the UK, spot heat treatments of an infested area or a particular machine is used as part of a program of rotating pest management treatments (TEAP, 2010).

5.9.4. Monitoring the effectiveness of pest control treatments

Campbell et al. (2010a) describe a study in which data from long-term red flour beetle pheromone trapping programs in two flour mills was used to evaluate the impact of structural fumigations of either methyl bromide or sulfuryl fluoride on pest populations. The two mills differed in mean number of beetles captured and proportion of traps with captures of one or more beetles, but in one of the mills the mean number of beetles captured was reduced after implementing a more intensive integrated pest management program. Mean number of beetles per trap and proportion of traps with captures immediately after fumigation were both positively correlated with number captured per trap and proportion of traps with captures in the monitoring period immediately before fumigation. Mean daily air temperature inside the mill fluctuated with the season, and although always warmer than the outside temperature, the relative difference varied with season. Although outside temperature differed between spring and fall fumigations, inside temperature and reduction in beetle captures was not affected by season.

The authors also examined population rebound of red flour beetles after fumigation (Campbell et al. 2010b). Rebound in mean number of beetles captured and the probability of a trap capturing one or more beetles was evaluated. Rebound to a threshold mean beetle capture of 2.5 beetles per trap per 2-wk period took 174 ± 33 days and rebound took longer rafter fall (248 ± 50 d) than spring (104 ± 21 d). Rebound to the probability of capture threshold of 0.50 was 120 ± 21 d, but there was no significant effect of season. The improved IPM practices in one mill were associated with an increase in time to reach the capture threshold defined above (49 ± 15 days before implementation of the program versus 246 ± 71 days after). Results show how an IPM program could reduce the need for fumigation and also provide a threshold number for evaluating risk due to red flour beetles for pest management programs inside flour mills. Simulation models have also been developed for red flour beetle populations in flour mills (Flinn et al. 2010), which can also be used as part of IPM programs.

One of the challenges in integrated pest management is using insect traps and product sampling to assess treatment efficacy from contact insecticides. Toews et al. (2009) conducted replicated studies in pilot-scale warehouses by first treating the warehouses with cyfluthrin, and then placing food patches infested with all red flour beetle life stages underneath shelving material. The food patches, those initially infested and additional uninfested, were surrounded by cyfluthrin bands to evaluate if insects would cross the bands. Results show that insect captures correlated with population trends determined by direct product samples in the untreated warehouses, but not the cyfluthrin-treated warehouses. However, dead insects recovered from the floor correlated with the insect densities observed with direct samples in the cyfluthrin-treated warehouses. The authors contended that pest management professionals relying on insect captures in pheromone-baited traps in cyfluthrin-treated structures could be deceived into believing that a residual insecticide application was suppressing population growth, when the population was actually increasing at the same rate as an untreated population. Interpreting trap catch data continues to be a challenge for integrated management of stored product insects.

5.9.5. Frequency of structural fumigation and heat treatments – and some thoughts on cost

Pest control managers report that determination is required to resolve the difficulties that are commonly experienced in the first trials of a new fumigant or technique (Bradley, 2008; Falvey, 2008; Watson, 2008). Although formerly mills and food processing facilities were commonly fumigated with methyl bromide 1-3 or more times per year, it is now uncommon that a full site methyl bromide fumigation be conducted more frequently than once a year. At this time in North America, for those facilities still using methyl bromide, full site fumigations are usually only conducted once per year or once per every few years during a normal shut-down holiday period.

In Canada, all the mills and food processing facilities now using CUN MB are located in regions where cold temperatures can extend from late October through April. Consequently, structural fumigations and heat treatments, including trials of alternatives, are still normally scheduled between mid-May and mid-November (and not in the cold months) (Environment Canada, 2010).

There have been reports from Canada and the US that that companies using full site heat treatment have to conduct those treatments more than once per year. Some food processing facilities using spot heat have a regular and frequent program which involves heating different sectors of the facility in rotation, effectively several times a year.

Since the transition to SF is still in flux at time of writing, the frequency of fumigations required for those mills and food processing facilities using SF is still uncertain. In its review of the effectiveness of the use of sulfuryl fluoride in Canada the Government of Canada reported that, "Trials completed to date confirm that SF will not reliably kill all life stages (eggs survive) of stored product pests, even under model fumigations that achieve target concentrations for the required period of time. This may require the need for two or more fumigations annually, even in mills with a history of one MBr fumigation annually." (Environment Canada, 2010).

The economics of methyl bromide alternatives are discussed in another chapter of this Assessment Report. No milling or food processing or pest control industry sector member will release cost data for fumigations. Some cost data have been reported resulting from the Canadian trials (Canadian National Millers, 2007). Knowing that the cost of sulfuryl fluoride is more costly on a per kilogram basis than is methyl bromide and that furthermore more sulfuryl fluoride has to be used per facility than would be required for methyl bromide, that heat treatment often has a high(er) energy cost, that if SF and supplemental heat are combined then costs increase, and the preponderance of informal comments leads MBTOC to the obvious conclusion alternative treatments cost more. But how much more is an unknown.

In discussing costs to its industry sector, Government of Canada indicated that for sulfuryl fluoride treatment, "…the cost implications are significant in that the amount of SF used in a fumigation is variable and highly weather-dependent (wind velocity, direction and ambient outdoor temperatures). The underlying point in this excerpt is that a practical necessity of using a greater quantity of an alternative fumigant in gas form in the interest of efficacy may give rise to unforeseen cost implications as well as raise questions about the environmental merit of the alternative in question (Environment Canada, 2010).

There are also significant capital costs being incurred for structural modifications and/or acquisition of heat generation and circulation equipment where mills have opted to adopt heat treatments in their longer term pest control programs.

5.9.6. Progress in adoption of structural alternatives

In 2003 and 2004 when Parties began to submit critical use nominations, MBTOC received CUNs for flour milling and food processing from: Belgium, Canada, France, Germany, Greece, Ireland, United Kingdom and United States. The European Commission reported to MBTOC that MB had been used in mills in 17 of the EU-27 countries at some time in past years. Now, however, all EU mills and food processing facilities are using alternatives to MB and are not using MB. Mills in the EU are using a wide range of alternatives, in combination with IPM (European Commission 2008; TEAP 2010).

In 2010, only Canada and the United States submitted critical use nominations for MB to disinfest flour mills and food processing facilities.

In Canada, critical use nominations were formerly submitted for 22 flour and cereal mills; in 2010, only ten flour mills were included in the CUN for 2012. In its CUN documents submitted to MBTOC (which MBTOC holds confidential), Canada describes the size of the mill, the percentage of the mill fumigated with MB, a description of the mill construction and age (which assists us to understand sealing and efficacy issues), a note on the availability of in-house steam boilers (which assists us to know if heat treatment is more reasonably accessible) and the presence of internal vacuum systems (which assists us to evaluate their IPM program).

Canada has achieved decreases of MB use in this sector of 7-25% per year. It did so by first having a multi-year cooperative research project funded jointly by government and industry, using the resources of industry and with a government research scientist (see references by Fields, numerous years). Information obtained on efficacy and costs of the trials of alternatives in this research program were shared within the sector and by MBTOC (without releasing the names or locations of the mill). Later, Environment Canada changed its pest control regulations to allow sharing of MB allocation among same sector industry members who were included in the CUN. This meant that mills did not have to ‘use or lose’ their annual MB allocation and in practise this meant that some mills began fumigating less often than once per year. Adoption of alternatives in this sector is continuing.

Reviewing information from Dow AgroSciences, MBTOC members and other sources, between 2008 and 2010, between four and six mills were fumigated with sulfuryl fluoride. This is estimated to represent about 55% of the Canadian fumigation market. The rest of the market share would be divided between methyl bromide and heat, plus the one or two mills which use the combination heat, phosphine and CO_2 method. We also believe that the fumigation market overall has decreased considerably as some mills have improved IPM systems such that their need for a full site treatment has considerably decreased.

In 2010, Canada submitted a CUN for 2011 which included three pasta processing facilities, with only part of each pasta plant included in the CUN. While the same three pasta facilities have been listed in Canada's pasta CUN for several years now, the frequency of fumigations has decreased, and the CUN included decreasing proportions of the facility. This sector was, until recently, behind in its adoption of alternatives. Recently however, the sector has begun commercial trials of sulfuryl fluoride and placed more emphasis on IPM procedures. Commendably, in late 2010, the sector notified Environment Canada that it would not submit CUNs in 2011 for 2012.

The United States submits a CUN for structures which includes flour and rice mills, and pet food facilities. It is unknown to MBTOC how many structures are included, their description or location. This CUN has decreased by 0-25% each year, in some years because MBTOC reduced nominations if the same amount was nominated as the year before. The use of MB by rice milling sector has decreased much faster than flour milling or pet food facilities. Essentially no verifiable data exists on the extent of adoption of alternatives by the mills and food processing facilities included in this sector. Additionally, MBTOC has been told that this sector is one of the sectors that uses the available pre-2005 MB stocks, but this is not verifiable.

Reviewing information from Dow AgroSciences, MBTOC members and other sources, we note that in 2009, sulfuryl fluoride had 46% and 55% of the flour milling and rice milling fumigation market in the US, and that 28% and 12% of SF sales were for flour mills and rice mills respectively.

The US also submits a CUN for food processing facilities which includes the equipment used to process herbs and spices and cheese infested while in storage in manufacturing facilities ('cheese stores'). This is the US NPMA CUN. It is unknown to MBTOC how many structures are included in their CUN. In 2010 MBTOC only recommended 200 kg of the nomination and only for the cheese stores portion (and did not recommend over 1.7 tonnes of MB for the other sectors in this CUN).

Reviewing information from Dow AgroSciences, MBTOC members and other sources, we note that in 2009, sulfuryl fluoride had 10% of the food processing fumigation market in the US. As explained below, the utilization of SF would be expected to increase in this market in 2011.

During 2010, the US National Pest Management Association (the NPMA CUN applicant), achieved a breakthrough in a key barrier to the use of SF as an alternative for this sector. After what was probably considerable work, the US Environmental Protection Agency agreed to clarify the interpretation of unclear wording in the label for sulfuryl fluoride, a controversy which had started with a letter from EPA (Hazen 2006). This effort by the industry sector, which involved explaining to the regulator how the sector manages to minimize the presence of food prior to and during a fumigation, resulted in a letter from EPA which the NPMA now says will allow its members to use SF without threat of legal prosecution, as long as the presence of food is minimized in the method outlined in the letter (Rossi, 2010). This breakthrough will also impact the use of SF in the structures CUN.

Commendably, the US NPMA has submitted a letter to the US EPA saying that as a result of the clarification from EPA, the US NPMA does not intend to submit a CUN in 2011 for

2013. In 2009, Parties had granted over 17 tonnes of methyl bromide for this use, so this case is an excellent illustration of how a regulatory change, even in just the interpretation of a regulation, can have an important impact on reducing methyl bromide use.

5.10. Pest control alternatives for commodities

5.10.1. Introduction

Essentially all stored food and agricultural commodities are subject to pest infestation. In addition, other commodities such as furniture, home décor items and historical artifacts are sometimes infested. In past decades, pest control of these items was accomplished through fumigation with methyl bromide.

Now, fewer types and volumes of commodities are fumigated with methyl bromide and numerous alternatives have been found, or more accurately re-purposed or re-utilized to control pests.

Most pests of stored commodities are common worldwide, or common worldwide in that type of commodity. Therefore, in this section, MBTOC is reviewing the alternatives not by commodity, but by alternative. The alternatives are discussed here alphabetically, but by far the most commonly used alternative for control of pests in stored commodities is phosphine. Note that new or current regulatory issues pertaining to these alternatives are discussed above, in the regulatory section; the reader is also directed to review labels for product use registered by each country's regulatory agencies.

The exception to the alphabetical listing of commodity treatments is Controlled Atmosphere. Since its last Assessment Report in 2006, adoption of controlled atmosphere techniques has significantly increased and so this subject is covered in more detail, with its own section.

Since pest control of dates is a problem of several countries. Since there have been separate Decisions of the Montreal Protocol concerning pest problems of dates, MBTOC has prepared a separate section of this Assessment Report on dates and alternatives treatments later in this Chapter.

5.10.2. Carbonyl sulphide

Carbonyl sulphide (COS) is a major sulphur compound (with a typical sulphide odour) naturally present in the atmosphere at 0.5 (± 0.05) ppb; it is a colourless gas (Wright, 2000). The average total worldwide release of carbonyl sulfide to the atmosphere has been estimated at about 3 million tons/year, of which less than one third is related to human activity (Hazardous Substances Data Bank, 1994). It is also present in foodstuffs such as cheese and prepared vegetables of the cabbage family. Traces of COS are naturally found in grains and seeds in the range of 0.05-0.1 mg kg^{-1} (Wright, 2000; Navarro, 2006). The compound is naturally present in the environment as part of the natural global sulphur cycle, occurs naturally in food and breaks down rapidly, with a high turnover (Obenland et al. 1998; Caddick 2004; Bartholomaeus & Haritos 2005). Plants are able to metabolise carbonyl sulphide and synthesise it (Protoschill-Klrebs & KesseMIer 1992; Feng & Hartel 1996).

The use of COS as a fumigant for the fumigation of durable commodities and structures was patented worldwide in 1992 by CSIRO; for several years registration has been sought in both Australia and New Zealand. A lack of data for chronic health levels is holding up registration in both countries. COS has been trademarked in Australia as COSMIC®. BOC Limited has an agreement with CSIRO for its manufacture and worldwide distribution (Ducom, 2006). It has good penetration action, and commodity sorption is generally less than that of either methyl bromide or methyl iodide (Schneider et al. 2003). Carbonyl sulphide has similar efficacy on a w/w basis against insects as methyl bromide, and faster efficacy than phosphine (Caddick 2004). It does not react as fast as methyl bromide with grain, and is thus easier to retain at higher concentrations. Where tolerant egg stages must be controlled, it is beneficial to extend the exposure time.

Carbonyl sulphide has a low boiling point of - 50.2°C with a vapour pressure of 9412mm Hg and is readily gasified at room temperature, Therefore it can be applied directly into the grain bulk where it is dispensed into the intergranular air space. This method of application provides simple, safe, fast application and even gas distribution in the silo (Ren et al 2007). This compares to MB, which has a boiling point of 3.7°C, and therefore should be applied using a heated vaporiser to distribute the fumigant and minimise residues.

COS does not show any reaction with a variety of materials including hard and soft timbers, paper, iron, steel and galvanized sheet, PVC, polyethylene, and brick applied with high concentrations at high temperature and relative humidity (Wright, 2000). However, to avoid corrosion on copper, Ren and Plarre (2002) suggested that COS for direct use as a fumigant must be manufactured to minimise hydrogen sulphide contamination (to <0.05%, v/v), or the fumigant scrubbed of H_2S before application on site. Sorption studies with higher moisture content commodities, such as wheat at 18% moisture content, show a rapid loss of COS, by hydrolysis to H_2S and carbon dioxide, at rates that would make COS fumigation impracticable (Wright 2000) and can result in a strong sulphur smell. This characteristic may make it unsuitable for fumigation of products such as export logs that have high moisture content within the fumigation enclosure and may result in ephemeral smells after treatment.

While COS is flammable with a range of 12 %(V) - 28,5 %(V) , this is well above the 2% or less suggested for fumigation of grain with standard precautions related to dilution.

5.10.2.1. Efficacy

Fumigation with carbonyl sulphide has been studied for control of insects in stored products, durable commodities and structures (Desmarchelier 1994; Zettler et al. 1997; Wright 2001).

COS at practical concentrations from 10 to 40 g/m^3 has been shown to be effective on a wide range of postharvest pests in all stages, including mites, at exposure times between 1-5 days at temperatures above 5°C (Desmarchelier, 1994). Amongst the tested pests, *Sitophilus oryzae* (L.) was found to be the most tolerant species to COS and could be controlled at 20 g/m^3 with 5 days of exposure at 30^{o}C (Weller et al 2001). Research on COS in Australia, Germany and the USA revealed that the egg stage was the most tolerant to the fumigant, however, the effective exposure period was half that of phosphine. COS is effective at temperatures above 5ºC (Rajendran, 2001). There have been exceptions whereby a 2h fumigation of carbonyl sulphide at 80 g/m3 failed to control codling moth eggs and red scale (Aung 2001). Eggs tended to be more tolerant of carbonyl sulphide fumigation than adult weevils, when fumigated with 25 g/m3 at 30°C (Weller & Morton 2001). Carbonyl sulphide fumigation should be conducted when the temperature is 15°C or above.

Wheat (Australian Standard White) with a moisture content of 10.2% was fumigated with liquid carbonyl sulphide (COS) via the top of the silo and released 2 m below the grain surface at a calculated application rate of 24.14 g m^3, in a sealed concrete vertical silo (3512 m3, 2500 t wheat) in Australia. With 2 h of recirculation using a 0.4 kW fan, the in-silo concentrations of COS achieved equilibrium with a concentration variation less than 5% of the mean. After a two-day exposure period, the COS concentration in the silo remained at 29 g m^3. The concentration×time product (Ct) was 1900 g h m−3, and this achieved complete kill of all life stages of mixed-age cultures of *Sitophilus oryzae*, *Rhyzopertha dominica*, *Tribolium castaneum* and *Trogoderma variabile*. After 2-days exposure, the silo was aired overnight with an aeration fan (25 kW) resulting in a COS in-silo concentration of below 4 ppm which is 2.5 times lower than the Australian Experimental Threshold Limit Value (TLV) of 10 ppm. Residues of COS in the wheat declined to below the Australian Experimental Maximum Residue Limit (MRL) of 0.2 mg kg−1 after overnight aeration. The COS was not detected in any outloading samples at concentrations above the detection limit (0.05 mg kg−1). The workspace and environmental levels of COS were monitored during application, fumigation, aeration and outloading. The levels of COS and hydrogen sulphide (H2S) were less than the detection limit of 0.1 ppm, which was 100 times lower than the TLV of 10 ppm. The treatment with COS had no affect on the wheat germination and seed colour when compared with untreated controls. Oil quality tests showed that COS had no effect on total lipid (made from treated wheat) content or the lipid colour (Ren et al 2008).

Short exposure times at 25°C have been investigated for treatment of surface insects on tropical fruits and flowers (Chen & Paull 1998). Avocados, mangos and papaya tolerated a 1% (26.5g/m3) treatment of carbonyl sulphide for 7, 3 and 16 h, respectively. Red ginger inflorescences were less tolerant of carbonyl sulphide than fruit, being able to withstand 1% (26.5g/m^3) for less than 2 h. Lemons can tolerate a 70 g/m^3 treatment for 8 h without reduction in market quality (Obenland et al. 1998). Fumigation of nectarines with 80 g/m^3 carbonyl sulphide for 2 h at 21°C intensified peel colour, delayed fruit softening and did not adversely affect fruit quality (Aung 2001). Phytotoxicity studies conducted on 12 species of cut flower have shown that phosphine is least toxic followed by carbonyl sulphide, methyl bromide and hydrogen cyanide. Carbonyl sulphide at the rate of 15 g/m^3 for 5 hours is very effective in controlling the target pests and caused phytotoxic damage to only two out of 12 treated cut flower species. Although phosphine (0.25 g/m^3 for 5 hours) was least toxic to the treated cut flowers, it was not as effective in controlling the target pests (Weller & van Graver Je 1998).

5.10.2.2. Phytoxicity

Seed germination in wheat, oats, barley and canola was not affected by COS fumigations (Wright, 2000). However, there are contradictory reports in the literature on negative effects of COS on germination of cereals except sorghum and barley, off odours in walnuts, in milled rice, and colour change in soybeans (Navarro, 2006). There has not been any adverse effect found on quality of bread, noodles or sponge cake (wheat flour) (Desmarchelier et al., 1998), on malting and brewing characteristics of barley, or on the oil content/colour of canola (Ren et al., 2000).

5.10.2.3. Conclusion

Currently, phosphine is the fumigant of choice for grains due to its low cost, availability, versatility in application, ease of use, and global acceptance as a residue free treatment. However, major stored product insects have already developed strong resistance against phosphine in some countries and unfortunately resistance is spreading throughout the world. COS may provide an alternative in some circumstances.

5.10.3. Ethyl Formate

There has been interest in ethyl formate, a high-boiling (54^0C) fumigant, for many years particularly in Australia; there has been renewed interest in the chemical recently in the search for alternatives to methyl bromide. In consequence, a few research reports have appeared since the last Assessment Report. However, MBTOC is unaware of any expanded major commercial use of ethyl formate. For information on the use of ethyl formate in Australia, where it has been used and registered for some years under the trade name Vapormate™, readers should refer to the MBTOC's 2006 Assessment Report.

Tests have been conducted in Israel on the effectiveness of ethyl formate as an alternative to MB for the control of nitulid beetles infesting dates in the immediate post-harvest period. Finkelman et al., (2010) used the fumigant formulation Vapormate™ containing 16.7% ethyl formate mixed with carbon dioxide. Under laboratory conditions using artificially infested feeding sites at 30^0C, varying dosage rates and a 12-hour exposure, larvae of *Carpophilus spp*. exposed to a concentration of 280 g m^{-3} of Vapormate™ resulted in 69.3% disinfestation and 79.9% mortality. Increasing the dosage rate increased larval mortality and optimal results were obtained at 420 g m^{-3} where 69.9% disinfestation and 100% mortality resulted. In commercial pilot-plant tests using the optimal dosage parameters, a 9 m^3 flexible liner made of a polypropylene/aluminium/polythene laminate was used to cover crates containing infested dates.

The effectiveness of ethyl formate was tested on naturally infested dates resulting in an average 100% disinfestation and 95% insect mortality, whilst with artificially infested dates, disinfestation was 95.6% and mortality 96%. In a second series of tests using a commercial rigid fumigation chamber of 95.6 m^3 capacity, 100% insect mortality was achieved in all dates using a 12-hour exposure period. Following these promising results, Vapormate ™ was registered in Israel for use on dates as an alternative to MB (Finkleman et al., 2010). (To assist the reader to understand the nuances of the terminology used in this research, the term disinfestation used here means that the insects exit the fruit before dying; mortality means death of the insect. Nitulid insects infest dates internally, and as a result, consumers may refuse to consume the dates, or may be prohibited to consume them on religious grounds.)

Recent research has included modeling the kinetics of ethyl formate sorption by wheat (Darby et.al., 2009). These workers found that grain rapidly adsorbs ethyl formate which may lead to inadequate fumigant concentrations and unacceptable residue levels in treated grain. The model successfully predicts air and grain fumigant concentrations relevant for grain disinfestation and food residue contamination. The form of the model should be applicable to all fumigant-grain systems, as it accounts for the diffusion and reaction influences known to occur with all modern fumigants under concentration and exposure conditions relevant to industry.

Haritos and co-workers (2006) suggest that the introduction of ethyl formate as an alternative to MB faces significant challenges due to its poor penetration through grain, significant losses due to sorption on grain, high concentrations needed to control insects and flammability risks. They suggest that these factors have limited its further development as a fumigant, but in a study these researchers found that the combination of carbon dioxide (5-20%) with ethyl formate significantly enhanced efficacy of the fumigant against external living stages of *S. oryzae, R dominica* and *T. castaneum*. In another investigation, a mixture of ethyl formate (100 mg L^{-1}) and 20% carbon dioxide was pumped through a model silo containing wheat (50 kg) for one gas exchange. A flow rate of 6 litres /min. gave a relatively even distribution of fumigant throughout the grain column and similar mortality levels were found among cultures of S. oryzae and *T.castaneum* placed at three positions, the top, middle and bottom of the column. Mortality of 99.8% of mixed stage cultures of *T. castaneum* and 95.1% of S. oryzae was achieved in 3 h exposures to 111 and 185 mgh/litre ethyl formate respectively. It is concluded that the combination of carbon dioxide with ethyl formate and dynamic application enhances distribution and efficacy of the fumigant against stored grain insects.

In a paper entitled "Use of fumigation for managing grain quality" Somiahnader and Ventakata-Rao (2007) suggest that, among other chemical fumigants reviewed as potential alternatives to MB, ethyl formate appears promising for on-farm storage and
for space treatments. They suggest also that studies are necessary to optimize the use of ethyl formate for such treatments.

Rajendran and Sriranjini (2008) have reported that ethyl formate in combination with essential oils derived from plants was found to be effective in controlling moth species such as *Corcyra cephalonica* and *Sitotroga cerealella*.

Deng et al. (2010) have previously examined the effectiveness of ethyl formate on the psocid *Liposcelis bostrychophila* demonstrating its effectiveness in controlling this pest of large grain depots in China and showing that control of the psocid could be achieved in 24 hours with better control at lower rather than higher temperatures. In more recent studies, they also report the effectiveness of ethyl formate to control DDVP and phosphine-resistant strains of *L.bostrochophila* in laboratory investigations using a range of concentrations, temperatures and exposure periods. It was concluded from the test programme that ethyl formate could be considered as an effective fumigant to control DDV- resistant strains of this psocid pest.

5.10.4. Modified Atmospheres

Modified atmosphere treatments include a variety of methods to modify the gases and conditions of storage to result in the death or control of pests. Modified atmosphere methods differ from controlled atmosphere treatments because they often do not maintain a standardized control of the atmosphere. Since the commercial adoption of controlled atmosphere treatments has really advanced since MBTOC's previous Assessment Report, we have included a separate section about it below.

Yang and co-workers in Beijing China investigated the effect of different oxygen concentrations and temperature on respiration of *Tribolium castaneum.* Low O_2 is the preferred controlled atmosphere treatment in China because CO_2 is expensive but they can manipulate low O_2 by manipulating nitrogen, which is less expensive in China. Controlling pests with O_2 is considered green technology and includes the additional benefit of inhibiting fungi in grain. Oxygen concentrations of less than 2% for more than 15 days will control heavy grain infestation (such as when grain arrives at the warehouse). Another approach is to control the O_2 concentration to between 5-10% for more than 2 months which will both inhibit pest development and fungi (Yang *et al*, 2008).

Riudavets and co-workers in Spain worked to find methods to shorten the time required for effective modified atmosphere (MA) treatment of rice against rice weevil. Current MA methods take too long for effective treatment (at 40 – 100% CO_2) it takes 5 days for control of eggs of *S. oryzae*. Because of the difficulty to obtain registered fumigants in the EU, Ruidavets et al looked at combining CO_2 with SO_2 which in EU is accepted as a food additive. 3% SO_2 and 70% CO_2 worked well; increasing concentrations of SO_2 increased effectiveness. At 50 -150 ppm SO_2, the researchers did not report flavour problems but this aspect was preliminary and the subject of future work. Examining rice, flour and almonds for residues, they found wheat flour sorbs the SO_2 most. Aeration to obtain 50ppm which is the regulatory limit, would take 24 hr to 7 days depending on fumigant concentration (Ruidavets *et al*, 2008).

Navarro reviewed achievements in modified atmospheres and fumigation in Israel. Treatment by modified atmospheres is carried out in a wide variety of structures, including rigid structures, plastic structures, flexible silos lined with wire mesh, liners to enclose bag stacks and storage cubes. Commodities disinfested with modified atmospheres in Israel include organic wheat, grains, cocoa beans, bulbs, dried fruits and museum artefacts (Navarro, 2008)

Elpano and Navarro used hermetic storage to control aflatoxin of high moisture corn under tropical conditions. Corn for animal feed is harvested in Philippines in unfavourable conditions (25.65% moisture content, and can be as high as 35% moisture content in harvest). This corn (Monsanto's Bt corn) needs to be stored gas tight, with minimal loss weight and quality. They used Grain-Pro cocoons and the sleeves which can line shipping containers. The test period was March to September and September to January. There were no significant changes in starch or alcohol content over time. Carbohydrates were converted to lactic and acetic acids; protein content increased. RH and temp stabilized by 500 hr. During the first four days there is an increase in temp, but then respiration stops. Aflatoxin increased from 59 ppb to 90 ppb in one week and stayed at that level. There was no reduction in palatability and digestibility for cattle and swine growth (Elpano and Navarro, 2008).

Jonfia-Essien and co-workers conducted a project for the Ghana Cocoa Board to examine the effectiveness of hermetic storage in insect control and quality preservation of cocoa beans in Ghana. Ghana does not use MB to disinfest cocoa beans; phosphine is used. Insect infestation breaks down the nib and cocoa butter and it increases free fatty acids and causes flavour problems. Some insecticides cause residues which are not accepted by importers. They wanted to use modified atmospheres to biogenerate an O_2 deficient and CO_2 rich atmosphere for insect control. And they wanted to reduce operational costs and reduce use of insecticide. A bag stack was built inside the cocoon using *Tribolium castaneum*, *Lassioderma serricorne*, *Carpophilus hemipterus* and *Araecerus fasciculatus* as test insects in bags in the cocoon. The cocoons were left outside (temperature ranged from 28 – 32° C). O_2 content in the cocoon decreased constantly each day so that by day 17-18 there was zero O_2. In the cocoons after 6 weeks there was 100% mortality of both pests in the cocoons.

Three weeks was not a sufficient treatment; the 3 week samples showed some pest survival. Pests crawled out of the cocoa bean and were found only on the bottom of the cocoon. The cocoon did not result in any condensation on the cocoa. After 9 weeks no change in quality was found. So, hermetic storage was better for pest control when they have extended storage periods, good for quality and more economical and convenient. They say this because their standard storage requires use of sand snakes for sealing fumigation sheets at floor level and insecticides, and these standard storage methods result in condensation which harms the cocoa. The researchers said that if not fumigated there are several insect species infesting cocoa beans with a usual infestation rate of about 40 – 60 insects per 60 kg bag (Jonfia-Essien *et al*, 2008).

Johnson, of USDA in California worked on vacuum treatment for California tree nuts, using GrainPro cocoons. Moisture content of the product and life stage of the pests can affect pest control efficacy, diapausing stages are very resistant. Structures used for modified atmospheres also hold vacuum and they can get a vacuum in 10 min. Looked at low, medium and high moisture content. At 25˚C, and higher moisture, and especially with diapausing pests they found lower levels of control. At 30˚C even in high moisture and with diapausing pests they achieved 100% mortality at 20 hours, except with walnuts where they never achieved 100% mortality even at 30˚C with diapausing pests. This researcher again reported difficulty zipping the cubes, but the problem was overcome with practise. They had to use sand snakes around stacks to prevent rodent incursion. In field trials there was the additional problem of decreasing ambient temp (as autumn progressed) which increased difficulty to kill pests. If ambient temp is below 25˚C, it is necessary to extend the treatment beyond 72 hours (Johnson, 2008).

5.10.5. Phosphine

Phosphine continues to be used worldwide for fumigating a very wide range of bagged and bulk agricultural durable crops, both in store after harvest and in transit, and has also been used to disinfest wooden pallets (Rajendran and Kumar, 2008). (MBTOC notes however, that the use of phosphine does not satisfy ISMP 15 quarantine treatment for wooden packaging materials.) MBTOC is not aware of any other new uses for the gas in addition to those given in the 2002 or 2006 Assessment Reports although more countries have adopted phosphine use for situations where a particular use has proved a success in another country.

Phosphine continues to be the only fumigant that is registered worldwide for the disinfestation of durable commodities. Although used principally on cereals, legumes and dried fruit, it is also used to treat a variety of other commodities. Generator-produced or cylinder-based supplies of phosphine gas, in addition to the traditional metal phosphide formulations releasing the gas, are now used as a direct replacement of methyl bromide for treatment of a wide range of commodities (Kostyukovsky et al., 2010; Ryan and Shore, 2010; Ryan et al., 2010; Wang et al., 2006).

The potential for further replacement of methyl bromide by phosphine is now very limited.

The toxic action of phosphine on insects is much slower than methyl bromide and in consequence, much longer exposure periods are required. There is a small advantage here of using a direct application of phosphine gas because concentrations in the commodity can build up within a few hours instead of over several days, but still an exposure time ranging from 3 to 15 days, depending on species and temperature, is needed for complete control of pests

(Romanko and Mamontov, 2009; Mordkovich, 2008). In addition, phosphine is often not recommended for use at temperatures below 15°C because the gas requires active metabolism of oxygen to be toxic and below 15°C some insects become almost quiescent and able to survive very long exposures, up to several weeks in some cases.

Phosphine's corrosive effects on copper has largely precluded its use where electric cabling and electric components would be at risk. Methods to avoid corrosion have been developed; a combination of phosphine, CO_2 and heat is used as a structural fumigant in some flour mills in Canada.

Also, in conditions of low relative humidity, solid chemical formulations generating phosphine may not be suitable because there may be insufficient moisture to enable release of the gas. This is in stark contrast to the 24-48 h period used successfully for methyl bromide over a wide range of temperatures and humidities. The relatively long periods required for effective fumigation using phosphine make it unsuitable as a replacement for methyl bromide where short-period treatments are essential.

5.10.5.1. Insect resistance to phosphine

The big issue regarding the continued successful use of phosphine for control of stored product pests is the development of resistance. Resistance to phosphine was first detected more than 30 years ago and details of the problem associated with resistance can be found in earlier MBTOC Reports (1994, 1998, 2002, 2006). Recent occurrences of strongly resistant strains have been reported from Australia (Nayak et al., 2010) in the rusty flat grain beetle Cryptolestes ferrugineus, surpassing the previously encountered high resistance levels in the lesser grain borer Rhyzopertha dominica, the psocid Liposcelis bostrychophila, the maize weevil Sitophilus zeamais and the rice weevil S. oryzae (Lorini et al., 2007; Nayak and Collins, 2008; Pimental et al., 2009; Wang et al., 2010). At 20°C a concentration of 720 ppm needs to be maintained for 24 days to achieve control. A report that very high phosphine concentrations of up to 4 times this level (4 g/m^3) could control a wide range of pests within 48 h at 20°C when applied rapidly by use of a heater ventilator device with magnesium phosphide plates as the gas source (Kostyukovski et al., 2010) remains to be tested against resistant strains.

Developing and adapting management strategies to cope with phosphine resistance is under continued study (Naito et al., 2007; Nayak and Collins, 2008; Sousa et al., 2008, Pimental et al., 2009; Emekci, 2010; Nayak et al., 2010) together with investigations on the nature and basis of the resistance mechanisms (Pimental et al., 2007; Campbell, 2008; Schlipalius et al., 2008; Park et al., 2008; Sousa et al., 2009; Thorne et al., 2010)

Further details of the use and properties of phosphine were given in the MBTOC's 2006 Assessment Report.

5.11. Controlled atmospheres, an alternative to the fumigation of commodities in chamber or silo

5.11.1. Controlled Atmosphere- the basics

Controlled atmosphere (CA) treatments are based on the establishment of a low-oxygen environment which kills pests. CA's are established by means of an oxygen converter system. The best method to use for this system is a pressure swing absorption converter to create low oxygen levels between 0.5% and 1.5%. CA can be applied in airtight environments ranging from 1m^3 to 1000 m^3. Insects in all stages are eliminated (99.996%) because of the lack of oxygen which causes the insects, larvae and eggs to dry out and suffocate.

The infested products are exposed to CA in airtight climate rooms equipped to handle variable sorts and quantities of products. The temperature, oxygen and humidity are controlled in each room within a specified range of parameters known to be lethal to the pest(s). The treatment normally requires 1 to 6 days, depending on the type infestation and product temperature. The treatment is fully automated and can be initiated, monitored, managed and halted online by computer if required.

CA is also a highly effective treatment to control insects in artefacts of historical value as this treatment does not affect paper, paint, leather, textile, wood, metal, plastic, ink and varnish. The objects or products can be treated even if packaged. For these products, the level of humidity in particular must be closely monitored in order to comply with local cultural heritage regulations. Emekci and Ferizli (2009) reported that methyl bromide use in Turkey has been completely banned in the postharvest sector (except quarantine and preshipment applications) since 2004. In that country museums and historic buildings containing cultural artifacts which were previously fumigated with MB faced a pest extermination problem after use of MB ceased. In their paper, Emekci and Ferizli reported on the effectiveness and applicability of high nitrogen gas treatments of historic artifacts, as one of the current alternative methods to MB now used in Turkey (Emekci and Ferizli, 2009).

The climate chambers are also suitable for the treatment of imported products or objects that might contain pests from foreign countries.

The use of controlled atmospheres on post-harvest durables is growing rapidly and replacing methyl bromide as well as phosphine in many circumstances. As commercial companies developed controlled atmosphere systems for customers they managed to resolve the practical difficulties and concerns that were previously voiced.

Several companies are making systems based on CA and far more companies are using CA to control all stages of insects, rats and mice in food, associated products, artefacts, silos, food (processing) facilities and barges. The use of CA is spreading worldwide at a very fast pace. At first controlled atmosphere treatment was mainly used in Western countries like the Netherlands, on food imports. Use of this technology has now grown very rapidly in food producing countries in the Mediterranean (Greece and Turkey) also in India and in South-East Asian countries, for example Vietnam, Thailand, Indonesia and the Philippines. There are also controlled atmosphere systems operational in Africa- and South America.

5.11.2. Tools and methods

To apply CA there are several techniques available on the market. The reader should be aware that modern controlled atmosphere systems employ broader and more advanced methods than techniques that solely focus on lowering the oxygen level in a “controlled” environment.

Techniques such as hermetic storage and flushing with carbon dioxide or nitrogen from bottles or tanks are not considered in this section because the actual atmospheric parameters are not fully in control. With CA, parameters such as nitrogen, oxygen, moisture and temperature of air (and product) are fully controlled because of the use of computerised equipment.

This full control of these parameters makes it possible to apply a tailor-made treatment of a certain product/insect/packing/temperature combination resulting in 100% effectiveness using the lowest treatment time while safeguarding the product quality.

5.11.2.1. Tools

There are two basic types of machines that can establish a Controlled Atmosphere in an enclosed environment:

Oxygen Converter Machine; this type of machine separates the oxygen from the air by the use of a PSA technique or a VSA technique.
Pressure Swing Adsorption (PSA) is a technology used to separate some gas species from a mixture of gases under pressure according to the species molecular characteristics and affinity for an adsorbent material.

Vacuum swing adsorption (VSA) is a non-cryogenic gas separation technology. Using special solids, or adsorbents, VSA segregates the gases from a gaseous mixture under minimal pressure according to the species' molecular characteristics and affinity for the adsorbents. These adsorbents form a molecular sieve and preferentially adsorb the target gas (oxygen) species at near ambient pressure. The process then swings to a vacuum to regenerate the adsorbent material.

Oxygen Burner Machine; this techniques simply burns the oxygen from the air via a gas powered burner. Air is recycled throughout the controlled environment, lowering the oxygen with every cycle. These burners are so advanced that there are no dangerous gasses created that have effects on product or humans. These machines are very complex and are not much used, except on some locations in Belgium and The Netherlands.

All different techniques have their advantages and disadvantages; also some companies have managed to further advance certain techniques in such a way that they have the sole purpose to be used in insect control. Enhancing these techniques has resulted in faster treatment times, better insect control and avoidance of product damage.

5.11.2.2. Methods

The techniques are applied via various methods, all suited for the specific variable set-up of circumstances. Between technique and method there are many complex steps of mechanics, electronics and operating procedures that play their part in effective pest control with the use of the CA Technique.

<u>Controlled Atmosphere Rooms</u>: Many infested products are packed in boxes, big bags, and crates etc. that are stacked on pallets. These wooden or plastics pallets can be driven with a

forklift in an airtight room which is then sealed with a special door. These rooms are normally constructed within a warehouse, sometimes used to create a “clean” and dirty “zone” with doors on both sides of the room.
In some conditions where there are facilities that are influenced by season patterns or the equipment is used within an agricultural co-operative, a containerised system is used that is suited to transport from one location to the other.

Silo Treatments; most grains and other agricultural bulk commodities are stored in silos. Although there are a lot of types of silos, CA can be applied to any silo as long as there is the possibility to create an airtight or almost airtight environment. Vroom and van Golen reported on the use of CA treatments for silos. Commodity silos are held in CA in 14 countries. Test results of the silo treatment with CA indicate that within 3 – 12 days, preferable product temperature of 20 – 30° C is achieved and the insects are controlled effectively in all stages of development. In these instances, CA was established by using the EcO_2 Converter System (Vroom and van Golen, 2009). In Switzerland, a Dutch Company, together with Silo Olten A.G. and the Pest Control Company Desinfecta A.G. commercialized the idea of silo’s equipped with the CA technique. This led to a successful implementation of CA based silo’s treatment against a variety of insects. The technique is applied in the following manner: nitrogen is injected with 6 Bar, such that even with a leakage rate of 20% a regime of less than 1% oxygen can be accomplished.

Treatments of Vessels and Barges; sea going vessels and more local-use barges are often infested with insects and require disinfestation treatment. Barges are normally treated on the quay in the port by placing a mobile treatment unit on the quay and connecting it, via special hoses, to the different storage compartments in the barge to create the most ideal atmosphere. Sea going bulk carriers have the advantage that the CA treatment can often take place while in transit. A special Marine-Certified CA System is in development at a company for this purpose.

Warehouses; the most advanced CA system are used in robotised warehouses; they started as fire prevention systems (low oxygen). Now, however, the systems are modified to control insects and rodents.

5.11.3 Controlled Atmosphere: 30 years of scientific research

Since the beginning of the previous century controlled atmospheres has been a subject of research and industry testing, the book: *Weevil in wheat & storage of grain in Bags: A record of Australian Experience during the war period (1915 – 1919) by D.C. Winterbottom, A.S.A.S.M.* described the applications of low oxygen storage in the grain industry in Australia.

The rise of the chemical industry, making it easy to use chemical pesticides and the early difficulties implementing low oxygen techniques, as well as the inconsistent effects of these techniques, resulted in a decreasing attention for CA after the Second World War. But from the 1980's onwards the attention for the CA technique has risen, especially when in the 1990's easy-to-install systems became available to apply the technique simple and effectively. MBTOC has reviewed several papers on the efficacy of controlled atmosphere from the early 1990's, but only those papers published since our last Assessment Report are reviewed in this section.

Vroom and van Golen (2008, 2009) reported on the use of controlled atmosphere for dried fruits and nuts, saying that CA is not only used for control of insects in organic commodities, but also used for conventional produced products. Researchers have conducted several tests for the control of insect pests of dried fruit together with different dried fruits.

In 2008, they reported that CA is used to control insects in sesame seed from Greece. Both conventional as well as organic sesame seed is treated with CA. The CA method used is based on low-oxygen in combination with increased temperatures (e.g. 35° C). Before commercial introduction began the treatment was shown to control *Tribolium* and *Sitophilus* (Greek origin) in sesame seed and dried figs (Vroom and Satiroudas, 2008).

The also reported on three additional tests in 2009: Test 1: Dried peaches from South Africa. The goal of this research was to specify the total time frame for increase in product temperature to an average of 30°C which is the ideal treatment temperature for control of dried fruit insects. The increase in temperature was measured by five different data loggers, placed in the dried peaches at different positions in a gastight treatment chamber. Results showed a total time of 21 hours to reach a product temperature of 30°C, starting from 15°C.

Test 2: Dried figs from Greece. The goal of this research was to specify the effectiveness of *Tribolium* and *Sitophilus* species, present in commercially packed dried figs. The experiment was conducted in November 2007 in winter season in Europe, applying CA in a gastight treatment room. Upon arrival of the test, temperature of the product was 11°C. In 2.5 days the product temperature reached the ideal treatment temperature of 32°C. Simultaneously during heating up of the products, the oxygen is decreased to < 1% in the room for effective insect control. Results showed 100% mortality of all *Tribolium* and *Sitophilus* species in all developmental stages. Total treatment duration was 5.5 days. Quality assurance tests of the treated dried figs, showed no negative effects on the quality of the products.

Test 3: Cashew Kernels from Vietnam. On 15th of June 2009, a test was performed with the goal to specify the total treatment time for cashew kernels, infested with saw-tooth grain beetle. In total 172 bags of cashew kernels were treated. Total duration of treatment was 3.5 days with an average product temperature of 35°C and low-oxygen level of < 1.5%. (Vroom and van Golen, 2009)

In 2008, Yang and co-workers in Beijing China investigated the effect of different oxygen concentrations and temperature on respiration of *Tribolium castaneum.* Low O_2 is the preferred controlled atmosphere treatment in China because CO_2 is expensive but they can manipulate low O_2 by manipulating nitrogen, which is less expensive in China. Controlling pests with O_2 is considered green technology and includes the additional benefit of inhibiting fungi in grain. Oxygen concentrations of less than 2% for more than 15 days will control heavy grain infestation (such as when grain arrives at the warehouse). Another approach is to control the O_2 concentration to between 5-10% for more than 2 months which will both inhibit pest development and fungi (Yang *et al*, 2008).

5.6.3.1. Pest control efficacy

5.6.3.1.1 Generic Treatment Times

Commercial suppliers of controlled atmosphere systems (e.g., ECO_2 b.v. of Netherlands) have an extensive database of products, insects and treatment parameters. The right method is required to result in cost effective insect lethality and product safety.
The following data for the most common pest, supplied by ECO_2, is available and based on 14 years of experience with the CA technology.

Reichmuth (2000) published a survey on the efficacy of various mixtures of inert gases under various conditions with reduced oxygen content to control various developmental stages of pest insects and mites. The resulting table (Table 22) includes numerous species and is found in Appendix A to this chapter.

TABLE 22. CONTROLLED ATMOSPHERE EFFICACY: INSECTS TESTED

The insects that were tested have been eliminated with CA using the following parameters			
Insect	**Stage**	**Type**	**Parameters**
Carpoglyphus lactis	All stages	CA	CA, 38°C, 24hrs
Acarus spp.	All stages	CA	CA, 32°C, 24hrs
Carpophilus dimidiatus	All stages	CA	CA, 40°C, 16hrs
Ephestia elutella	All stages	CA	CA, 35°C, 10hrs
Ephestia Cautella	All stages	CA	CA, 35°C, 10hrs
Plodia interpunctella	All stages	CA	CA, 34°C, 16 hrs
Oryzaephilus mercator	All stages	CA	CA, 36°C, 16hrs
Oryzaephilus surinamensis	All stages	CA	CA, 30°C, 24hrs
Sitophilus oryzae	All stages	CA	CA, 35°C, 48hrs
Sitophilus granarius	All stages	CA	CA, 30°C, 4days
Stegobium paniceum	All stages	CA	CA, 32°C, 24hrs
Tribolium castaneum	All stages	CA	CA, 34°C, 24hrs
Bruchus ssp.	All stages	CA	CA, 32°C, 2days
Rhizopertha dominica	All stages	CA	CA, 32°C, 3days
Sitotroga cerealella	All stages	CA	CA, 30°C, 3days
Tribolium confusum	All stages	CA	CA, 30°C, 36hrs

5.6.3.2. Tobacco Case Study

Case study: Use of CA to control Lasioderma Serricorne and Ephesia Elutella in tobacco
In close co-operation with an international tobacco company, a treatment trial was performed using CA in the treatment facility in Ridderkerk (the Netherlands) to control the *Lasioderma Serricorne* and *Ephesia Elutella* in seven different types of raw tobacco, different tobacco products and tobacco seed. Adult insects were inserted in seven wooden tubes (total 87 adults) and wrapped and sealed according current production of the tobacco products (cigarette packs and cigar tubes). Adults, pupae, larvae and eggs were inserted in seven containers (a 300 cubic centimetre) inside the tobacco bales.
Treatment used was CA based on low-oxygen and raised temperatures. Results of the wooden tubes showed that adults were 100% eliminated after treatment with CA within 4 days. A control tube (not treated with CA), which contained 10 adults, showed 100%

vitality. Results of the containers showed that adults, larvae and pupae were 100% eliminated with the CA method. A control container showed adults, larvae and pupae highly vital when stored in an environment between 20 – 24 °C.
Organoleptic analyses showed no negative influences on the different types of cigarettes and cigars treated. Furthermore, tobacco specific N-Nitrosamines were analysed by determination of the following N-Nitrosamines:
N-nitrosonornicotine (NNN)
N-nitrosoanatabine (NAT)
N-nitrosoanabasine (NAB)
4-methylnitrosamino-1-(3-pyridyl)-1-butanone (NNK)

After treatment with CA, analyses showed that there were no increase on the determined tobacco specific N-nitrosamines on tobacco types.

The reader should also refer to the case study on CA in dates in the section on pest control of dates elsewhere in this Chapter.

5.12. Pest control issues of fresh dates

In 2003, MBTOC noted that technically and economically effective alternatives had not been identified for fresh, high-moisture dates. The Parties then passed Decision XV/12 which noted the problem and its resulting impact on MB use in those Parties. The Decision also indicated a need for a project to identify suitable alternatives and a workshop to share this information.

Parties, particularly the North African countries of Algeria and Tunisia, have discussed with deep concern the problem of controlling pests in high-moisture dates. Currently methyl bromide is used by several Parties to disinfest dates and prevent fermentation. In the United States, dates are included in a commodity CUN.

In 2008, UNIDO took the initiative to respond to Decision XV/12. A member of MBTOC SC and additional experts carried out an extensive preliminary investigation of potential pest control techniques for this sector. Five alternatives were tested. As a result of this study, considerable information about potential alternatives was identified and discussed at a UNIDO workshop in Vienna in 2009 on the replacement of methyl bromide for disinfestation of high moisture dates (Ducom and Ciesla, 2009).

UNIDO held a workshop on the replacement of methyl bromide for disinfestation of high moisture dates in Vienna April 16-17, 2009. Present at the workshop were executives from major date-exporting companies from Algeria and Tunisia; scientific and technical experts from those countries and Israel; MBTOC members from Canada, France, Germany, Morocco, United Kingdom and United States of America; ozone officers from North Africa; and UNIDO officers.

As a result of the study, and following discussions during the workshop, one key technical problem was resolved. It had previously been identified by MBTOC members that lack of information on moisture content of dates in various producing countries was preventing understanding of the issue. MBTOC members consider moisture content to be a key determinant of the selection of an effective disinfestant. After the presentation of information about date production in Algeria, Israel, Morocco, Tunisia and the USA, it became apparent that “dates at high moisture content” such as it appears in Decision XV/12 must be specifically defined.

Consequently, the following definition was accepted and approved at the workshop and subsequently by MBTOC:

“Dates at high water content”, so called “fresh dates”, are dates of the Deglet-Nour variety with a moisture content from 30 to 40% (compared to the net weight). The colour of such dates is light and somewhat transparent. These dates are marketed still attached to small branches. The relative humidity in equilibrium with these high-moisture dates allows the rapid development of yeasts resulting in fermentation, if the dates are either stored or fumigated in gas tight conditions. Gas tightness sufficient for fermentation can also occur in consumer packaging. In contrast, dates with moisture content between 17-23 % may be considered as dried fruit.” (MBTOC, 2009 in TEAP Progress Report, May 2009)

The results of the laboratory tests in France and research in Israel were discussed at the workshop, and the potential alternatives were evaluated as summarized below.

Controlled atmosphere facilitated fermentation, resulting in a high loss of the quality of the fruit.

Sulfuryl fluoride and ethyl formate were both promising in that they controlled pests, they can be used in the existing vacuum chambers, and they only require short exposure times. Unfortunately, following discussion at the workshop, these potential alternatives were determined to be impractical for further study or use in North African countries. Sulfuryl fluoride is not available in North African countries because of lack of registration and lack of suppliers.

Ethyl formate is not registered as an insecticide in the EU, the principal market of North African dates and no company seems eager to register it. So, although ethyl formate has been registered in Israel and found effective for the control of pests in high moisture dates, it is not available to North African date exporters.

A phosphine product formulated as gas mixed with CO_2 was effective but it was determined to be not available to North African date producers because the product has been withdrawn from sale in the EU by its producer.

Phosphine generated in pure form (and not from formulations containing ammonia), was found to be technically effective for high moisture dates on branches, although using this technique resulted in the need to change treatment logistics. Managing treatment time when using this technique is important. If treatment time exceeds 72 hours, fermentation can result. Thus, further work is needed to clarify this method.

Heat treatment, (50˚C for 2 hours with a 2 hr come-up time) was previously found to be effective for other date varieties and at drier moisture contents (Navarro et al, 2004; Finkleman et al, 2006). Recent preliminary studies in Israel found the same method to be quite promising for high moisture dates on branches. Work on this technique is ongoing. If not done properly, heat can produce a non-desirable effect of cracking and pasty texture. Thus, further work is also needed to clarify this method for high moisture dates.

A date producer reported that deep freezing (- 25˚C) is currently used for the treatment of fresh Deglet-Nour in branches for the organic market. This treatment requires a very high investment and high operating costs so it was determined it could not be considered as an alternative for the entire production of fresh and high-moisture dates.

MBTOC noted clear and significant positive results from the preliminary laboratory work and the workshop. The official report from UNIDO later identified further project work in this field, but in 2009, UNIDO decided not to conduct the research which had been recommended to further this investigation. Later, UNIDO indicated that a revised research project would be conducted in the North African countries most affected by the loss of methyl bromide and where work on the pests specific to that region could be more easily conducted. Further information has not been submitted to MBTOC.

In 2009, two MBTOC SC members (Ducom, France and Reichmuth, Germany), French scientist Ciesla and the USDA scientist currently conducting date research (Walse), visited the date growing area in the Coachella Valley of California. This valley is the primary date production site in the United States. The visit included packing and storage areas and infrastructure. Deglet Noor and Medjoul varieties are grown in this area. (Note, in the US, the variety referred to as Deglet Nour in Europe is referred to as Deglet Noor.)

However, the moisture content of the dates at harvest is region specific; it is 17-23% in California compared to 35-40% in North Africa. Thus, MBTOC considers US dates as "dried fruit" and the dates in North Africa as "high moisture fruit", leading to different regulatory considerations.

MBTOC first discussed this issue in its 2009 text box for the US commodities CUN, writing,

"….In 2003, MBTOC agreed that it did not, at that time, know of pest control alternatives to high moisture fresh dates. However, MBTOC has recently gained the understanding that the moisture content of US dates at time of harvest is between 17-23%. In the instance of US dates it appears that the length of time needed to achieve date maturity on the tree, also results in considerable drying, while the dates are still on the tree. Thus, US dates were referred to as 'fresh' but the American definition stands in contrast to the Deglet-Noor dates of North African countries which are also harvested 'fresh' at maturity but are at 35-40% moisture content. It is the moisture content and not the freshness of recent picking that impacts the potential for alternatives to be effective.

When dates are at 17-23% moisture content, they are a dried fruit from the viewpoint of spoilage potential. In the case of the US, the word 'fresh' in this instance is a marketing term. Therefore, heat, phosphine, controlled atmosphere and cold treatment seem likely to be effective and are registered for use in the US.

In addition, sulfuryl fluoride is also registered for treatment of 'dried' dates and recent trials have indicated efficacy, at least for adults and larvae of some pests. As noted above, recently submitted preliminary research indicates potential problems with efficacy for egg kill for one pest of dried fruit (Walse, 2008). It remains to be seen whether this is an actual barrier to adoption of sulfuryl fluoride for dates, or whether manipulation of fumigation parameters such as temperature could resolve this problem…." (TEAP, 2009, excerpt from MBTOC US Commodities CUN Recommendation, October 2009)

Since the SF label in the US includes dried dates and since from a technical perspective MBTOC considered the US dates to be dried; MBTOC, in 2009, interpreted the label to mean that these California dates can be subject to treatment with SF under the US label. MBTOC requested the USG to investigate this regulatory interpretation. The USG responded, however, that the US dates at harvest are not considered dried dates. Parties are not required to explain the reasoning for regulatory decisions to MBTOC.

All dates require post harvest disinfestations of field insect pests.

The primary insect pests targeted in CA are the same as those in the other major date-producing countries, chiefly: Algeria, Tunisia, Israel, Iran and Iraq:

- Carob moth (*Apomyelois ceratoniae*) (Lepidoptera: Pyralidae). The eggs are laid on the fruit, the larvae migrate inside the date (between the flesh and the core) to nourish and to carry out its developmental cycle. They leave the date once the adult stage has been reached.

- Dried fruit beetle (*Carpophilus hemipterus*) (Coleoptera: Nitidulidae). The eggs are laid on the surface of the fruit, even inside when it is already sufficiently deteriorated, and the larvae nourish on the internal and external flesh of fruits. (Ciesla et al, 2009)

According to the climatic conditions of a given production year, infestation by these two insects can result in 20% loss of the total harvest. Although a suite of pre-harvest systems-based, IPM, and chemical pest-control programs are in place, dates require disinfestation of field pests (just after harvest), as well as, storage pests in processed dates if re-infested (as well as control of microbial colonization).

In California, chamber fumigations with MB are presently used for disinfestation of freshly harvested dates. Fumigations are conducted with methyl bromide under plastic tarpaulins on dates in harvest bins stacked directly on top of sandy soil. The frequency and duration of these fumigations vary with the severity of infestation; however, they typically last from three days to four weeks. The exposure is 24 g/m^3 methyl bromide for 12 hours.

Ciesla *et al* (2009) reported on the review of USDA date research conducted by Walse by some MBTOC members summarized that the dose of sulfuryl fluoride required for satisfactory mortality of dried fruit beetle eggs greatly exceeds the maximum allowable dose on the label across all temperature scenarios. This insecticidal shortcoming could potentially be avoided by consecutive fumigations at a ~ 5 day interval to allow for egg hatch of most stored-product pests, including dried fruit beetle. However, the economic and logistical repercussions of this adaptation are prohibitive; high-valued “fresh date” product, which drive the annual profit margin, bottleneck at the processing facility within a 2-3 week span and must be shipped prior to the holiday season in late December.

The use of sulfuryl fluoride in the stored-product scenarios creates interesting registration and residue dilemmas. The maximum “CT” exposures on the US label were set so as not to exceed maximum residue levels (MRLs). Repeat 12-24 hour fumigations with sulfuryl fluoride, or single multiple-day fumigations with sulfuryl fluoride, are expected to surpass the residue MRLs and “CT” maximums set for dates, respectively.

Researchers with Dow AgroSciences, a supplier of SF, reported the investigation of the efficacy and economics of using SF on dates in California. Previous work showed that 2.1x more SF was required than MB, and this resulted in an increased cost. Improved painting and door sealing reduced half-loss time to 12-15 hours. Adding a small fan further improved treatment efficacy. These changes resulted in the efficiency of only needing the same volume of SF as was formerly used with MB, with resulting cost savings. In California about 70% of dates are fumigated in stacks of bins under tarps on yards when time is not critical. Dates might be stored, under fumigation, for weeks or even months. The tarp stacks are fairly gas tight; SF fumigation of these tarp stacks could be conducted with lower dosage and longer fumigation times (Williams, 2009).

The date industry is reported to be actively supporting research to improve the ovicidal efficacy of sulfuryl fluoride so that it can be incorporated into chamber fumigations for preprocessing field disinfestations.

US date growers have been advised that there are technically and economically advantageous chemical alternatives to methyl bromide for use in stored-product and other scenarios when fumigation is required after the initial field disinfestations. At present, tarpaulin fumigations with phosphine, typically lasting 3-30 days, are utilized for stored-dates disinfestations.

The date industry is also actively supporting research to determine the dose-mortality relationship between high-concentration cylinderized phosphine and dried fruit beetle, as well as, carob moth strains endemic to the Coachella Valley, as this critical data has not yet been determined. Based on related species, at least 48 hour exposures are expected for complete control. Again, this operational timeframe would greatly impede productivity and profitability during the “rush” of dates to the US holiday markets.

Concomitant to its long history of use in this capacity has been recognition and associated concern regarding the development of phosphine-resistance in target insects. Date growers have been advised of the risk associated with conducting stored-product tarpaulin fumigations with phosphine in close proximity to processing facilities; escape of target insects from tarpaulin-containment can fuel the spread of genes that express resistance.

Chemical fumigation is not the only alternative for dates; controlled atmosphere (CA) is both effective and in commercial use. In Tunisia, one of the biggest dates producers (in Kebili) built a CA Terminal. The facility has a capacity of 1300 tonnes per year and performs 70 treatment shifts per year. Treatment time (including pull down and ventilation) is 5 days from products coming in until products coming out for further processing. The insect that is the target of the process is *Ectomyelois Ceratoniae* , and the type of dates that is treated is the "Deglet Nour" (high and low moisture) (Vroom, 2009).

Given the infrastructural, logistic, food quality, and pest-control scenarios facing the California date industry, phosphine treatment may be an alternative for those dates that can be stored for two weeks. If a regulatory interpretation were to be made by the US EPA that California dates could be SF treated, it could be an alternative for a quick disinfestation of these dates, provided that the temperature during treatment is higher than 25°C. How the US government and its date growing sector resolves these situations remain to be seen.

5.12.1 Case Study: Effective commercial introduction of controlled atmosphere disinfestation of dates in Tunisia

For one of the biggest dates producers in Tunisia a controlled atmosphere (CA) Terminal has been built in Kebili. The facility has a capacity of 1300 tonnes per year and performs 70 treatment shifts per year. Treatment time (including pull down and ventilation) is 5 days from products coming in until products coming out for further processing. The date processing industry is experiencing rapid change, spurred by the implementation of CA.
The insect that is the target of the process is the so called worm of dates (*Ectomyelois Ceratoniae* Zeller). And the type of dates that is treated is the "Deglet Nour" (high and low-moisture). The treatment results of February and March for 2010 are:

TABLE 23. CONTROLLED ATMOSPHERE TREATMENT OF DATES: CASE STUDY RESULTS

Treat-ment	Product	Packaging	Number of Packaging	Quantity	Start date	End date	Insect	Mortality
10139	Dates	Plastic Boxes	1000	15000	26-3-2010	31-3-2010	*Ectomlyelois Ceratoniae Zeller*	100%
10281	Dates	Plastic Boxes	1000	15000	12-3-2010	17-3-2010	*Ectomlyelois Ceratoniae Zeller*	100%
10197	Dates Industrial	Plastic Boxes	1050	15000	11-2-2010	16-2-2010	*Ectomlyelois Ceratoniae Zeller*	100%
10167	Dates	Plastic Boxes	854	12800	3-2-2010	8-2-2010	*Ectomlyelois Ceratoniae Zeller*	100%
10146	Dates	Plastic Boxes	976	14500	28-1-2010	1-2-2010	*Ectomlyelois Ceratoniae Zeller*	100%
Total February. – March 2010				***72300***				

5.13. References

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Appendix A to Chapter 5.

Table 3. Survey of mortality data of insects and mites in controlled atmospheres

Table: Survey on mortality data for the control of pest insects and mites in stored product protection and material protection by aid of inert atmospheres with low residual oxygen content or carbon dioxide under elevated pressure provided by Reichmuth and co-workers at Institute for Ecological Chemistry, Plant Analysis and Stored Product Protection of the Federal Institute for Cultivated Plants, Berlin Germany. (**literature by number with the author in Berlin, Reichmuth@t-online.de)

The following species are covered:

Acanthoscelides obtectus
Anobium punctatum
Anthrenus verbasci
Callosobruchus maculatus
Callosobruchus subinnotatus
Corcyra cephalonica
Dermestes maculatus
Dinoderus bifoveolatus
Dinoderus porcellus
Ephestia elutella
Hylotrupes bajulus
Lasioderma serricorne
Lyctus brunneus
Oryzaephilus mercator
Oryzaephilus surinamensis
Plodia interpunctella
Prostephanus truncatus
Reticulitermes santonensis
Rhizopertha dominica
Sitophilus granarius
Sitotroga cerealella
Tineola bisselliella
Tribolium castaeum
Tribolium confusum
Trogoderma angustum
Trogoderma grasmani
Trogoderma inclusum

Explanation of abbreviations

*The values beyond 5 days are calculated with regression by the TABLECURVE program)

jL:	young larva
L1:	young larva
L3:	medium old larva
AL:	old larva
I:	Imago
InT:	n days old Imago
Ln:	n days old larva
pP:	prepupa
P:	pupa
E:	eggs
L:	larva
schw B:	light infestation (1 - 2 larvae per bean)
st B:	heavy infestation (10 - 12 larvae per bean)

Species Stadium and Age	O_2	CO_2	N_2	LD_{95} in days	Temp.	No of the reference, list by author**
	Volume content in %					
Acanthoscelides obtectus aL	1	0	99	9	25	67
Acanthoscelides obtectus aL	1	0	99	5	32	67
Acanthoscelides obtectus aL	2	0	98	11	25	67
Acanthoscelides obtectus aL	2	0	98	9	32	67
Acanthoscelides obtectus aL	3	0	97	9	25	67
Acanthoscelides obtectus aL	3	0	97	7	32	67
Acanthoscelides obtectus aL	0	0	100	8.1	25	44
Acanthoscelides obtectus aL	0	0	100	3.3	32	44
Acanthoscelides obtectus aL	2,4	88	9,6	5	25	42
Acanthoscelides obtectus aL	2,4	88	9,6	5	32	42
Acanthoscelides obtectus aL*	6	70	24	8	25	42
Acanthoscelides obtectus aL*	6	70	24	5.4	32	42
Acanthoscelides obtectus aL*	8	60	32	10	25	42
Acanthoscelides obtectus aL*	8	60	32	5.5	32	42
Acanthoscelides obtectus aL*	10	50	40	15	25	42
Acanthoscelides obtectus aL*	10	50	40	13	32	42
Acanthoscelides obtectus E	0	100	0	1	25	41
Acanthoscelides obtectus E	0	100	0	1	32	41
Acanthoscelides obtectus E	1	0	99	1	25	67
Acanthoscelides obtectus E	1	0	99	1	32	67
Acanthoscelides obtectus E	2	0	98	2	25	67
Acanthoscelides obtectus E	2	0	98	1	32	67
Acanthoscelides obtectus E	3	0	97	4	25	67
Acanthoscelides obtectus E	3	0	97	1	32	67
Acanthoscelides obtectus E	0	0	100	3.5	25	44
Acanthoscelides obtectus E	0	0	100	1.4	32	44
Acanthoscelides obtectus E	2,4	88	9,6	1	25	42
Acanthoscelides obtectus E	2,4	88	9,6	1	32	42
Acanthoscelides obtectus E	6	70	24	3	25	42
Acanthoscelides obtectus E	6	70	24	1	32	42
Acanthoscelides obtectus E	8	60	32	5	25	42
Acanthoscelides obtectus E	8	60	32	3	32	42
Acanthoscelides obtectus E	10	50	40	5	25	42
Acanthoscelides obtectus E	10	50	40	3	32	42
Acanthoscelides obtectus I	0	100	0	1	25	41
Acanthoscelides obtectus I	0	100	0	1	32	41
Acanthoscelides obtectus I	1	0	99	2	25	67
Acanthoscelides obtectus I	1	0	99	1	32	67
Acanthoscelides obtectus I	2	0	98	2	25	67
Acanthoscelides obtectus I	2	0	98	1	32	67
Acanthoscelides obtectus I	3	0	97	3	25	67
Acanthoscelides obtectus I	3	0	97	2	32	67
Acanthoscelides obtectus I	0	0	100	1	25	44
Acanthoscelides obtectus I	0	0	100	1	32	44
Acanthoscelides obtectus I	2,4	88	9,6	1	25	42
Acanthoscelides obtectus I	2,4	88	9,6	1	32	42
Acanthoscelides obtectus I	6	70	24	1	25	42
Acanthoscelides obtectus I	6	70	24	1	32	42
Acanthoscelides obtectus I	8	60	32	1	25	42
Acanthoscelides obtectus I	8	60	32	1	32	42
Acanthoscelides obtectus I	10	50	40	3	25	42
Acanthoscelides obtectus I	10	50	40	1	32	42
Acanthoscelides obtectus jL	1	0	99	5	25	67
Acanthoscelides obtectus jL	1	0	99	3	32	67
Acanthoscelides obtectus jL	2	0	98	7	25	67
Acanthoscelides obtectus jL	2	0	98	5	32	67
Acanthoscelides obtectus jL	3	0	97	7	25	67

Acanthoscelides obtectus jL	3	0	97	5	32	67
Acanthoscelides obtectus jL	0	0	100	3.3	25	44
Acanthoscelides obtectus jL	0	0	100	1.4	32	44
Acanthoscelides obtectus jL	2,4	88	9,6	3	25	42
Acanthoscelides obtectus jL	2,4	88	9,6	3	32	42
Acanthoscelides obtectus jL	6	70	24	5	25	42
Acanthoscelides obtectus jL	6	70	24	3	32	42
Acanthoscelides obtectus jL	8	60	32	5	25	42
Acanthoscelides obtectus jL	8	60	32	3	32	42
Acanthoscelides obtectus jL	10	50	40	3	32	42
Acanthoscelides obtectus jL*	10	50	40	6	25	42
Acanthoscelides obtectus L	0	100	0	3	32	41
Acanthoscelides obtectus P	0	100	0	6	25	41
Acanthoscelides obtectus P	0	100	0	4	32	41
Acanthoscelides obtectus P	1	0	99	9	25	67
Acanthoscelides obtectus P	1	0	99	5	32	67
Acanthoscelides obtectus P	2	0	98	11	25	67
Acanthoscelides obtectus P	2	0	98	7	32	67
Acanthoscelides obtectus P	3	0	97	11	25	67
Acanthoscelides obtectus P	3	0	97	9	32	67
Acanthoscelides obtectus P	0	0	100	7.3	25	44
Acanthoscelides obtectus P	0	0	100	3.4	32	44
Acanthoscelides obtectus P	2,4	88	9,6	5	25	42
Acanthoscelides obtectus P	2,4	88	9,6	3	32	42
Acanthoscelides obtectus P*	6	70	24	10	25	42
Acanthoscelides obtectus P*	6	70	24	7	32	42
Acanthoscelides obtectus P*	8	60	32	9	25	42
Acanthoscelides obtectus P*	8	60	32	5.3	32	42
Acanthoscelides obtectus P*	10	50	40	15	25	42
Acanthoscelides obtectus P*	10	50	40	7	32	42
Acanthoscelides obtectusL	0	100	0	4	25	41
Anobium punctatum L	0	0	100	29.7	20	28
Anobium punctatum L	0	0	100	35	16	72
Anobium punctatum L	0	0	100	28	22	72
Anobium punctatum L (LD100)	1,1	0	98,9	21	35	69
Anthrenus verbasci L	0	4	96	3.5	25	28
Anthrenus verbasci L	0	10	90	2.4	25	28
Anthrenus verbasci L	0	0	100	5.6	25	28
Callosobruchus maculatus aL	0	100	0	4	32	40
Callosobruchus maculatus aL	1	0	99	11	25	67
Callosobruchus maculatus aL	1	0	99	7	32	67
Callosobruchus maculatus aL	2	0	98	11	25	67
Callosobruchus maculatus aL	2	0	98	9	32	67
Callosobruchus maculatus aL	3	0	97	13	25	67
Callosobruchus maculatus aL	3	0	97	11	32	67
Callosobruchus maculatus aL	0	0	100	8.8	25	44
Callosobruchus maculatus aL	0	0	100	3.9	32	44
Callosobruchus maculatus aL	2,4	88	9,6	4.4	25	43
Callosobruchus maculatus aL	2,4	88	9,6	2.4	32	43
Callosobruchus maculatus aL	6	70	24	10.7	25	43
Callosobruchus maculatus aL	6	70	24	5.1	32	43
Callosobruchus maculatus aL	8	60	32	10.4	25	43
Callosobruchus maculatus aL	8	60	32	5.5	32	43
Callosobruchus maculatus aL	10	50	40	11.4	25	43
Callosobruchus maculatus aL	10	50	40	6.4	32	43
Callosobruchus maculatus E	0	100	0	1	25	40
Callosobruchus maculatus E	0	100	0	1	32	40
Callosobruchus maculatus E	1	0	99	3	25	67
Callosobruchus maculatus E	1	0	99	2	32	67
Callosobruchus maculatus E	2	0	98	3	25	67
Callosobruchus maculatus E	2	0	98	2	32	67
Callosobruchus maculatus E	3	0	97	4	25	67
Callosobruchus maculatus E	3	0	97	3	32	67
Callosobruchus maculatus E	0	0	100	3.2	25	67
Callosobruchus maculatus E	0	0	100	1.3	32	67
Callosobruchus maculatus E	2,4	88	9,6	1	25	43
Callosobruchus maculatus E	2,4	88	9,6	1	32	43

Callosobruchus maculatus E	6	70	24	2	25	43
Callosobruchus maculatus E	6	70	24	1	32	43
Callosobruchus maculatus E	8	60	32	3	25	43
Callosobruchus maculatus E	8	60	32	2	32	43
Callosobruchus maculatus E	10	50	40	3	25	43
Callosobruchus maculatus E	10	50	40	3	32	43
Callosobruchus maculatus I	0	100	0	1	25	40
Callosobruchus maculatus I	0	100	0	1	32	40
Callosobruchus maculatus I	1	0	99	2	25	67
Callosobruchus maculatus I	1	0	99	1	32	67
Callosobruchus maculatus I	2	0	98	4	25	67
Callosobruchus maculatus I	2	0	98	2	32	67
Callosobruchus maculatus I	3	0	97	5	25	67
Callosobruchus maculatus I	3	0	97	3	32	67
Callosobruchus maculatus I	0	0	100	1	25	44
Callosobruchus maculatus I	0	0	100	1	32	44
Callosobruchus maculatus I	2,4	88	9,6	1	25	43
Callosobruchus maculatus I	2,4	88	9,6	1	32	43
Callosobruchus maculatus I	6	70	24	1	25	43
Callosobruchus maculatus I	6	70	24	1	32	43
Callosobruchus maculatus I	8	60	32	2	25	43
Callosobruchus maculatus I	8	60	32	1	32	43
Callosobruchus maculatus I	10	50	40	3	25	43
Callosobruchus maculatus I	10	50	40	2	32	26
Callosobruchus maculatus jL	0	100	0	4	25	40
Callosobruchus maculatus jL	0	100	0	3	32	40
Callosobruchus maculatus jL	1	0	99	7	25	67
Callosobruchus maculatus jL	1	0	99	5	32	67
Callosobruchus maculatus jL	2	0	98	9	25	67
Callosobruchus maculatus jL	2	0	98	7	32	67
Callosobruchus maculatus jL	3	0	97	9	25	67
Callosobruchus maculatus jL	3	0	97	7	32	67
Callosobruchus maculatus jL	0	0	100	8.8	25	44
Callosobruchus maculatus jL	0	0	100	3.7	32	44
Callosobruchus maculatus jL	2,4	88	9,6	3	25	43
Callosobruchus maculatus jL	2,4	88	9,6	2	32	43
Callosobruchus maculatus jL	6	70	24	5	25	43
Callosobruchus maculatus jL	6	70	24	4	32	43
Callosobruchus maculatus jL	8	60	32	6.2	25	43
Callosobruchus maculatus jL	8	60	32	3.9	32	43
Callosobruchus maculatus jL	10	50	40	4.9	25	43
Callosobruchus maculatus jL	10	50	40	4.2	32	43
Callosobruchus maculatus L schw B	6	70	24	6.3	27	45
Callosobruchus maculatus L schw B	1	0	99	6.4	27	45
Callosobruchus maculatus L schw B	14	30	56	9.3	27	45
Callosobruchus maculatus L schw B	4	0	96	8.6	27	45
Callosobruchus maculatus L st B	6	70	24	9.1	27	45
Callosobruchus maculatus L st B	1	0	99	9.4	27	45
Callosobruchus maculatus L st B	14	30	56	10.7	27	45
Callosobruchus maculatus L st B	4	0	96	14	27	45
Callosobruchus maculatus P	1	0	99	9	25	67
Callosobruchus maculatus P	1	0	99	5	32	67
Callosobruchus maculatus P	2	0	98	9	25	67
Callosobruchus maculatus P	2	0	98	7	32	67
Callosobruchus maculatus P	3	0	97	15	25	67
Callosobruchus maculatus P	3	0	97	11	32	67
Callosobruchus maculatus P	0	0	100	8	25	44
Callosobruchus maculatus P	0	0	100	3.9	32	44
Callosobruchus maculatus P	2,4	88	9,6	4.6	25	43
Callosobruchus maculatus P	2,4	88	9,6	3.6	32	43
Callosobruchus maculatus P	6	70	24	10.9	25	43
Callosobruchus maculatus P	6	70	24	5.5	32	43
Callosobruchus maculatus P	8	60	32	11.4	25	43
Callosobruchus maculatus P	8	60	32	5.1	32	43
Callosobruchus maculatus P	10	50	40	11	25	43
Callosobruchus maculatus P	10	50	40	6.2	32	43
Callosobruchus maculatus P schw B	6	70	24	6.6	27	45
Callosobruchus maculatus P schw B	1	0	99	6.6	27	45
Callosobruchus maculatus P schw B	14	30	56	9.3	27	45
Callosobruchus maculatus P schw B	4	0	96	9.1	27	45

Callosobruchus maculatus P st B	6	70	24	10.8	27	45
Callosobruchus maculatus P st B	1	0	99	10.4	27	45
Callosobruchus maculatus P st B	14	30	56	10.7	27	45
Callosobruchus maculatus P st B	4	0	96	10.8	27	45
Callosobruchus subinnotatus E	0	0	100	1.25	32	34
Callosobruchus subinnotatus100 E	0	100	0	1.25	32	34
Callosobruchus subinnotatus100 I	0	0	100	1	30	34
Callosobruchus subinnotatus100 I	0	100	0	1	30	34
Callosobruchus subinnotatus100 I	0	0	100	0.67	32	34
Callosobruchus subinnotatus100 I	0	100	0	0.67	32	34
Callosobruchus subinnotatus100 I1T	0	0	100	1	32	34
Callosobruchus subinnotatus100 I1T	0	100	0	1	32	34
Callosobruchus subinnotatus100 I3T	0	0	100	0.92	32	34
Callosobruchus subinnotatus100 I3T	0	100	0	0.92	32	34
Callosobruchus subinnotatus100 I6T	0	0	100	0.75	32	34
Callosobruchus subinnotatus100 I6T	0	100	0	0.75	32	34
Callosobruchus subinnotatus100 L1	0	0	100	3	32	34
Callosobruchus subinnotatus100 L1	0	100	0	3	32	34
Callosobruchus subinnotatus100 L3	0	0	100	4	32	34
Callosobruchus subinnotatus100 L3	0	100	0	4	32	34
Callosobruchus subinnotatus100 Ll	0	0	100	4	32	34
Callosobruchus subinnotatus100 Ll	0	100	0	4	32	34
Callosobruchus subinnotatus100 P	0	0	100	6	32	34
Callosobruchus subinnotatus100 P	0	100	0	6	32	34
Callosobruchus subinnotatus100 pP	0	0	100	6	32	34
Callosobruchus subinnotatus100 pP	0	100	0	6	32	34
Corcyra cephalonica E	16	20	94	5.4	15	31
Corcyra cephalonica E	12	40	48	5.5	15	31
Corcyra cephalonica E	8	60	32	3.9	15	31
Corcyra cephalonica E	2	90	8	3.3	15	31
Corcyra cephalonica E	16	20	94	4.9	25	31
Corcyra cephalonica E	12	40	48	4.2	25	31
Corcyra cephalonica E	8	60	32	4.8	25	31
Corcyra cephalonica E	2	90	8	3.2	25	31
Dermestes maculatus	0	0	100	2	25	75
Dermestes maculatus	0	0	100	2	25	75
Dermestes maculatus	2	0	98	2	25	75
Dermestes maculatus	0	0	100	2	25	75
Dermestes maculatus	0	0	100	2	25	75
Dermestes maculatus	2	0	98	2	25	75
Dermestes maculatus	0	0	100	2	25	75
Dermestes maculatus	0	0	100	2	25	75
Dermestes maculatus	2	0	98	2	25	75
Dermestes maculatus E	0	0	100	1	25	75
Dermestes maculatus E	0	0	100	1	25	75
Dermestes maculatus E	2	0	98	1	25	75
Dermestes maculatus E	8	60	32	1	25	75
Dermestes maculatus I	0	0	100	2	25	75
Dermestes maculatus I	0	0	100	2	25	75
Dermestes maculatus I	2	0	98	2	25	75
Dermestes maculatus L	0	0	100	2	25	75
Dermestes maculatus L	0	0	100	2	25	75
Dermestes maculatus L	2	0	98	2	25	75
Dermestes maculatus P	0	0	100	2	25	75
Dermestes maculatus P	0	0	100	2	25	75
Dermestes maculatus P	2	0	98	2	25	75
Dinoderus bifoveolatus I	16	40	44	5.2	30	32
Dinoderus bifoveolatus I	8	60	32	1.6	30	32
Dinoderus bifoveolatus I	2	0	98	1.9	30	32
Dinoderus porcellus I	16	40	44	3.8	30	32
Dinoderus porcellus I	8	60	32	1.1	30	32
Dinoderus porcellus I	2	0	98	1.3	30	32
Ephestia elutella E	16	20	94	7.3	15	31
Ephestia elutella E	12	40	48	6.4	15	31

Ephestia elutella E	8	60	32	5.8	15	31
Ephestia elutella E	2	90	8	5.3	15	31
Ephestia elutella E	16	20	94	3.6	25	31
Ephestia elutella E	12	40	48	2.9	25	31
Ephestia elutella E	8	60	32	2.2	25	31
Ephestia elutella E	2	90	8	1.7	25	31
Hylotrupes bajulus	0	0	100	28	22	72
Hylotrupes bajulus E	0	0	100	35	16	72
Hylotrupes bajulus L	0	0	100	35	16	72
Hylotrupes bajulus L (LD100)	1,1	0	98,9	21	35	69
Lasioderma serricorne E (25 bar)	0	100	0	80 min	25	80
Lasioderma serricorne E (30 bar)	0	100	0	52 min	25	80
Lasioderma serricorne E (30 bar)	0	100	0	70 min	15	80
Lasioderma serricorne E (35 bar)	0	100	0	36 min	25	80
Lasioderma serricorne E (35 bar)	0	100	0	48 min	15	80
Lasioderma serricorne E (40 bar)	0	100	0	20 min	25	80
Lasioderma serricorne E (40 bar)	0	100	0	32 min	15	80
Lasioderma serricorne I (20 bar)	0	100	0	3.7 min	25	78
Lasioderma serricorne I (10 bar)	0	100	0	477.8 min	25	78
Lasioderma serricorne I (10 bar)	0	100	0	85 min	35	78
Lasioderma serricorne I (10 bar)	0	100	0	478 min	25	78
Lasioderma serricorne I (15 bar)	0	100	0	28 min	35	80
Lasioderma serricorne I (15 bar)	0	100	0	50 min	25	80
Lasioderma serricorne I (15 bar)	0	100	0	130 min	15	80
Lasioderma serricorne I (15 bar)	0	100	0	80 min	35	80
Lasioderma serricorne I (15 bar)	0	100	0	49 min	25	80
Lasioderma serricorne I (15 bar)	0	100	0	170 min	15	80
Lasioderma serricorne I (20 bar)	0	100	0	4.5 min	35	80
Lasioderma serricorne I (20 bar)	0	100	0	25 min	25	80
Lasioderma serricorne I (20 bar)	0	100	0	40 min	15	80
Lasioderma serricorne I (20 bar)	0	100	0	0.2 min	25	80
Lasioderma serricorne I (20 bar)	0	100	0	4 min	15	80
Lasioderma serricorne I (20 bar)	0	100	0	24.9 min	25	78
Lasioderma serricorne I (20 bar)	0	100	0	38.9 min	15	78
Lasioderma serricorne I (20 bar)	0	100	0	24.9 min	25	78
Lasioderma serricorne I (20 bar)	0	100	0	35 min	35	78
Lasioderma serricorne I (20 bar)	0	100	0	10 min	35	78
Lasioderma serricorne I (20 bar)	0	100	0	25 min	25	78
Lasioderma serricorne I (20 bar)	0	100	0	40 min	15	78
Lasioderma serricorne I (25 bar)	0	100	0	8 min	35	78
Lasioderma serricorne I (25 bar)	0	100	0	4.6 min	25	78
Lasioderma serricorne I (25 bar)	0	100	0	30 min	15	78
Lasioderma serricorne I (30 bar)	0	100	0	1.1 min	35	80
Lasioderma serricorne I (30 bar)	0	100	0	2.5 min	25	80
Lasioderma serricorne I (30 bar)	0	100	0	10 min	15	80
Lasioderma serricorne I (30 bar)	0	100	0	4 min	35	78
Lasioderma serricorne I (30 bar)	0	100	0	2.5 min	25	78
Lasioderma serricorne I (30 bar)	0	100	0	10 min	15	78
Lasioderma serricorne I (35 bar)	0	100	0	1.3 min	25	78
Lasioderma serricorne I (35 bar)	0	100	0	6 min	15	78
Lasioderma serricorne I (40 bar)	0	100	0	0.3 min	25	78
Lasioderma serricorne L (15 bar)	0	100	0	61 min	25	78
Lasioderma serricorne L (20 bar)	0	100	0	20 min	35	80
Lasioderma serricorne L (20 bar)	0	100	0	95 min	25	80
Lasioderma serricorne L (20 bar)	0	100	0	120 min	15	80
Lasioderma serricorne L (20 bar)	0	100	0	114 min	25	78
Lasioderma serricorne L (25 bar)	0	100	0	31 min	25	78
Lasioderma serricorne L (30 bar)	0	100	0	4 min	35	78
Lasioderma serricorne L (30 bar)	0	100	0	13 min	25	78
Lasioderma serricorne L (30 bar)	0	100	0	65 min	15	78
Lasioderma serricorne L (30 bar)	0	100	0	2.5 min	25	80
Lasioderma serricorne L (30 bar)	0	100	0	14 min	25	39
Lasioderma serricorne L (35 bar)	0	100	0	6 min	25	80
Lasioderma serricorne L (40 bar)	0	100	0	3 min	15	80
Lasioderma serricorne L (40 bar)	0	100	0	0.3 min	25	80
Lasioderma serricorne L (40 bar)	0	100	0	2.7 min	25	80
Lasioderma serricorne P (25 bar)	0	100	0	30 min	25	80

Lyctus brunneus	0	0	100	21	35	72
Lyctus brunneus breed 10W. interior	0	0	100	16.8	25	28
Lyctus brunneus breed 10W. interior	0	4	96	10.4	25	28
Lyctus brunneus breed 13W. interior	0	0	100	18.4	25	28
Lyctus brunneus breed 13W. interior	0	4	96	14.8	25	28
Lyctus brunneus breed 1W. interior	0	0	100	13.3	25	28
Lyctus brunneus breed 1W. interior	0	4	96	8.08	25	28
Lyctus brunneus breed 4W. interior	0	0	100	13.1	25	28
Lyctus brunneus breed 4W. interior	0	4	96	8.11	25	28
Lyctus brunneus breed 7W. interior	0	0	100	16.55	25	28
Lyctus brunneus breed 7W. interior	0	4	96	15.7	25	28
Lyctus brunneus I exterior	0	0	100	7.2	20	28
Lyctus brunneus I exterior	0	0	100	1.73	25	28
Lyctus brunneus I exterior	0	0	100	1.43	28	28
Lyctus brunneus I exterior	0	4	96	4.05	25	28
Lyctus brunneus I exerior	0	10	96	2.77	25	28
Lyctus brunneus L exterior	0	0	100	22	20	28
Lyctus brunneus L exterior	0	0	100	14.7	25	28
Lyctus brunneus L exterior	0	0	100	11.86	28	28
Lyctus brunneus L exterior	0	4	96	7.4	25	28
Lyctus brunneus L exterior	0	10	90	13	25	28
Oryzaephilus mercator I	16	40	44	1.4	30	48
Oryzaephilus mercator I	8	60	32	1.0	30	48
Oryzaephilus mercator I	2	0	98	1.1	30	48
Oryzaephilus surinamensis	2	0	98	4	15	53
Oryzaephilus surinamensis	2	18	80	5	15	53
Oryzaephilus surinamensis	2	90	8	3	15	53
Oryzaephilus surinamensis	2	0	98	4	20	53
Oryzaephilus surinamensis	2	18	80	3	20	53
Oryzaephilus surinamensis	2	90	8	2	20	53
Oryzaephilus surinamensis I	16	40	44	5.9	30	48
Oryzaephilus surinamensis I	8	60	32	2.9	30	48
Oryzaephilus surinamensis I	2	0	98	2.63	30	48
Plodia interpunctella	2	0	98	4.5	15	53
Plodia interpunctella	2	18	80	5	15	53
Plodia interpunctella	2	90	8	8	15	53
Plodia interpunctella	2	0	98	2.5	20	53
Plodia interpunctella	2	18	80	3.5	20	53
Plodia interpunctella	2	90	8	3	20	53
Plodia interpunctella E (15 bar)	0	100	0	40 min	25	53
Plodia interpunctella E (20 bar)	0	100	0	10 min	25	53
Plodia interpunctella E (20 bar)	0	100	0	30 min	25	53
Prostephanus truncates	5	75	20	2.04	20	29
Prostephanus truncates	10	50	40	3.5	20	29
Prostephanus truncatus	15	25	60	6	20	29
Prostephanus truncates	5	75	20	1.25	30	29
Prostephanus truncates	10	50	40	2.75	30	29
Prostephanus truncates	15	25	60	3.5	30	29
Prostephanus truncates	15	25	60	6.3	20	30
Prostephanus truncates	10	50	50	3.1	20	30
Prostephanus truncates	5	75	20	2.2	20	30
Prostephanus truncates	10	50	50	2.7	20	30
Prostephanus truncates	15	25	60	3.5	30	30
Prostephanus truncates	10	50	50	2.8	30	30
Prostephanus truncates	10	50	50	1.8	30	30
Reticulitermes santonensis	0	0	100	28	22	72
Rhyzopertha domenica	5	75	20	1.75	20	29
Rhyzopertha domenica	10	50	40	2.5	20	29
Rhyzopertha domenica	15	25	60	5	20	29
Rhyzopertha domenica	5	75	20	0.92	30	29
Rhyzopertha domenica	10	50	40	2.5	30	29
Rhyzopertha domenica	15	25	60	3.5	30	29
Rhyzopertha domenica	15	25	60	4.7	20	30
Rhyzopertha domenica	5	75	20	1.9	20	30

Rhyzopertha domenica	15	25	60	3.3	30	30
Sitophilus granarius	2	0	98	21	15	17
Sitophilus granarius	1	0	99	10.8	15	50
Sitophilus granarius	1	19	80	13.4	15	50
Sitophilus granarius	1	95	4	8	15	50
Sitophilus granarius	2	0	98	13.1	15	50
Sitophilus granarius	2	18	80	7.3	15	50
Sitophilus granarius	2	90	8	6.7	15	50
Sitophilus granarius	3	0	97	6.9	15	50
Sitophilus granarius	3	17	80	5.1	15	50
Sitophilus granarius	3	12	85	3.9	15	50
Sitophilus granarius	4	0	96	21.9	15	50
Sitophilus granarius	4	16	80	8.4	15	50
Sitophilus granarius	4	80	16	6.2	15	50
Sitophilus granarius	1	0	99	13	20	50
Sitophilus granarius	1	19	80	5.8	20	50
Sitophilus granarius	1	95	4	4.7	20	50
Sitophilus granarius	2	0	98	7.4	20	50
Sitophilus granarius	2	18	80	9.8	20	50
Sitophilus granarius	2	90	8	2.9	20	50
Sitophilus granarius	3	0	97	5.3	20	50
Sitophilus granarius	3	17	80	2.8	20	50
Sitophilus granarius	3	12	85	2.3	20	50
Sitophilus granarius	4	0	96	6.4	20	50
Sitophilus granarius	4	16	80	5.7	20	50
Sitophilus granarius	4	80	16	2.2	20	50
Sitophilus granarius aL	1	0	99	37	20	50
Sitophilus granarius breed and adults	0	100		0.02	40 bar	70
Sitophilus granarius breed and adults	0	100		0.04	30 bar	70
Sitophilus granarius breed and adults	0	100		0.08	20 bar	70
Sitophilus granarius breed and adults	0	100		0.33	10 bar	70
Sitophilus granarius breed and adults	0	100	0	1	40	70
Sitophilus granarius breed and adults	0	100	0	3	35	70
Sitophilus granarius breed and adults	0	100	0	7	30	70
Sitophilus granarius breed and adults	0	100	0	14	25	70
Sitophilus granarius breed and adults	0	100	0	25	20	70
Sitophilus granarius breed and adults	0	100	0	42	15	70
Sitophilus granarius breed, stadium 4	1	0	99	40	15	52
Sitophilus granarius breed, stadium 4	1	19	80	60	15	52
Sitophilus granarius breed, stadium 4	1	95	4	22	15	52
Sitophilus granarius breed, stadium 4	2	0	98	60	15	52
Sitophilus granarius breed, stadium 4	2	18	80	53	15	52
Sitophilus granarius breed, stadium 4	2	90	8	15	15	52
Sitophilus granarius breed, stadium 4	3	0	97	65	15	52
Sitophilus granarius breed, stadium 4	3	17	80	50	15	52
Sitophilus granarius breed, stadium 4	3	12	85	24	15	52
Sitophilus granarius breed, stadium 4	4	0	96	60	15	52
Sitophilus granarius breed, stadium 4	4	16	80	48	15	52
Sitophilus granarius breed, stadium 4	4	80	16	39	15	52
Sitophilus granarius breed, stadium 4	1	0	99	30	20	52
Sitophilus granarius breed, stadium 4	1	19	80	30	20	52
Sitophilus granarius breed, stadium 4	1	90	8	20	20	52
Sitophilus granarius breed, stadium 4	2	0	98	31	20	52
Sitophilus granarius breed, stadium 4	2	18	80	25	20	52
Sitophilus granarius breed, stadium 4	2	95	4	7	20	52
Sitophilus granarius breed, stadium 4	3	0	97	35	20	52
Sitophilus granarius breed, stadium 4	3	17	80	42	20	52
Sitophilus granarius breed, stadium 4	3	12	85	15	20	52
Sitophilus granarius breed, stadium 4	4	0	96	40	20	52
Sitophilus granarius breed, stadium 4	4	16	80	31	20	52
Sitophilus granarius breed, stadium 4	4	80	16	40	20	52
Sitophilus granarius breed, stadium 5	1	0	99	45	15	52
Sitophilus granarius breed, stadium 5	1	19	80	39	15	52
Sitophilus granarius breed, stadium 5	1	95	4	35	15	52
Sitophilus granarius breed, stadium 5	2	0	98	52	15	52
Sitophilus granarius breed, stadium 5	2	18	80	49	15	52
Sitophilus granarius breed, stadium 5	2	90	8	27	15	52
Sitophilus granarius breed, stadium 5	3	0	97	53	15	52
Sitophilus granarius breed, stadium 5	3	17	80	41	15	52

Sitophilus granarius breed, stadium 5	3	12	85	34	15	52
Sitophilus granarius breed, stadium 5	4	0	96	55	15	52
Sitophilus granarius breed, stadium 5	4	16	80	49	15	52
Sitophilus granarius breed, stadium 5	4	80	16	40	15	52
Sitophilus granarius breed, stadium 5	1	0	99	30	20	52
Sitophilus granarius breed, stadium 5	1	19	80	32	20	52
Sitophilus granarius breed, stadium 5	1	95	4	24	20	52
Sitophilus granarius breed, stadium 5	2	0	98	25	20	52
Sitophilus granarius breed, stadium 5	2	18	80	21	20	52
Sitophilus granarius breed, stadium 5	2	90	8	19	20	52
Sitophilus granarius breed, stadium 5	3	0	97	30	20	52
Sitophilus granarius breed, stadium 5	3	17	80	45	20	52
Sitophilus granarius breed, stadium 5	3	12	85	26	20	52
Sitophilus granarius breed, stadium 5	4	0	96	40	20	52
Sitophilus granarius breed, stadium 5	4	16	80	32	20	52
Sitophilus granarius breed, stadium 5	4	80	16	38	20	52
Sitophilus granarius E	1	0	99	10	20	64
Sitophilus granarius I	1	0	99	10	20	64
Sitophilus granarius jL	1	0	99	10	20	64
Sitophilus granarius mL	1	0	99	21	20	64
Sitophilus granarius P	1	0	99	42	20	64
Sitotroga cerealella E	16	20	94	7.1	15	31
Sitotroga cerealella E	12	40	48	7.0	15	31
Sitotroga cerealella E	8	60	32	5.2	15	31
Sitotroga cerealella E	2	90	8	4.8	15	31
Sitotroga cerealella E	16	20	94	4.8	25	31
Sitotroga cerealella E	12	40	48	2.8	25	31
Sitotroga cerealella E	8	60	32	2.1	25	31
Sitotroga cerealella E	2	90	8	1.9	25	31
Tineola bisselliella	0	100	0	28	22	72
Tineola bisselliella E	2	0	98	7	25	85
Tribolium castaeum	16	20	64		28	27
Tribolium castaeum	10	50	40	2.46	28	27
Tribolium castaeum	4.4	78	17.6	0.96	28	27
Tribolium castaneum I	16	40	44	6.2	30	26
Tribolium castaneum I	8	60	32	4.5	30	26
Tribolium castaneum I	2	0	98	3.7	30	26
Tribolium confusum	2	0	98	4.5	15	53
Tribolium confusum	2	18	80	5	15	53
Tribolium confusum	2	90	8	5	15	53
Tribolium confusum	2	0	98	4	20	53
Tribolium confusum	2	18	80	3	20	53
Tribolium confusum	2	90	8	2	20	53
Tribolium confusum I	16	40	44	5.4	30	26
Tribolium confusum I	8	60	32	4.2	30	26
Tribolium confusum I	2	0	98	3.7	30	26
Trogoderma angustum L	0	0	100	6.6	25	28
Trogoderma angustum L	0	4	96	3.6	25	28
Trogoderma angustum L	0	10	96	2.9	25	28
Trogoderma grasmani I	16	40	44	2.2	30	32
Trogoderma grasmani I	8	60	32	1.4	30	32
Trogoderma grasmani I	2	0	98	1.8	30	32
Trogoderma inclusum I	16	40	44	4.5	30	32
Trogoderma inclusum I	8	60	32	4.0	30	32
Trogoderma inclusum I	2	0	98	2.8	30	32

6

6. Alternatives to methyl bromide for Quarantine and Pre-shipment applications

6.1. Introduction

Quarantine and pre-shipment (QPS) treatments with methyl bromide (MB) are being used when necessary to kill pests on perishable and durable commodities to reduce or eliminate listed quarantine pests (quarantine); on durable and perishable commodities or in trade to render them "practically free" of injurious and other organisms (pre-shipment); QPS treatments are also used on soils, and in structures and commodities to eliminate or control exotic organisms of quarantine significance. Periodic QPS uses of MB have been made within countries to try and prevent spread of pests, when an exotic pest is found in a new region. Since 2003, some countries have interpreted that treatment to avoid movement of soil pests within a country on propagation material may also qualify for QPS MB use.

Typically QPS treatments with methyl bromide (MB) are applied to commodities in trade between countries and between quarantine regions within a country. Perishable commodities include fresh fruit and vegetables, cut flowers, ornamental plants, fresh root crops and bulbs. Durable commodities are those with low moisture content that, in the absence of pest attack, can be safely stored for long periods. They include foods such as grains, dried fruits and beverage crops and non-foods such as cotton, wood products and tobacco and other non-agricultural goods that may harbour quarantine pests such as tiles, household goods, and industrial goods.

The production and consumption of methyl bromide (MB) for QPS is exempted from the control measures (phaseout) agreed under Article 2H para 6 of the Montreal Protocol.
Some implementation of alternatives to MB for QPS has occurred since the last MBTOC Assessment in 2006, and in response to Decision XXI/10 MBTOC has made initial estimates of amounts of MB used for QPS purposes that could be replaced with alternatives, for the major use categories. The Protocol's Technology and Economic Assessment Panel (TEAP) has recently provided extensive reports on QPS, through its QPS Task Force (QPSTF) of 2009 (TEAP, 2009 ab) and its MBTOC (TEAP, 2010) and previously (TEAP 1999, TEAP 2002, TEAP 2006, MBTOC 2007). These reports include examples of treatments considered by TEAP to be QPS, QPS consumption and production, QPS categories of use, QPS alternatives, prospects for recapture and recovery, containment and recycling of MB used for QPS and QPS relationship to other conventions and treaties. The key conclusions of these recent reports are included in this chapter.

Development of methyl bromide alternatives for Quarantine applications on commodities continues to be a difficult process, exacerbated by the multitude of commodities being treated, the diverse situations where treatments are applied, a constantly changing trade and regulatory landscape, requirements for bilateral agreement on QPS measures, requirement for very high levels of proven effectiveness, often for several different target species, lack of patent coverage or other commercial protection for some potential alternatives, and the low price and plentiful supply of methyl bromide for QPS purposes. Regulations favouring methyl bromide treatment or prescribing methyl bromide alone are a major barrier to adoption of alternatives as often there is little incentive for the regulation to be changed.

This chapter provides:

- Official definitions of Quarantine and Pre-shipment (QPS)
- An overview of Decisions taken by the Parties to the Montreal Protocol referring to MB uses for QPS purposes
- An overview of the main use categories of MB for QPS purposes, key peststo be controlled and existing and potential alternatives to the main uses – sawn timber and wood packaging material, logs, grain and similar foodstuffs, logs and fresh fruit and vegetables. Scope for replacement of MB presently used for QPS purposes
- Scope for replacement of MB presently used for QPS purposes
- Constraints to adoption of alternatives
- A thorough analysis of MB production and consumption for QPS (exempted) – producers and consumers, regional trends in production and consumption and others.

6.2. Reasons for QPS uses of methyl bromide

Many perishable and durable commodities in trade and storage can be attacked by pests including insects, mites and fungi, causing loss of quality and value. These commodities may also carry pests and diseases that can be a threat to agriculture, health or the environment. There are a wide variety of measures that can be taken to manage these pests so that the damage they cause or risk that they pose is lowered to an acceptable level. Fumigation with MB is one such measure.

Most current uses of MB on durables and perishable commodities worldwide are highly specialised. MB use has been in routine use for decades as a well-developed system with a good record of successful use. Some examples of current QPS uses include:

- Fumigation of cut flowers found to be infested on arrival in the importing country with quarantine pests (quarantine treatment);
- Fumigation of fruit before export to meet the official phytosanitary requirements of the importing country for mandatory fumigation of an officially-listed quarantine pest (quarantine treatment);
- Fumigation of grain before export to meet the importing country's existing import regulations that require fumigation of all export grain consignments (pre-shipment treatment);
- Fumigation of log exports either prior to shipment or on arrival against official quarantine pests.

Further examples of treatments that may be QPS have been provided in previous reports

Requirements for MB alternatives are often compared with MB's properties which include such desirable features as:

- Rapid speed of treatment. This is particularly useful for perishable products that must be marketed rapidly;
- Low cost for fumigation;
- Relatively non-corrosive and applied easily to shipping fumigation facilities, containers or to bagged, palletised or bulk commodities 'under sheets';
- A long history of recognition as a suitable treatment by quarantine authorities;
- Broad registration for use;
- Good ability to penetrate into the commodity where pests might be located; and
- Rapid release of gas from the commodity after exposure;

MB also has a number of undesirable features including:

- A high level of toxicity to humans;
- Odourless, making it difficult to detect;
- A significant ozone depleting potential;
- Adverse effects on some commodities, particularly loss of viability, quality reduction, reduced shelf life and taint;
- Slow desorption from some commodities and at low temperatures, leading to hazardous concentrations of MB in storage and transport subsequent to fumigation; and
- Excessive bromide residues retained in the product.

In certain situations, MB is the only treatment approved by national quarantine authorities for QPS applications for international trade. Quarantine treatments are supported by extensive scientific data documenting the responses of pests to MB as these data are required to verify a high level of treatment efficacy for pests that are considered to be serious threats to the agriculture, natural resources or public health of the importing country. Intracountry quarantines are aimed at curtailing the spread, containing or eradicating spread of quarantine pests that may be established in a restricted area or region of the country. In some cases, production of propagation material of certified high plant health status is considered a quarantine activity. Pre-shipment treatments are aimed at ensuring that products in international trade meet set standards of lack of pests.

6.3. Definitions of Quarantine and Pre-shipment

6.3.1. Origin and original intent of the QPS exemption

At the 1992 Meeting of the Parties in Copenhagen that established methyl bromide as a controlled Ozone Depleting Substance, Article 2H of the Protocol specifically excluded QPS from control measures when it stated, *inter alia*:

> *'The calculated levels of consumption and production ...shall not include the amounts used by the Party for quarantine and pre-shipment applications'*

This was the first time that QPS was mentioned in the Protocol documentation. Definition of 'quarantine' and 'pre-shipment' was deferred to a later meeting.

At the time that Article 2H was agreed in Copenhagen in 1992, the Parties understood that there were no alternatives to MB for a diverse range of treatments carried out with MB for

QPS. The Parties recognised that although QPS consumption was about 10% of global MB consumption at the time, this volume was nevertheless very significant in allowing inter- and intra-country trade in commodities *in the absence of site-specific alternatives*.

Unless site specific alternatives to MB were available for QPS that were tested and approved in both A 5 and non-A 5 countries, there was a strong likelihood of disruption to international trade if the exemption for QPS were not available. For some A 5 and non-A 5 that rely on export receipts for MB-treated commodities as a significant proportion of their income from specific commodities, the exemption was considered very important as it specifically avoided '…new non-tariff barriers to trade…' (Decision VI/11) that could be introduced if such an exemption were not in place.

Invasions by new pest species into a country or region can have serious adverse effects economically and on agricultural production and natural resources (e.g. recreational values, extinction of indigenous species). An objective of the quarantine treatments of the QPS exemption is to prevent establishment of these new pest species in areas hitherto free of them. The combined economic costs of new pests may be significant, with implications for environmental policy and resource management; yet full economic impact assessments are rare at a national scale. A Canadian study (Colautti *et al*. 2004) characterised and projected economic costs associated with new pest species in Canada, through a combination of case-studies and an empirical model derived from 21 identified effects of 16 new pest species. Despite a lack of data, characterised costs associated with ten species in Canadian fisheries, agriculture and forestry were estimated to cost $ CDN 187 million per year.

These costs were dwarfed by the 'invisible tax' projected for sixteen new pest species found in Canada, which was estimated at between $ CDN 13.3 and 34.5 billion per year. One study reported that 79 exotic species in the USA had caused approximately $US 97 billion in damages during the period 1906–1991 (OTA 1993). Another study in the USA (Pimental *et al.* 2000) estimated the non-indigenous species caused some $US 137 billion damage per year.

The containment and eradication of a newly discovered pest is generally difficult, often highly controversial, and frequently requires substantial resources costing millions of dollars and the commitment of all involved (e.g., Myers and Hosking, 2002; Simberloff, 2002, 2003). However, as Brockerhoff *et al*. (unpublished) found there are many examples of successful eradication campaigns. These include several recent successful eradication campaigns against tree-defoliating Lepidoptera in New Zealand (at a cost of $NZ 94 million) and North America (e.g., Myers and Hosking, 2002; Suckling *et al*., 2007a). A number of other pest insects and diseases have been successfully eradicated, including the screw-worm fly (*Cochliomyia hominivorax*) in the USA (Myers *et al*., 1998), Central America (Galvin and Wyss, 1996), and North Africa (Gillman, 1992), the Mediterranean fruit fly (*Ceratitis capitata*) in Mexico, parts of Central America, Chile, Australia and California (Hendrichs *et al*., 2002), and the red imported fire ant (*Solenopsis invicta*) in New Zealand (Sarty, 2007). Methyl bromide treatment is considered an important tool for some eradication and containment attempts. It was successfully used in the eradication of khapra beetle from both western USA in the 1950s and more recently from Perth, Western Australia (Emery *et al.,* 2010). It was recently being used as a soil fumigant to contain and possibly eradicate the exotic nematodes *Globodera pallida* and *R. rostochiensis* in parts of USA (TEAP, 2009, section 6.2.3.2.).

Countries involved in trade have relied on effective quarantine measures to prevent the incursion of new pest species. Among other pest control methods, methyl bromide has provided a key role for over 70 years.

6.3.2. ‘Quarantine’ and ’Pre-shipment’

The scope of the QPS exemption set out in Article 2H paragraph 6 has been clarified in Decisions VII/5 and XI/12 of the Protocol relating to the terms 'Quarantine' and 'Pre-shipment'. TEAP (2002) provided some discussion and examples of cases that might or might not fall within the QPS exemption. There is also discussion of the scope of the exemption from control under the Protocol for QPS uses of methyl bromide in TEAP (1999) and the UNEP/IPPC (2008) publication ‘Methyl Bromide: Quarantine and Pre-shipment Uses’.
Differences in interpretation of the scope and application of the QPS exemption by individual Parties have led to some differences in the uses that were reported as QPS in the data accessed by MBTOC.

Specifically, the Seventh Meeting of the Parties decided in Decision VII/5 that:

a) “Quarantine applications”, with respect to methyl bromide, are treatments to prevent the introduction, establishment and/or spread of quarantine pests (including diseases), or to ensure their official control, where:

   i. Official control is that performed by, or authorised by, a national plant, animal or environmental protection or health authority;
   ii. Quarantine pests are pests of potential importance to the areas endangered thereby and not yet present there, or present but not widely distributed and being officially controlled

b) *"Pre-shipment applications"* are those treatments applied directly preceding and in relation to export, to meet the phytosanitary or sanitary requirements of the importing country or existing phytosanitary or sanitary requirements of the exporting country;

The definition of 'Pre-shipment' is unique to the Montreal Protocol. It is given and elaborated in Decisions VII/5 and XI/12. The Eleventh Meeting of the Parties decided in Decision XI/12 that pre-shipment applications are *"those non-quarantine applications applied within 21 days prior to export to meet the official requirements of the importing country or existing official requirements of the exporting country”*.

As per decision VII/5, official requirements are those, which are “performed by, or authorised by a national plant, animal, environmental, health or stored product authority".
The International Plant Protection Convention, Codex Alimentarius Commission (Food Standards) and the International Office of Epizootics (Animal Standards) all fall under the mantle of the principles of the Sanitary and Phytosanitary Agreement (SPS) which itself is under the World Trade Organisation. The main SPS principle is that no Member should be prevented from adopting or enforcing measures necessary to protect human, animal or plant life or health.

The Agreement applies to all sanitary and phytosanitary measures that may, directly or indirectly, affect international trade. However, 'Members shall ensure that any sanitary or phytosanitary measure is applied only to the extent necessary to protect human, animal or plant life or health, is based on scientific principles and is not maintained without sufficient scientific evidence, except as provided for in paragraph 7 of Article 5.' (Article 2.2). Members may introduce or maintain sanitary or phytosanitary measures which result in a higher level of sanitary or phytosanitary protection than would be achieved by measures based on the relevant international standards, guidelines or recommendations, if there is a scientific justification. Members shall accept the sanitary or phytosanitary measures of other Members as equivalent, even if these measures differ from their own or from those used by other Members trading in the same product, if the exporting Member objectively demonstrates to the importing Member that its measures achieve the importing Member's appropriate level of sanitary or phytosanitary protection. Another important principle of the SPS agreement is *"To harmonize sanitary and phytosanitary measures on as wide a basis as possible, Members shall base their sanitary or phytosanitary measures on international standards, guidelines or recommendations, where they exist, except as otherwise provided for in this Agreement ..."* (Article 3,1). The SPS agreement also requires parties to base their phytosanitary measures on risk assessment, taking into account scientific evidence and the risk assessment techniques developed by the relevant international organizations (Article 5.1). The SPS agreement does not talk about quarantine pests but defines what sanitary or phytosanitary measures are.

Sanitary or phytosanitary measure — any measure applied:

a) to protect animal or plant life or health within the territory of the Member from risks arising from the entry, establishment or spread of pests, diseases, disease-carrying organisms or disease-causing organisms;

b) to protect human or animal life or health within the territory of the Member from risks arising from additives, contaminants, toxins or disease-causing organisms in foods, beverages or feedstuffs;

c) to protect human life or health within the territory of the Member from risks arising from diseases carried by animals, plants or products thereof, or from the entry, establishment or spread of pests; or

d) to prevent or limit other damage within the territory of the Member from the entry, establishment or spread of pests.

In the International Plant Protection Convention, the following definitions apply:

"Quarantine pest" - a pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled;

"Regulated non-quarantine pest" - a non-quarantine pest whose presence in plants for planting affects the intended use of those plants with an economically unacceptable impact and which is therefore regulated within the territory of the importing contracting party.

MBTOC notes that '*not yet present there'* is referring to exotic pests, rather than an endemic pest. Exotic pests may be long established in defined regions of a country, but still subject to quarantine measures for regions where they are not established or host material moving between regions.

The definition of a quarantine pest under the Montreal Protocol differs from that under the IPPC by one word, 'economic': the Montreal Protocol refers to *"pests of potential importance"* while the Convention definition refers to "*pests of potential economic importance"*. However, under the IPPC, it has been clarified in a supplement to ISPM No. 5 that 'economic' includes the effect of changes (e.g. in biodiversity, ecosystems, managed resources or natural resources) on human welfare.

The IPPC deals with pests of plants, and not of livestock, which would have potential economic impact, again including environmental considerations. The scope of the IPPC covers international measures for the protection of cultivated plants in agriculture (including horticulture and forestry), uncultivated/unmanaged plants, wild flora, habitats and ecosystems. IPPC measures are not directly concerned with domestic phytosanitary and quarantine measures, excepting where they impact international measures.

The IPPC definition of a quarantine pest relates to official control, which means the active enforcement of mandatory phytosanitary regulations and the application of mandatory phytosanitary procedures with the objective of eradication or containment of quarantine pests or for the management of regulated non-quarantine pests. The latter are specifically pests of propagation material and seeds for planting, and do not include pests that affect quality in storage.

The Montreal Protocol's definition covers environmental and other pests that might endanger a region without direct quantifiable economic loss. An interpretation of Decision VII/7 is that the use of methyl bromide as a quarantine treatment may only be for pests that are officially recognised as quarantine pests and must be officially authorised by a competent authority.

The IPPC definition of a quarantine pest relates to official control, which means established, authorised or performed by a national plant protection organisation. Under the Montreal Protocol definitions, 'competent authorities' include not only national plant protection organisations, but also national animal or environmental protection authorities or national official health authorities. An interpretation is that commercial and contractual arrangements to supply fumigated or pest-free commodity do not qualify a treatment as 'quarantine' nor 'pre-shipment'.

QPS treatments under the Montreal Protocol relate not only to official phytosanitary treatments, but may also apply to 'sanitary' treatments, e.g., against human or animal pathogens and vectors (e.g. mosquitoes), covered by International Agreements (IAs, multilateral agreements) such as the World Animal Health Organisation (OIE) and World Health Organization (WHO).

Pre-shipment treatments target non-quarantine pests that may be present in both the exporting and importing country. These pests are usually ones that affect storage or end-use quality of the exported commodities, and are outside the direct scope of the IPPC. However, the model Phytosanitary certificate from Guidelines for Phytosanitary

Certificates provided in ISPM 12 contains the following optional clause: "They are deemed to be practically free from other pests." This relates to Pre-shipment uses where a certification is needed to meet commodity shipping requirements.

As a result of the broad coverage of the Montreal Protocol QPS concept, the actual QPS uses are covered by several different IAs and domestic regulatory bodies. Breakdown of this coverage is given in Table 25.

6.4. Decisions relating to QPS use of methyl bromide

Since 1992, there have been various Decisions taken by the Parties to the Montreal Protocol related to this QPS exemption. These have concerned definitions and clarification of definitions, and have also requested TEAP to conduct closer evaluations of MB uses for QPS purposes and their possible alternatives or opportunities for reducing emissions. TEAP has responded to these Decisions through its MBTOC as well as appointing special task forces.

Table 24 below lists decisions relating to QPS uses of MB and summarises the main issues comprised by each:

TABLE 24: SUMMARY OF DECISIONS RELATING TO QPS USES OF METHYL BROMIDE

Decision No.	Decision title	Summary
VI/11(c)	Clarification of «quarantine» and «pre-shipment» applications for control of methyl bromide	Gives definitions of quarantine and pre-shipment. Urges non-A5 Parties to refrain from MB use and use non ozone-depleting technologies whenever possible. Where MB is used Parties are urged to minimise emissions and use containment and recovery and recycling methodologies to the extent possible
VII/5	Definition of «quarantine» and «pre-shipment» applications	Provides definitions for QPS. In applying them, all countries are urged to refrain from the use of MB and to use non-ozone depleting technologies when possible. Where MB is used, Parties are urged to minimise emissions and use MB through containment and recovery and recycling methodologies to the extent possible
XI/12	Definition of pre-shipment applications	Defines a maximum time period of 21 days prior to export for application of treatments to qualify as 'Pre-shipment'
XI/13	Quarantine and pre-shipment	Requests that the 2003 TEAP Report evaluate the technical and economic feasibility of alternatives that can replace MB for QPS uses; and to estimate the volume of MB that would be replaced by the implementation of such alternatives, reported by commodity and/or application. Requests Parties to review their national regulations with a view to removing the requirement for the use of MB for QPS where alternatives exist. Urges Parties to implement procedures to monitor the uses of MB by commodity and quantity for QPS uses. Encourages the use of recycling and recovery technologies for those uses with no feasible alternatives

XVI/10	Reporting of information relating to quarantine and pre-shipment uses of methyl bromide	Requests TEAP to establish a QPS Task Force to prepare the report under Dec XI/13; requests Parties to submit information on QPS uses of MB if not already done so. Requires TF to report on the data submitted by Parties in response to the April 2004 methyl bromide QPS for the 25th OEWG. Data to be presented in a written report in a format aggregated by commodity and application so as to provide a global use pattern overview, and to include available information on potential alternatives for those uses identified by the Parties' submitted data
XVII/9	Critical-use exemptions for methyl bromide for 2006 and 2007	To request the QPSTF to evaluate whether soil fumigation with MB to control quarantine pests on living plant material can in practice control pests to applicable quarantine standards, and to evaluate the long-term effectiveness of pest control several months after fumigation for this purpose, and to provide a report in time for the 26th meeting of the OEWG.
XX/6	Actions by Parties to reduce methyl bromide use for quarantine and pre-shipment purposes and related emissions	Requests the QPSTF, in consultation with the IPPC secretariat, to review all relevant, currently available information on the use of MB for QPS applications and related emissions; to assess trends in the major uses; available alternatives; other mitigation options and barriers to the adoption of alternatives; and to determine what additional information or action may be required to meet those objectives.
XXI/10	Quarantine and preshipment uses of methyl bromide	Requests the TEAP and its MBTOC in consultation with other relevant experts and the IPPC to submit a review on the technical and economic feasibility of alternatives for a. Sawn timber and WPM (ISPM 15); b. Grains and similar foodstuffs; c. Pre-plant soil use; and d. Logs, including their current availability and market penetration rate and their relation with regulatory requirements and other drivers for the implementation of alternatives. Also requests an update on estimated replaceable quantities of MB used for QPS purposes distinguishing between A5 and non-A5 parties and a description of a draft methodology including assumptions, limitations, objective parameters and variations within and between countries that TEAP would use for assessing the technical and economical feasibility of alternatives, of the impact of their implementation and of the impacts of restricting the quantities of MB production and consumption for QPS

Source: Montreal Protocol Handbook and Ozone Secretariat website, 2010

6.5. Policies on QPS uses of methyl bromide

6.5.1. Legislation that requires methyl bromide use for QPS

In response to Decision XX/6, the QPSTF collected information on examples of regulations that cover the handling and use of methyl bromide as a product and regulations which influence the use for QPS purposes.

Use of MB for QPS for commodity treatments is mostly associated with international trade where regulations are usually imposed by the importing country on the exporting country. MB is used in response to either pests found during inspection and/or needed for a phytosanitary certificate, which requires the commodity to be free from quarantine pests and MB may be used or certified that MB has been applied at the rate required by the importing country. The driving force for what treatments are required, allowed or not allowed are those of the importing country. Under IPPC and Montreal Protocol definitions, quarantine regulations concern control of a quarantine pest, not of endemic pests. In the case of bilateral trade and quarantine use, the importing country may allow the treatment to be conducted in the importing country, but often the treatment must be conducted in the exporting country. In many cases, QPS use of MB is covered by a number of national and local regulations, which often need to be considered in conjunction with one another.

There are also instances where internal regulations are imposed by national or state jurisdictions to use MB for movement of commodities across state or county borders. These relate to movement of quarantine pests that are known to be absent within the state or county.

MBTOC encountered very few regulations that required or specified MB use only, however those that do tend to use substantial amounts of MB such as in the log trade. However, there are many regulations that require plants to be free of insect and other pests, with MB as the only practical fumigant available especially at portside in the importing country i.e. when inspection at the importing port finds quarantine pests fumigation with MB may be the only available way to destroy the infestation, short of destroying the shipment. In some cases where MB is not deleterious to the commodity and relatively cheap, there may be little incentive to search for alternatives especially since the alternative treatments usually have to be developed in the exporting country which may lack resources to do this. For some commodities, MB causes deleterious changes in the commodity being exported and this should serve as an incentive to develop alternatives. However in the absence of data to prove effective control of all pests with an alternative to a standard similar to MB it is understandable that importing Parties are unwilling to adopt the alternative.

Information on regulations that require the use of MB is available in phytosanitary treatment manuals and treatment schedules that can be found in the official national phytosanitary authorities' (NPPOs) websites, and related publications.

6.5.2. Reasons for methyl bromide as the treatment of choice

- MB is portable and requires little in the way of specialized equipment or facilities.
- It is tolerated by a wide range of commodities.
- It is effective against all life stages of a wide range of pest organisms.
- It is much faster acting than most registered alternatives which is particularly important for perishable commodities,
- Non fumigant alternatives tend to be very specific to particular commodities, pests and situations, i.e. hot water treatment of mangoes.
- In some cases, MB is cheaper than alternatives.
- Long experience with successful use

Research to develop and confirm effectiveness of alternatives for quarantine treatments for international trade is expensive and time consuming and generally must be done in the exporting country because only they have access to the pest in question. A very high level of efficacy (often Probit 9 – LD 99.9968%) is usually required for quarantine pests where methyl bromide fumigation is used as the major or sole control step.

6.5.3. Policies and recommendations on methyl bromide and its alternatives under the International Plant Protection Convention

Some international standards produced by the IPPC (ISPMs) relate directly or indirectly to phytosanitary (quarantine) processes that either use methyl bromide at present or avoid the need for QPS methyl bromide treatments.

The main ISPM that specifically deals with a major volume use of methyl bromide is ISPM 15, as revised (IPPC 2009b). The standard deals with the disinfestation of wood packaging material in international trade as a quarantine measure against various pests of wood and forests. The standard contains specifications for both heat treatment and methyl bromide fumigation. The standard recognises that methyl bromide is an ozone-depleting substance (p.5 of Appendix 4). It states, *"In the absence of alternative treatments being available for certain situations or to all countries, or the availability of other appropriate packaging materials, methyl bromide treatment is included in this standard."* (IPPC 2006, 2009). The recently revised ISPM 15 standard also encourages national quarantine authorities to promote the use of an approved MB alternative: *'NPPOs are encouraged to promote the use of alternative treatments approved in this standard'* (CPM-4 report, April 2009, p.11 of Appendix 4)

Other ISPM standards (https://www.ippc.int/index.php?id=ispms&no_cache=1&L=0) relevant to methyl bromide treatments and alternatives are:

- ISPM No. 02 (2007) Framework for pest risk analysis
- ISPM No. 10 (1999) Requirements for the establishment of pest free places of production and pest free production sites
- ISPM No. 11 (2004) Pest risk analysis for quarantine pests including analysis of environmental risks and living modified organisms
- ISPM No. 12 (2001) Guidelines for phytosanitary certificates
- ISPM No. 14 (2002) The use of integrated measures in a systems approach for pest risk management
- ISPM No. 16 (2002) Regulated non-quarantine pests: concept and application
- ISPM No. 18 (2003) Guidelines for the use of irradiation as a phytosanitary measure
- ISPM No. 21 (2004) Pest risk analysis for regulated non quarantine pests
- ISPM No. 22 (2005) Requirements for the establishment of areas of low pest prevalence
- ISPM No. 24 (2005) Guidelines for the determination and recognition of equivalence of phytosanitary measures
- ISPM No. 26 (2006) Establishment of pest free areas for fruit flies (Tephritidae)
- ISPM No. 28 (2009) Phytosanitary treatments for regulated pests
- ISPM No. 29 (2007) Recognition of pest free areas and areas of low pest prevalence
- ISPM No. 30 (2008) Establishment of areas of low pest prevalence for fruit flies (Tephritidae)

6.5.4. Party strategies (QPS)

Two non-Article 5 parties – the EU and the USA- have submitted National Management strategies for QPS:

- The EU stopped all uses of MB including QPS in 2010. The strategy includes measures taken to stop MB usage, authorized and available alternatives, regulations, economic issues and others. The strategy can be accessed at http://ozone.unep.org/Exemption_Information/Quarantinne_and_preshipment/Dec_xx-6_Strategy_to_reduce_emmission_of_mbr_for_QPS-European_Commission-07072010.pdf

- The USA strategy provides an overview of QPS uses in the USA (import, export and domestic); alternatives that could replace MB use; and treatments under development. It discusses barriers to adoption of alternatives (e.g. registration, efficacy, phytotoxicity, differences in quarantine security, bilateral agreements and logistics); and opportunities for physically reducing emissions. The US Management Strategy can be accessed at the Ozone Secretariat website.

6.6. Main Uses of Methyl Bromide for QPS purposes

6.6.1. Proportions of QPS use covered by IAs and domestic regulations

Based on data supplied by the Parties relating to QPS consumption for individual uses, with QPSTF input, it is possible to give an approximate breakdown of QPS consumption into various overall categories of use (Table 6.3). This analysis identifies approximate quantities of use lying outside plant quarantine measures relating to international trade, and allocates the balance of use to the latter category. This breakdown distinguishes Quarantine treatments against quarantine (regulated) pests, and Preshipment treatments to ensure 'pest-free' status of commodities, as defined in Decision VII/5 and XI/12.

TABLE 25. ESTIMATED QPS GLOBAL METHYL BROMIDE CONSUMPTION FOR 2007 BY OVERALL CATEGORY OF USE.

	Approx. % fracion of 2007 QPS use	Tonnage used (mt)	Official agency or International Agreement	Examples of category
Quarantine – international trade,	65%	5486	IPPC	Fumigation of export logs against regulated pests
Quarantine – international trade, measures against Animal	1%	100	National quarantine agencies	Fumigation of import used tyres against mosquitoes and other disease vectors
Quarantine – intracountry trade, including some soil	14%	1200	National and regional regulatory agencies	Fumigation of fresh fruit or soils to meet intra country quarantine regulations
Preshipment – international trade	20%	1700	National (import or export) trading regulations relating to product quality (pest-free	Fumigation of some export grains.
Totals	100%	8486		
Unidentified or surplus of consumption over		2128		
Total reported consumption		10614	Article 7 reporting by the Parties	

6.6.2. Main individual categories of use by volume

At various stages since 1994, TEAP and MBTOC have carried out surveys and/or contacted national experts in order to compile information about major QPS uses, and to estimate methyl bromide volumes used in some cases (e.g. MBTOC 1995, 1998, 2003, 2007).

While there remain some data gaps and uncertainties, MBTOC and previously the QPSTF were able to make estimates that covered more than 83% of total global 2007 reported QPS use or consumption by volume, with over 70% of this resulting from 5 major categories of use (TEAP, Oct 2009).

In keeping with past Decisions (i.e. XX/6), MBTOC followed the same categories of use for QPS as those used by the IPPC, with some additions and modifications. These were as used in Annex 6 of 3CPM – *Recommendation for the replacement or reduction of the use of methyl bromide as a phytosanitary measure* (IPPC, 2008) and are given in Table 26. The additional categories marked with an asterisk in Table 26 were added to cover areas not covered by the IPPC.

TABLE 26: MAIN CATEGORIES OF MB USE FOR QPS PURPOSES

Category	Uses
Commodities	Bulbs, corms, tubers and rhizomes (intended for planting)
	Cut flowers and branches (including foliage)
	Fresh fruit and vegetables
	Grain, cereals and oil seeds for consumption including rice (not intended for planting)
	Dried foodstuffs (including herbs, dried fruit, coffee, cocoa)
	Nursery stock (plants intended for planting other than seed), and associated soil and other growing media
	Seeds (intended for planting)
	Soil and other growing media as a commodity, including soil exports and soil associated with living material such as nursery stock*
	Wood packaging materials
	Wood (including sawn wood and wood chips)
	Whole logs (with or without bark)
	Hay, straw, thatch grass, dried animal fodder (other than grains and cereals listed above)
	Cotton and other fibre crops and products
	Tree nuts (e.g. almonds, walnuts, hazelnuts)
Structures and equipment	Buildings with quarantine pests (including elevators, dwellings, factories, storage facilities)
	Equipment (including used machinery and vehicles) and empty shipping containers and reused packaging
Soil as agricultural land*	Pre-plant and disinfestation fumigation of agricultural land*
Miscellaneous small volume uses	Personal effects, furniture, air* and watercraft*, artifacts, hides, fur and skins

Source: IPPC (2008) list of categories; *Not on IPPC (2008) list

6.6.3. Quantity of methyl bromide used

Dosages of MB at 80-200 g h m^{-3} mainly control insects, mites and vertebrate pests but higher rates typically exceeding 5000 g h m^{-3} are required for control of nematodes, snails and fungi; and for devitalising seeds.

A general analysis on categories of use by volume was conducted, on the basis of information received from Parties in response to a survey conducted by MBTOC in 2010 amongst key Parties, supplemented by information contained in the QPSTF report (TEAP, 2009) in response to Decision XX/6, as well as data from previous surveys of QPS uses (TEAP 2006, UNEP/ ROAP 2008).

As requested by Decision XXI/10, TEAP (2010)[4] estimated the availability and market penetration of technically and economically feasible alternatives of the four largest consuming categories of methyl bromide for QPS:

1) Sawn timber and wood packaging material (ISPM-15)
2) Grains and similar foodstuffs
3) Pre-plant soils use and
4) Logs.

These four uses consumed more than 70% by weight of the methyl bromide used for QPS in 2008.

On the basis of these estimates, TEAP calculated that 1,937 to 2,942 tonnes of QPS consumed in 2008 in these four categories were replaceable globally with immediately available technologies, which represented 31% to 47% of global consumption in 2008 by these four categories of use.

Total consumption reported by A5 Parties to the QPSTF in response to Decision XX/6 and consumption identified from other sources as explained, amounted to approximately 5,262 metric tonnes of methyl bromide. Total consumption reported by A5 Parties to the Ozone Secretariat for 2007 as per Article 7 was 5,803 tonnes. Brazil confirmed a reported use of 167 tonnes but did not provide a breakdown of uses. This leaves 541 tonnes for which uses have not been allocated. However, over 95% of this figure corresponds to two Parties – India (reported 2007 QPS consumption of 360.5 tonnes), and Singapore (153 tonnes).

For non-A5 Parties, total consumption reported to the QPSTF or identified from other sources amounted to 3,667 metric tonnes, whilst total consumption reported as per Article 7 data for 2007 was 4,950 tonnes.

Israel recently reported a consumption of 210 tonnes for 2007, providing a breakdown of uses for 16.5 tonnes, which is the amount used by Israel only. The remaining amount of 195 tonnes is consumed by the Palestinian Authority and no specific description of uses is available. As highlighted in the section on production and consumption, in 2009 Israel reported a large consumption of 2182 tonnes, however no breakdown on categories of use was received.

In 2007, the QPSTF highlighted a difference for 2007 between reported consumption and estimated use of 1,283 tonnes for the US. The US does not keep statistics by sector but did submit an estimate of 1,969 tonnes in 2005 in response to Decision XVI/10; it was however acknowledged that this survey was incomplete. Total consumption reported for that year (Article 7) was 2,931 tonnes. At this time the fate of this surplus is unidentified, but could include accumulation of QPS-labelled stocks of methyl bromide. Table 27, Figure 19 and Figure 20 present QPS use categories in A5 and non-A5 Parties by volume estimated for 2009.

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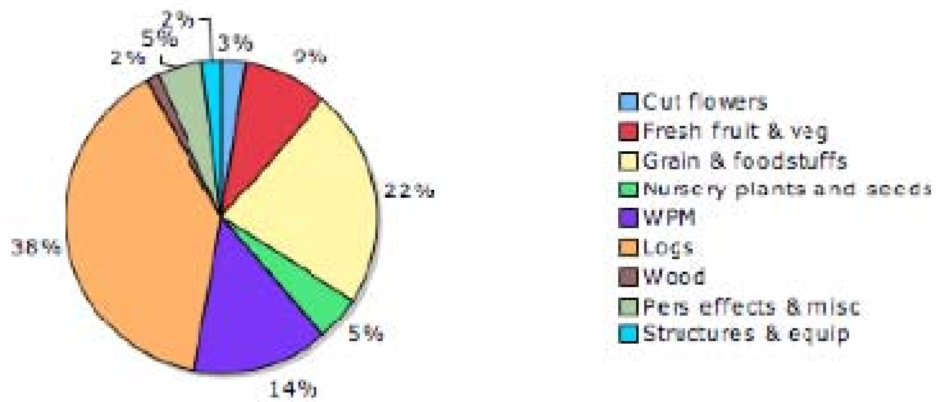
4 TEAP. 2010. TEAP Progress Report (Volume 2). Pages 89-157.

TABLE 27: VOLUMES (METRIC TONNES) AND PERCENTAGE OF MB USED FOR QPS BY CATEGORY IN ARTICLE 5, NON-ARTICLE 5 COUNTRIES.

Use category	A 5 Parties*		Non- A 5 Parties**		Global	
	Tonnes	%	Tonnes	%	Tonnes	%
Fruit and vegetables	363	7%	291	6%	646	8%
Grain	928	17%	325	7%	1272	12%
Wood Packaging Material	538	11%	270	6%	1385	13%
Wood	66	1%	84	2%	244	2%
Logs	1603	29%	804	17%	2236	21%
Soil in situ	1	0%	1489	30%	1531	14%
Dried Foodstuffs	27	1%	5	<1%	220	2%
Cut Flowers and bulbs	104	2%	7	<1%	175	1%
Equipment	75	1%	8	<1%	<1%	<1%
Seeds	190	3%	10	<1%	126	1%
Miscellaneous	210	4%	131	3%	263	2%
Undefined or Other	1380	25%	195	3%	684	6%
Total – identified uses	**4105**	**75%**	**3667**	**70%**	**8486**	**80%**
Total in 2009 – as per A7 data	**5485**	**100%**	**4950**	**100 %**	**10614**	**100%**
Difference – unidentified or unallocated	1380	25%	1283	30%	1824	20%

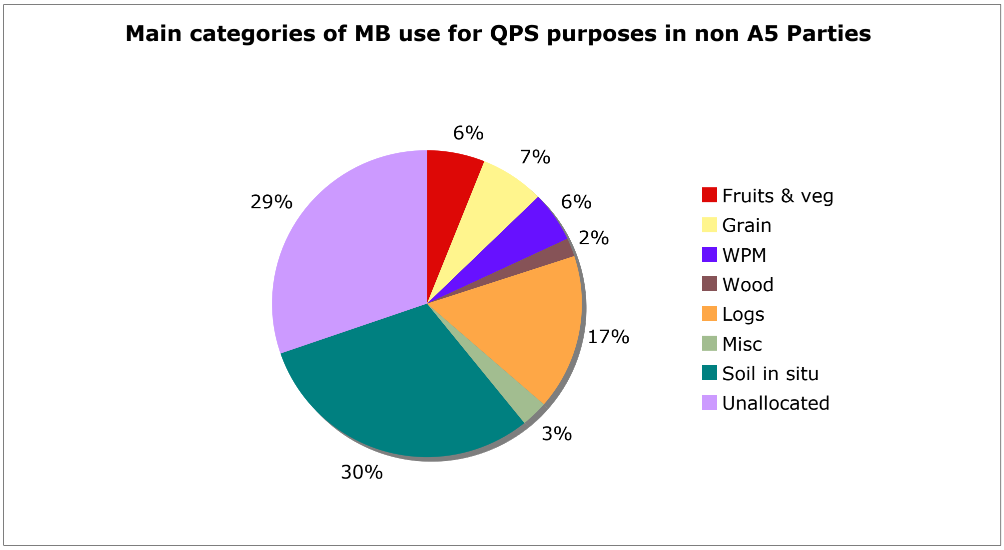
*Mostly for 2009. ** 2007 or 2008.

FIGURE 19. ESTIMATED CATEGORIES OF MB USE (QPS PURPOSES) IN A5 PARTIES, 2009



Sources: MBTOC survey of QPS uses in A5 parties with reported consumption at or above 100 tonnes; UNEP/ ROAP, 2008; NOUs, regional networks and national experts

FIGURE 20. ESTIMATED CATEGORIES OF MB USE (QPS PURPOSES) IN NON-A5 PARTIES, 2007



6.7. Key quarantine pests controlled with methyl bromide

Target pests for QPS treatments vary from country to country. The procedures for handling the issue of defining the target pests also differ. The target pests for Quarantine and for Pre-shipment are distinct, as discussed below.

For pre-shipment treatments required by official authorities, the objective of treatments is to produce goods that are 'pest-free', or sometimes to some standard sampling level. While in practice the target species are typically insect pests (beetles, moths and psocids) that are widely distributed and associated with quality losses in storage, treatments are also expected to eliminate the other living insect species that may contaminate commodities during harvesting, storage and handling, even when they do not pose a direct threat to the quality of the commodity.

For quarantine treatments, the National Plant Protection Organisations (NPPOs) of particular Parties publish master lists of regulated pests, being recognised quarantine pest species. These can be found through the IPPC portal (IPPC 2009). Only some of these pests are controlled by methyl bromide as the treatment of choice or exclusive approved treatment. Some quarantine authorities have regulations for species not found in their country that require quarantine action if the species is known to be a pest that would cause damage or vector diseases in their country or if there is evidence to suggest a risk of such damage. Likewise species that would substantially endanger human or animal health or comfort, especially by spreading exotic disease, would likewise be considered a quarantine species. Species of quarantine concern to one country will not necessarily be of concern to another country: the pest might attack a crop not grown in the country, climatic conditions in the country might not be favourable to establishment of the species or the country might already have the species in their country. Nonetheless, there are certain groups of organisms that are responsible for most quarantine action in the world currently involving methyl bromide treatment.

Table 28 shows the main target pests of quarantine significance in the major classes of methyl bromide use, by volume, for plant Quarantine purposes. Examples of key pests of quarantine significance were provided to the QPSTF in 2009 by several Parties and can be found in the QPSTF report of 2009 (TEAP, 2009b).

TABLE 28: MAIN TARGET PESTS OF PLANT QUARANTINE SIGNIFICANCE IN THE MAJOR CLASSES OF MB USE FOR QPS PURPOSES

Treated commodity or situation	Main target quarantine pests
Whole logs, not debarked	Various species of bark beetles, wood borers, Sirex spp., pinewood nematodes, fungi (oak wilt, *Ceratocystis ulmi*).
Solid wood packaging	Various species of bark beetles, wood borers, Sirex spp., pinewood nematodes (*Bursaphelenchus xylophilus*).
Grain and similar foodstuffs	*Trogoderma* spp., particularly *T. granarium*; *Prostephanus truncatus*; *Sitophilus granarius*; cotton boll worm, various snails.
Fresh fruit and vegetables	Numerous species of Tephritidae (fruit flies), thrips, aphids, scale insects and other sucking bugs, various Lepidoptera and Coleoptera, various mites.
Soil for crop production, including propagation material	Exotic nematodes such as the Pale Potato Cyst Nematode (*Globodera pallida)*,Golden nematode (*Globodera rostochiensis)*,, exotic weeds, including *Orobanche* spp. Regulations in the USA also allow general 'certification' of nematodes to be considered QPS.

Key quarantine pests that are sometimes controlled in international trade with methyl bromide that lie outside the scope of the IPPC include various mosquito species (human and animal disease vectors, nuisance species), tramp ant species including red imported fire ant (*Solenopsis invicta*) (animal and ecological health, invasive species), rodents (disease vectors, stored product pest), snakes (invasive species), and cockroaches (human health disease vectors).

6.8. Existing and potential alternatives for the major QPS use categories

Previous MBTOC and TEAP reports have provided details of existing alternatives for various QPS uses (e.g. MBTOC 1995, 1998, 2002, 2007; TEAP 1999, 2007, 2009, 2010). The 2002 and 2006 MBTOC Assessment Reports (MBTOC 2002, 2007) provided detailed discussion of alternatives to QPS methyl bromide use on commodities in specific circumstances.

Detailed reports on QPS and alternatives are given in TEAP (2003), produced in response to Decision XI/13(4) and in TEAP (2009 ab, 2010) in response to Decisions XX/6 and XXI/10.
MBTOC (2002) recognised thirteen different categories of alternative treatment, such as heat, cold and irradiation that are approved by regulatory agencies as QPS treatments in one

or more countries against specific quarantine (regulated) pests for disinfestation of particular perishable and durable commodities. More information can be found in the QPSTF interim and final reports (TEAP 2009 ab). The MBAIS database (AQIS 2009a) provides a listing of references to methyl bromide alternatives for QPS and other uses.

Existing alternatives to MB for QPS treatment of perishable and durable commodities are based on (1) pre-harvest practices and inspection procedures; (2) non-chemical (physical) treatments; and (3) chemical treatments.

Many quarantine treatments are 'post-entry'. This is where a treatment is required either if inspection finds a quarantine organism in the shipment at the port of entry or quarantine or other treatments have been insufficient to adequately manage the risk of importing quarantine pests in sufficient numbers to be a quarantine threat. Many countries prohibit imports of particular cargoes where the risk of carrying quarantine pests is unacceptable and there is no system or treatment available to manage this risk to an adequate level. In effect, this avoids the need for post-entry quarantine measures, including methyl bromide fumigation.

Typically, treatment options are more restricted practically for post-entry quarantine treatments than for treatment before shipment. In many post-entry situations, methyl bromide fumigation is the only technically and economically available and approved process to meet quarantine standards to allow importation. There is usually limited infrastructure to apply alternatives to methyl bromide available at import ports and ports often lack alternative treatment facilities at present. The cargos are often containerized and removal (unpacking and treating) from the container is uneconomic. Methyl bromide fumigation may be ordered before the commodity can be released for distribution. Rejection or destruction of the cargo remains the default option if the treatment is not carried out.

MBTOC (2002) noted more than 300 individual alternatives approved for quarantine treatment of perishables and more than 70 approved as QPS treatments for durable commodities. These examples are often specific to a particular commodity and export trade and are drawn from several categories of alternatives (such as cold, heat, pest-free zones, systems approach, physical removal of pests, controlled atmospheres, pesticides, alternative fumigants, debarking, irradiation and combination treatments (MBTOC 2002; 2007)).
National Plant Protection Organisations may publish listings of approved treatments for imports, with specifications varying according to phytosanitary requirements of receiving countries and pest risk. In many cases, methyl bromide fumigation may be specified as a quarantine treatment, but often there are also approved alternative treatments or processes given.

Examples of manuals of approved quarantine treatments for international trade include:

USA - APHIS PPQ manuals –
http://www.aphis.usda.gov/import_export/plants/manuals/index.shtml
Australia – AQIS Import Conditions database
http://www.aqis.gov.au/icon32/asp/ex_querycontent.asp
New Zealand - Approved Biosecurity Treatments for Risk Goods Directed for Treatment - http://www.biosecurity.govt.nz/files/regs/stds/bnz-std-abtrt.pdf
Japan - Theory and Practice of Plant Quarantine Treatments (revised edition 2002) (JFTA 2002)

Some NPPOs also keep listings of treatments required to meet the quarantine and pre-shipment requirements of importing countries (e.g. PHYTO (AQIS 2009)). These can include both methyl bromide and approved alternatives.

A listing of alternatives for various Quarantine uses was given in the IPPC recommendation (IPPC 2008) to its contacting Parties on preferential use of alternatives in place of MB, together with considerations affect the choice of a phytosanitary measure to replace methyl bromide use. The listing is reproduced in
Table 29.

TABLE 29: EXAMPLES OF POTENTIAL PHYTOSANITARY TREATMENTS TO CONSIDER TO REPLACE OR REDUCE METHYL BROMIDE

List of articles fumigated	Examples of potential phytosanitary treatments to consider to replace or reduce methyl bromide[5]
Commodities	
Bulbs, corms, tubers and rhizomes (intended for planting)	Hot water, pre-plant quarantine soil sterilization (steam or chemical), pesticide dip, or a combination of these treatments
Cut flowers and branches (including foliage)	Controlled atmosphere (CO_2, N_2) + combination treatment, hot water, irradiation, phosphine, phosphine/carbon dioxide mixture, pyrethroids + carbon dioxide, ethyl formate + carbon dioxide
Fresh fruit and vegetables	Cold treatment, high-temperature forced air, hot water, irradiation, quick freeze, vapour heat treatment, chemical dip, phosphine, combination of treatments, ethyl formate + carbon dioxide
Grain, cereals and oil seeds for consumption including rice (not intended for planting)	Heat treatment, irradiation, ethyl formate, carbonyl sulphide, phosphine, phosphine + carbon dioxide, sulfuryl fluoride, controlled atmosphere (CO_2, N_2)
Dried foodstuffs (including herbs, dried fruit, coffee, cocoa)	Heat treatment, carbon dioxide under high pressure, irradiation, ethyl formate, phosphine, phosphine + carbon dioxide, controlled atmosphere (CO_2, N_2), sulfuryl fluoride, propylene oxide-+-
Nursery stock (plants intended for planting other than seed), and associated soil and other growing media	Hot water, soil sterilization (steam or chemical e.g. methyl isothiocyanate (MITC) fumigants), pesticides dip, phosphine, combination of any of these treatments
Seeds (intended for planting)	Hot water, pesticide dip or dusting, phosphine, combination treatments
Wood packaging materials	Heat treatment (contained in Annex 1 of ISPM No. 15). Further alternative treatments may be added in the future.
Wood (including round wood, sawn wood, Wood chips)	Heat treatment, kiln-drying, removal of bark, microwave, irradiation, MITC/sulfuryl fluoride mixture, methyl iodide, chemical impregnation or immersion, phosphine, sulfuryl fluoride
Whole logs (with or without bark)	Heat treatment, irradiation, removal of bark, phosphine, sulfuryl fluoride. MITC/sulfuryl fluoride mixture, methyl iodide.
Hay, straw, thatch grass, dried animal fodder (other than grains and cereals above)	Heat treatment, irradiation, high pressure + phosphine, phosphine, sulfuryl fluoride
Cotton and other fibre crops and products	Heat treatment, compression, irradiation, phosphine, sulfuryl fluoride CO_2

[5] Examples are given that are generally applicable and likely to meet prevailing standards for treatment or disinfestation. Some alternatives may not be appropriate on particular commodities within the general category or in specific situations.

List of articles fumigated	Examples of potential phytosanitary treatments to consider to replace or reduce methyl bromide[5]
Tree nuts (almonds, walnuts, hazelnuts etc.)	Carbon dioxide under high pressure, controlled atmosphere (CO_2, N_2), heat treatment, irradiation, ethylene oxide, ethyl formate, phosphine, phosphine + carbon dioxide, propylene oxide, sulfuryl fluoride
Buildings with quarantine pests (including elevators, dwellings, factories, storage facilities)	Controlled atmosphere (CO_2, N_2), heat treatment, pesticide spray or fogging, phosphine, sulfuryl fluoride
Equipment (including used agricultural machinery and vehicles), empty shipping containers and reused packaging	Controlled atmosphere (CO_2, N_2), heat treatment, steam, hot water, pesticide spray or fogging, phosphine, sulfuryl fluoride
Other items	
Personal effects, furniture, crafts, artefacts, hides, fur and skins	Controlled atmosphere (CO_2, N_2), heat treatment, irradiation, ethylene oxide, pesticide spray or fogging, phosphine, sulfuryl fluoride

The QPSTF in 2009 identified four major QPS categories of use for MB: Wood and wood packaging material (WPM); grain and similar foodstuffs; logs; and soils used for the production of certified plant material for propagation purposes. These uses represent more than 70% of the total reported global consumption of MB for QPS, thus discussion in the section below will provide more in depth information on them.

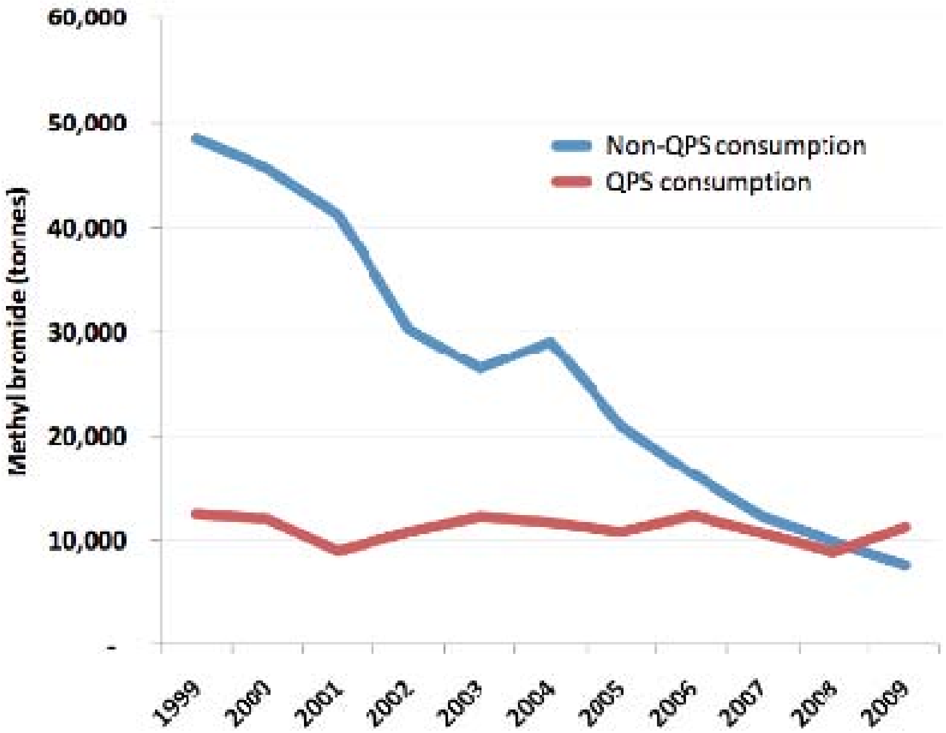
6.9. Production and consumption of MB for QPS uses

6.9.1. Introduction

Since 1999 there has been a continuous reduction in controlled uses of methyl bromide ("non-QPS") as alternatives have been adopted in many countries. In contrast, QPS consumption has not decreased but remained relatively constant over the last decade, as shown in Figure 21. However, QPS consumption in 2009 was 46% higher than non-QPS consumption in 2009 (Figure 21). In 2009 the QPS use exceeded non-QPS for the first time.

This was partly due to the continued decrease in the non-QPS uses, as well as recategorisation by some Parties of uses previously considered non QPS to QPS and an increase in QPS in some Parties in 2009 compared to 2008. Although officially reported data for consumption shows that QPS amounts were greater than non QPS amounts, other official data and MBTOC reports show that probable uses in both categories in 2009 were similar, or around 10,000 t. The main reasons for the differences are that consumption data for 2009 does not account for use of stocks or for leakage in the use of QPS production for controlled uses. Since 2003 an amount of methyl bromide included in the initial baseline estimates for controlled MB uses, between 1400 to 2850 t, has been recategorised to QPS MB use for the preplant soil treatment of propagation material.

FIGURE 21: COMPARISON OF NON-QPS AND QPS CONSUMPTON IN THE PERIOD 1999 TO 2009



This section:

- Provides information on the source of QPS data and analysis methods;
- Provides information and analysis of QPS production (global, A5 and non-A5);
- Provides information and analysis of QPS consumption (global, regional, A5 and non-A5);
- Compares regional, A5 and non-A5 QPS consumption;
- Examines QPS consumption by Parties according to "consumption bands";
- Provides information on QPS uses and consumption; and
- Provides conclusions.

6.9.2. General methods of analysis

This analysis of trends in QPS production and consumption is based solely on the data which has been officially submitted to the Ozone Secretariat by Parties in their Article 7 ODS data reporting forms.

The Beijing Amendment of 1999 required Parties to report QPS data under Article 7 as follows:

> *'Each Party shall provide to the Secretariat statistical data on the annual amount of the controlled substance listed in Annex E used for quarantine and pre-shipment applications.'*

The Beijing Amendment came into force from 2002 onwards[6]. By June 2008, 142 Parties had ratified the Amendment. By August 2010 (current data) this had increased to 165 Parties. The QPS reporting requirement has therefore applied to the majority of Parties for several years.

Since 1997 the official Article 7 ODS data reporting forms have prompted Parties to report the total quantity of methyl bromide produced, imported and exported for all purposes (including QPS and feedstock) and, separately, *the quantity produced or imported for use as QPS*, and feedstock. Decision IX/28(3) of 1997 adopted revised forms[7] and instructions for Parties to use when reporting national ODS data under Article 7. Paragraph 6 of Decision IX/28 also clarified QPS reporting as follows:

> *'...for the purpose of the data-collection only, when reporting data on the consumption of methyl bromide for quarantine and pre-shipment applications, the Parties shall report the amount consumed (i.e., import plus production minus export) and not actual "use".'*

The General Instructions[8] adopted by Decision IX/28 provided the following guidance to Parties when completing the import forms for Article 7 reports:

> *'When calculating a Party's* [controlled] *consumption the Montreal Protocol does not include quantities of methyl bromide which is used for quarantine and pre-shipment. In Data Form 1, quantities of methyl bromide imported for quarantine and pre-shipment applications should be entered separately in Column 6 ...'*

The General Instructions provided similar guidance on methyl bromide produced or exported for QPS. The Secretariat then calculated a Party's QPS consumption using the submitted data.

Several Decisions have also encouraged or reminded Parties to submit QPS data, for example Decisions X/11 (1998), and XI/13 (2001) and XX/6 (2008).

6.9.3. Source of data and analysis

The ODS data that were submitted by Parties pursuant to Article 7 of the Montreal Protocol "*Reporting of Data*" were analysed by the Ozone Secretariat and placed in a database. According to the Secretariat, "*…a blank* [in the Article 7 Reporting Form submitted by a Party] *is non-available or non-reported data and zero means that a Party reported quantities that result in zero calculated consumption or production*"[9]. On the basis of this

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6 The Beijing Amendment came into force on 25 February 2002 when at least 20 Parties had ratified it. For other Parties, the Amendment came into force 90 days after the Party had ratified.

7 The forms are shown in annex VII of MOP-9 meeting report.

8 MoP-9 report, Annex VII, II. General Instructions, paragraph 4.

9 Email from Mr Marco Gonzalez to Dr Lee Risby (GEF), copied to Dr Tom Batchelor, 12 March 2009.

explanation, MBTOC did not assume that any blanks in the Secretariat's database indicated zero consumption by the Party, unless the database indicated that zero consumption was specifically reported.

The database was interrogated using the tools available on the Secretariat's "*Data Access Centre*[10]". "*Comma delimited files*" were used to transfer data from the database to Excel for further analysis. Logic formulae in Excel were used to analyse trends within regional groupings and specific consumption bands. Internal checks were added to the worksheets to confirm computational consistency.

The analysis applied the regional groupings provided in the Ozone Secretariat's Data Access Centre[11]. The Asia group contains 56 countries; the "Western Europe and others" group (WEO) contains 29 mainly European countries as well as Australia, Canada and the USA; Eastern Europe consists of 25 countries the Russian Federation and countries in Central Asia, and includes the data prior to 2004 reported by Parties that are now members of the EU[12]; Africa contains 53 countries; Latin America and the Caribbean (LAC) consists of 33 countries. The total number of countries in these groups is 193 countries, which is three fewer than the number of Parties that have ratified the Montreal Protocol[13].

6.9.4. QPS Production trends

The quantities of QPS produced by two A5 Parties and five non-A5 Parties that were reported to the Ozone Secretariat are shown in Table 30 for the period 1999 to 2009. According to the Article 7 reports, QPS production in France, Ukraine and India ceased by 2003, 2003 and 2006 respectively. QPS production currently occurs in four Parties (USA, Israel, China and Japan), as indicated in Table 30.

Table 30 shows that global QPS production was 8,922 tonnes in 2009, which was 6.5% more than in 2008 but close to the average (10,708 tonnes) for the past 11 years.

China (1,605 tonnes, 18%) Israel (2,182 tonnes, 24%) and USA (4,612 tonnes, 52%) together produced 94% of the global QPS in 2009 (Table 30, Figure 24).

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[10] http://ozone.unep.org/Data_Reporting/Data_Access/

[11] http://ozone.unep.org/Data_Reporting/Data_Access/ provides a list of the countries within each regional grouping.

[12] Recent ODS data from eastern European countries that are now members of the EU are reported in the "Western Europe and others" regional group.

[13] The Ozone Secretariat has not assigned the 3 Parties that have recently ratified the Montreal Protocol to the country groups.

TABLE 30: PRODUCTION OF QPS IN A5 AND NON-A5 PARTIES FROM 1999 TO 2009

Year	Production of QPS in Article 5(1) Parties			Production of QPS in Non-Article 5(1) Parties (Tonnes)						Total A5 + A2
	China	India	A5 Total	USA	Israel	Japan	France	Ukraine	A2 Total	
2009	1,605	-	1,605	4,612	2,182	524	-	-	7,317	8,922
2008	1,262	-	1,262	3,788	2,641	684	-	-	7,112	8,374
2007	1,535	-	1,535	6,903	3,760	787	-	-	11,449	12,984
2006	1,314	-	1,314	6,633	1,477	851	-	-	8,961	10,275
2005	1,358	-	1,358	4,770	6,502	1,101	85	-	12,458	13,815
2004	1,077	-	1,077	4,552	3,706	1,240	85	-	9,583	10,660
2003	1,384	-	1,384	3,722	3,495	1,454	191	-	8,862	10,246
2002	1,836	21	1,857	3,729	4,425	1,037	85	136	9,412	11,269
2001	-	92	92	2,590	5,395	949	85	385	9,404	9,496
2000	-	118	118	3,663	4,402	1,031	297	282	9,675	9,793
1999	700	132	832	4,038	5,073	1,212	387	409	11,119	11,950

Source: Ozone Secretariat Data Access Centre, 26 October 2010.

Compared to 2008, the quantity of QPS produced in 2009 increased in the USA, but declined slightly in Israel and Japan (Figure 22). Japan shows the most consistent reduction trend, whereas the USA and Israel have shown relatively large annual fluctuations over the last 10 years, as shown in Figure 22.

FIGURE 22: PRODUCTION OF QPS IN NON-A5 PARTIES FROM 1999 TO 2009

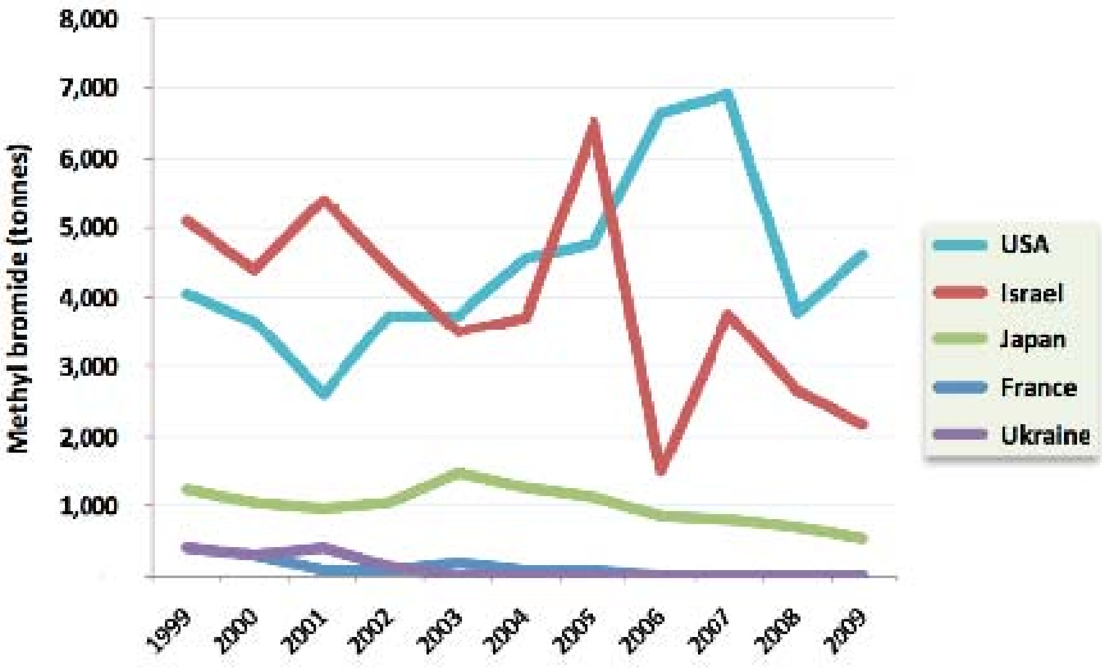
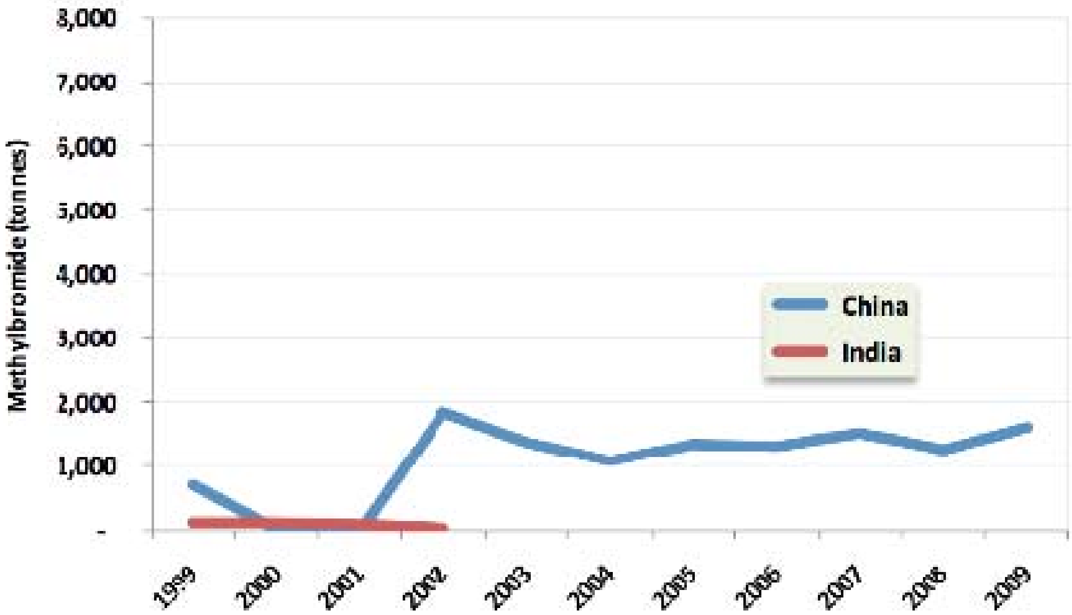
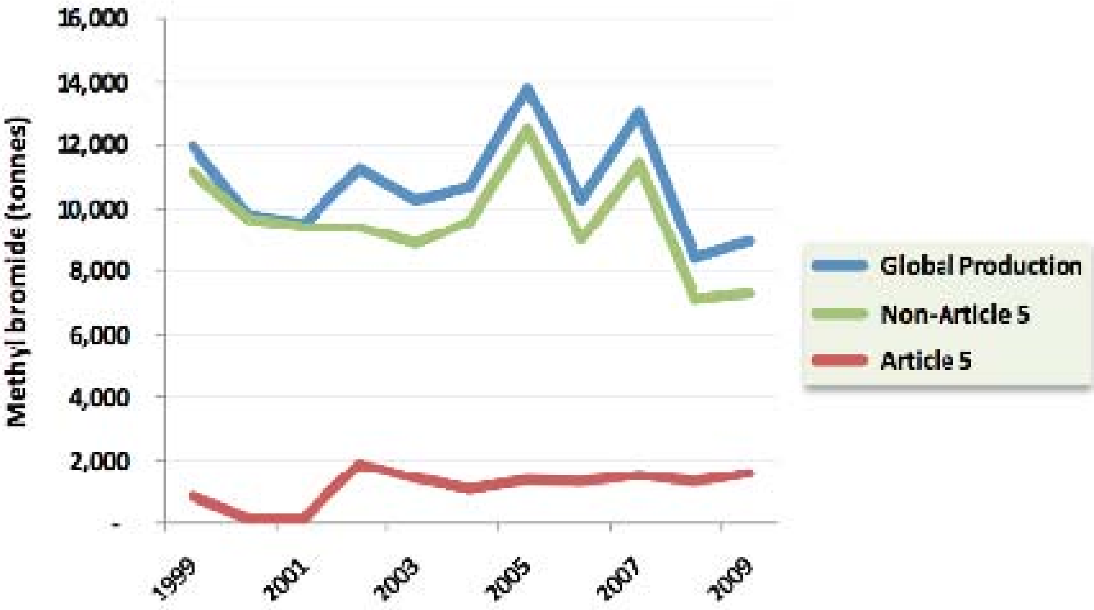


FIGURE 23: PRODUCTION OF QPS IN A5 PARTIES FROM 1999 TO 2009



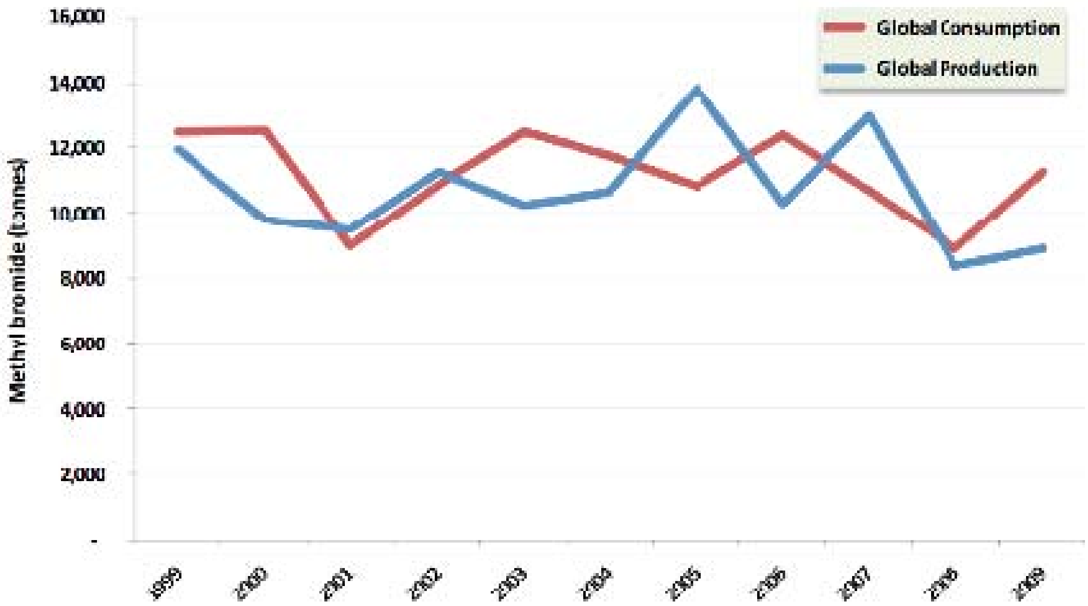
In A5 countries, India last reported QPS production in 2002 and has not reported any production since that time. China's production each year has ranged from 1,077 to 1,836 tonnes since 2002. These trends are summarised in Figure 23.

FIGURE 24: GLOBAL, NON-A5 AND A5 QPS PRODUCTION FROM 1999 TO 2009



Source: Ozone Secretariat website data access centre, December 2010

FIGURE 25. GLOBAL CONSUMPTION AND PRODUCTION OF QPS FROM 1999 TO 2009



Source: Ozone Secretariat website data access centre, December 2010

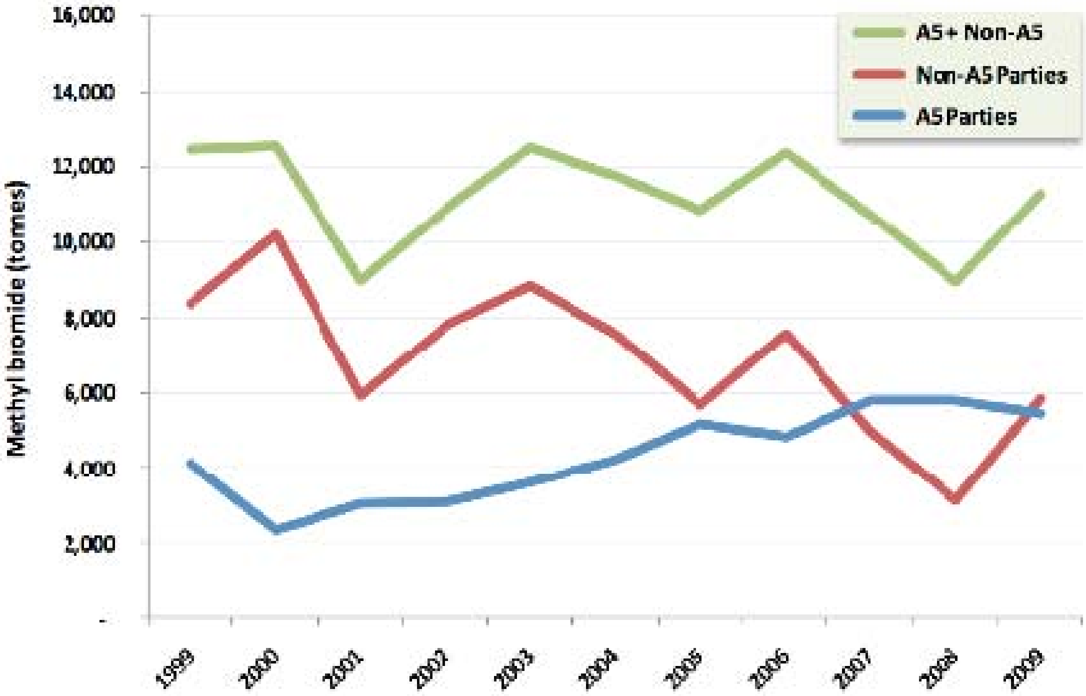
In 2009, global QPS consumption exceeded global QPS production by 2,334 tonnes (Source: Ozone Secretariat website data access centre, December 2010
Figure 25). However, production and consumption fluctuate from year to year. Production has exceeded consumption in several years since 1999. It may indicate that producers produce more QPS than can be consumed in the year of production, leading to consumption that exceeds production in the following year.

6.9.5. QPS Consumption trends

6.9.5.1. Global QPS consumption

In 2008, QPS consumption in A5 Parties (5,786 tonnes) was 85% higher than in non-A5 Parties (3,120 tonnes). In 2009, this position was reversed: non-A5 Party consumption (5,823) was 7% higher than A5 Party consumption (5,433 tonnes), largely due to an increase in Israel (Table 31, Figure 26).

FIGURE 26: GLOBAL, NON-A5 AND A5 CONSUMPTION OF QPS FROM 1999 TO 2009



Consumption in A5 Parties has trended upward over the past 10 years (Figure 26), whereas consumption in non-A5 Parties has trended downward over the same time period (**Error! Reference source not found.**). But overall the global QPS consumption has been relatively stable. The global consumption averaged 11,197 tonnes over the period 1999 to 2009 (Figure 26, top line). Global consumption in 2009 (11,256 tonnes) was close to the average.

FIGURE 27: A5 PARTY CONSUMPTION OF QPS FROM 1999 TO 2009

FIGURE 28: NON-A5 PARTY CONSUMPTION OF QPS FROM 1999 TO 2009

6.9.5.2. Regional consumption

Regional consumption of QPS was examined according to regional groups of countries established by the Ozone Secretariat[14]. The overall increase in A5 consumption was due to increases in Asia, which has the largest global share of the consumption of QPS (Figure 29 and Figure 30). The Asian region consumed 7,038 tonnes and accounted for 63% of global QPS consumption in 2009.

FIGURE 29: REGIONAL CONSUMPTION OF QPS FROM 1999 TO 2009

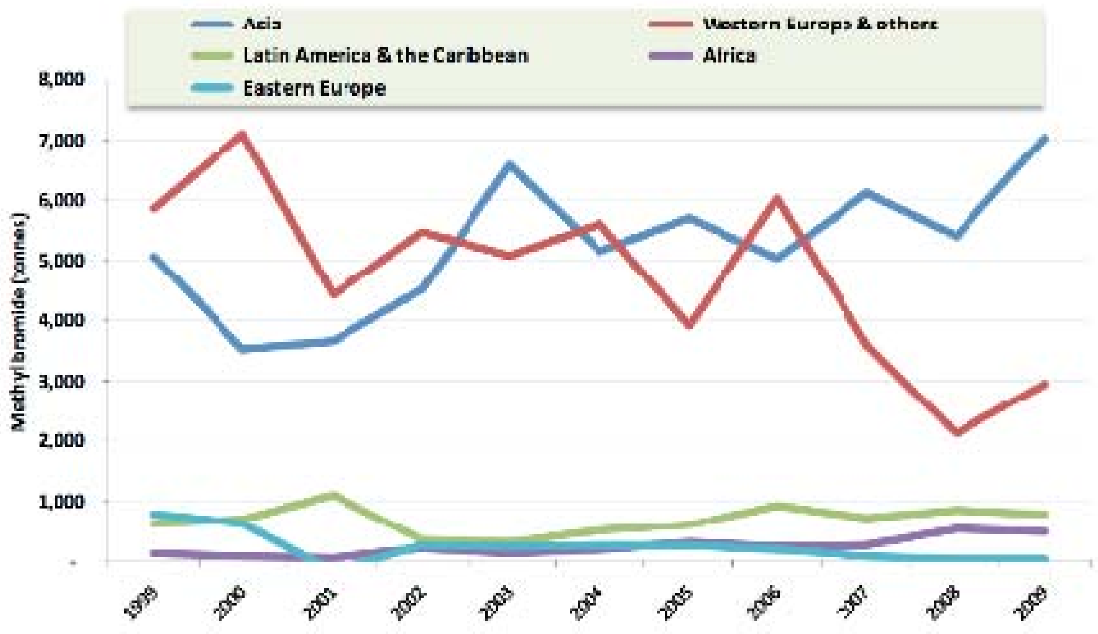
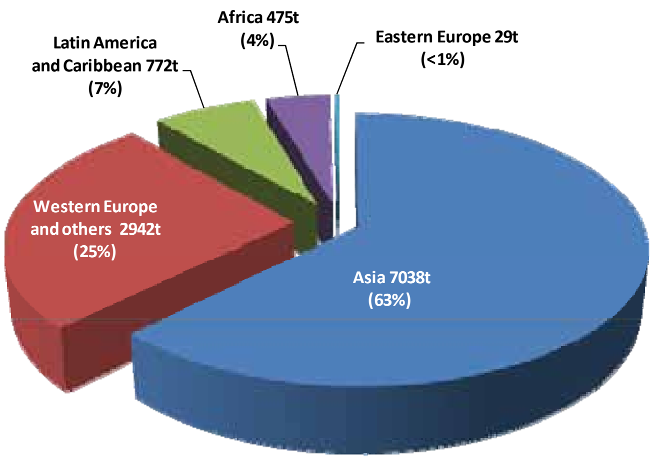


FIGURE 30: REGIONAL CONSUMPTION OF QPS IN 2009



Consumption in the Asia regional group was more than twice that of the “Western Europe and Others” (WEO), group and about ten times more than the Latin America and Caribbean (LAC) group. The consumption in the LAC, Africa and Eastern Europe regions has

14 See http://ozone.unep.org/Data_Reporting/Data_Access/ for a list of the countries.

remained much lower since 1999 than in Asia and WEO, and the consumption in these three regional groups is stable or decreasing in 2008-2009.

To determine the recent major changes within each regional group, Parties that reported consumption of more than 10 tonnes for QPS were ranked from highest to lowest according to their consumption in 2009 (see Table 31, column 4). The consumption in 2009 was compared with the average consumption over the previous 3-year period from 2007 to 2008. Parties were assigned to the same regional groupings as described in Section 6.9 above.

TABLE 31: COMPARISON OF 2009 MB-PS CONSUMPTION WITH THE AVERAGE CONSUMPTION OF EACH PARTY IN THE THREE PREVIOUS YEARS, IN ALL PARTIES THAT REPORTED CONSUMPTION OF MORE THAN 10 TONNES OF QPS IN 2009.

Rank	Party	Consumption				A5 or non-A5	Region
		Average of 2006, 2007 & 2008	2009 (highest at top)	2009 (column 4) compared to average (column 3)	Change (4-3)		
1	2	3	4	5	6	7	8
1	Israel	211.3	2,181.5	Increased	1,970.2	Non-A5	Asia
2	USA	3,077.0	2,099.3	Reduced	-977.7	Non-A5	WEO
3	China	1,372.9	1,073.5	Reduced	-299.4	A5	Asia
4	Vietnam	676.3	739.0	Increased	62.7	A5	Asia
5	R. Korea	335.8	708.0	Increased	372.2	A5	Asia
6	Japan	1,020.5	697.3	Reduced	-323.2	Non-A5	Asia
7	India	417.6	540.3	Increased	122.7	A5	Asia
8	Australia	347.8	502.3	Increased	154.6	Non-A5	WEO
9	Thailand	547.6	465.2	Reduced	-82.4	A5	Asia
10	Mexico	268.3	458.0	Increased	189.7	A5	LAC
11	Egypt	200.0	379.0	Increased	179.0	A5	Africa
12	Indonesia	300.1	288.0	Reduced	-12.1	A5	Asia
13	New Zealand	224.6	271.0	Increased	46.4	Non-A5	WEO
14	Singapore	119.2	165.5	Increased	46.3	A5	Asia
15	El Salvador	51.8	70.2	Increased	18.4	A5	LAC
16	Kenya	60.3	65.0	Increased	4.7	A5	Africa
17	Brazil	207.7	61.3	Reduced	-146.4	A5	LAC
18	EU	243.4	52.7	Reduced	-190.8	Non-A5	WEO
19	Philippines	84.8	48.0	Reduced	-36.8	A5	Asia
20	Uruguay	38.1	43.0	Increased	4.9	A5	LAC
21	Argentina	37.2	38.8	Increased	1.6	A5	LAC
22	Iran (IR)	32.3	30.0	Reduced	-2.3	A5	Asia
23	Pakistan	32.7	30.0	Reduced	-2.7	A5	Asia
24	Turkey	26.0	27.0	Increased	1.0	A5	EE
25	Guatemala	43.7	26.7	Reduced	-17.0	A5	LAC
26	Chile	121.3	25.8	Reduced	-95.4	A5	LAC
27	Nicaragua	16.9	22.5	Increased	5.6	A5	LAC
28	Cameroon	17.3	21.0	Increased	3.7	A5	Africa
29	Sri Lanka	21.5	18.5	Reduced	-3.0	A5	Asia
30	Canada	14.4	16.8	Increased	2.4	Non-A5	WEO
31	Pap. New Guinea	7.5	15.0	Increased	7.5	A5	Asia
32	Honduras	8.6	11.8	Increased	3.3	A5	LAC
33	Morocco	10.0	10.0	Reduced	Zero	A5	Africa

The results showed that some Parties increased consumption in 2009 compared to the average of the previous 3-years, while others decreased their consumption of QPS.

Within the Africa group, Morocco's QPS consumption remained the same in 2009 as its average consumption in the previous two years. Increased consumption of QPS by three Parties (Cameroon, Egypt and Kenya) resulted in a net increase of 187.3 tonnes in the Africa group, compared to the collective average consumption of these four Parties over the three previous years.
Within the Africa group, Morocco's QPS consumption remained the same in 2009 as its average consumption in the previous two years. Increased consumption of QPS by three Parties (Cameroon, Egypt and Kenya) resulted in a net increase of 187.3 tonnes in the Africa group, compared to their collective average consumption of these four Parties over the previous three years.

Within the Eastern Europe group, only Turkey contributed to a net overall increase of 1 tonne of QPS. With the Western Europe and Others (WEO) group, the reduction in QPS consumption by two Parties (the EU and the USA) of 1,168.4 tonnes was somewhat offset by increases in consumption by three Parties (Australia, Canada and New Zealand) of 203.3 tonnes. The net change was a reduction in QPS in the WEO group of 965.1 tonnes, compared to their combined average consumption of these five Parties over the previous three years. For this reason, the WEO group shows a decreasing QPS consumption trend over the past 4 years.
Table 32 summarises the changes in consumption, according to Parties and their regional groupings. The A5/non-A5 affiliations were distinguished within the Asia group, as this was the only regional grouping that contained both.

Within the Asia group, eight Parties (China, Indonesia, Iran, Pakistan, Philippines, Sri Lanka, Thailand and Japan) contributed to an *overall reduction* of 762 tonnes[15] of QPS in 2009, compared to their combined average consumption over the previous three years. Within the Asia group, six Parties (India, Israel, Papua New Guinea, Rep. of Korea, Singapore and Vietnam) contributed to an *overall increase* of 2,581.60 tonnes of QPS in 2009, compared to their collective average consumption over the previous three years. The *net change* within the Asian group is an overall increase of 1,819.6 tonnes of QPS in 2009, compared to the combined average consumption of these Parties over the previous three years. Israel contributed 91% of the net increase in QPS in the Asia group. Largely due to the QPS consumption by Israel, the Asia group shows an increasing QPS consumption trend over the past four years.

Within the LAC group, the QPS reductions made by three Parties (Brazil, Chile and Guatemala) of 258.8 tonnes were offset up increases in QPS consumption by six Parties (Argentina, El Salvador, Honduras, Mexico, Nicaragua and Uruguay) of 223.4 tonnes. However, the net change was a reduction in QPS in the LAC group of 35.4 tonnes, compared to their combined average consumption of these nine Parties over the previous three years.

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[15] Calculated as -438.0 - 323.2 = -762 tonnes, for the Asia regional group.

Within the Africa group, Morocco's QPS consumption remained the same in 2009 as its average consumption in the previous two years. Increased consumption of QPS by three Parties (Cameroon, Egypt and Kenya) resulted in a net increase of 187.3 tonnes in the Africa group, compared to their collective average consumption of these four Parties over the previous three years.

Within the Eastern Europe group, only Turkey contributed to a net overall increase of 1 tonne of QPS. With the Western Europe and Others (WEO) group, the reduction in QPS consumption by two Parties (the EU and the USA) of 1,168.4 tonnes was somewhat offset by increases in consumption by three Parties (Australia, Canada and New Zealand) of 203.3 tonnes. The net change was a reduction in QPS in the WEO group of 965.1 tonnes, compared to their combined average consumption of these five Parties over the previous three years. For this reason, the WEO group shows a decreasing QPS consumption trend over the past 4 years.

TABLE 32: SUMMARY OF THE CHANGES IN QPS CONSUMPTION DESCRIBED IN TABLE 31, BY REGIONAL GROUP

	QPS reductions			QPS increases			
Group	**Parties**	**No. of Parties**	**Total reduction**	**Parties**	**No. of Parties**	**Total increase**	**Net change**
Asia (A5)	China Indonesia Iran Pakistan Philippines Sri Lanka Thailand	7	-438.8	India Pap. New Guinea Rep. of Korea Singapore Vietnam	5	611.4	172.6
Asia (Non-A5)	Japan	1	-323.2	Israel	1	1,970.2	1,647.0
Latin America and Caribbean	Brazil Chile Guatemala	3	-258.8	Argentina El Salvador Honduras Mexico Nicaragua Uruguay	6	223.4	-35.4
Africa	Morocco	1	0	Cameroon Egypt Kenya	3	187.3	187.3
Eastern Europe	None	0	0	Turkey	1	1.0	1.0
Western Europe and Others group	EU USA	2	-1168.4	Australia Canada New Zealand	3	203.3	-965.1

6.9.6. Article 5 QPS consumption

The consumption in nine A5 Parties that reported consumption of more than 100 tonnes in 2009 is shown in Table 33. These nine A5 Parties accounted for 89% of the total A5 QPS consumption in 2009. China was the largest consumer (1,074 tonnes) among these nine Parties, but its consumption in 2009 was lower than in the previous two years.

TABLE 33: CONSUMPTION OF QPS FROM 1999 TO 2009 IN A5 PARTIES THAT CONSUMED MORE THAN 100 TONNES IN 2009

Year	China	Vietnam	Rep. of Korea	India	Thailand
2009	1,074	739	708	540	465
2008	1,236	696	339	562	546
2007	1,855	677	381	361	558
2006	1,029	656	288	330	539
2005	1,519	599	425	301	455
2004	725	530	536	382	620
2003	1,291	336	377		375
2002	1,118		543	114	
2001	121	325	516	295	208
2000	223	250	350	308	146
1999	889	380	884	211	458

Year	Mexico	Egypt	Indonesia	Singapore
2009	458	379	288	166
2008	307	312	439	107
2007	260	138	250	153
2006	239	150	211	98
2005	240	160	337	85
2004	135	89	252	46
2003	96	54	252	52
2002	155	200	252	35
2001	715		189	35
2000	359			109
1999	312		210	231

6.9.6.1. Article 5 QPS consumption bands

The Ozone Secretariat database showed 72 A5 Parties had reported consumption of QPS at least once in the period 1986 to 2009. A further 75 (51%) A5 Parties had never reported consumption of QPS during this period. The total number of A5 Parties is therefore 147. The consumption of QPS reported by A5 Parties totalled 5,433 tonnes in 2009.

Figure 31 shows the number of A5 Parties in each QPS consumption band, according to their annual consumption reported for 2009.

FIGURE 31. NUMBER OF A5 PARTIES IN SPECIFIC CONSUMPTION BANDS IN 2009

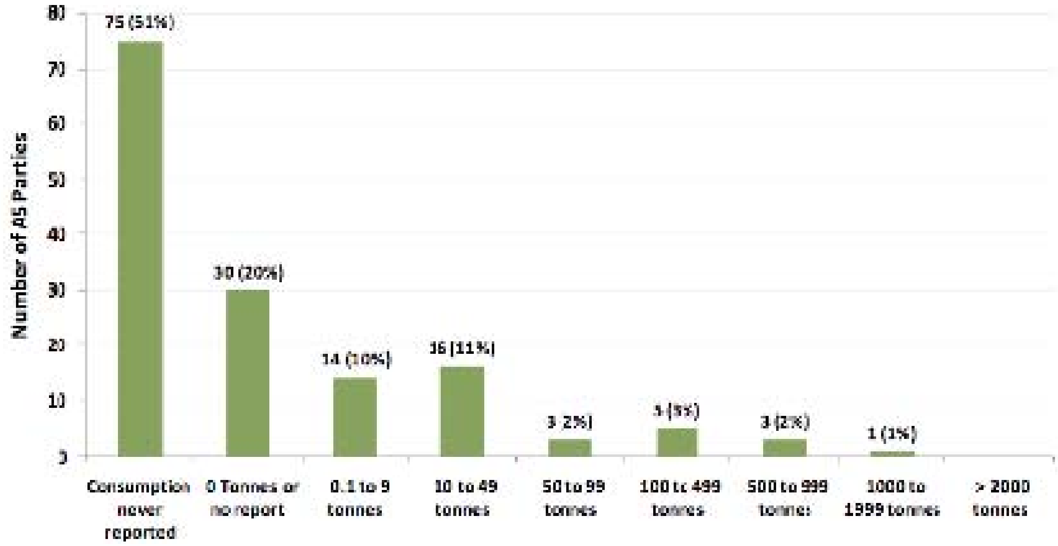
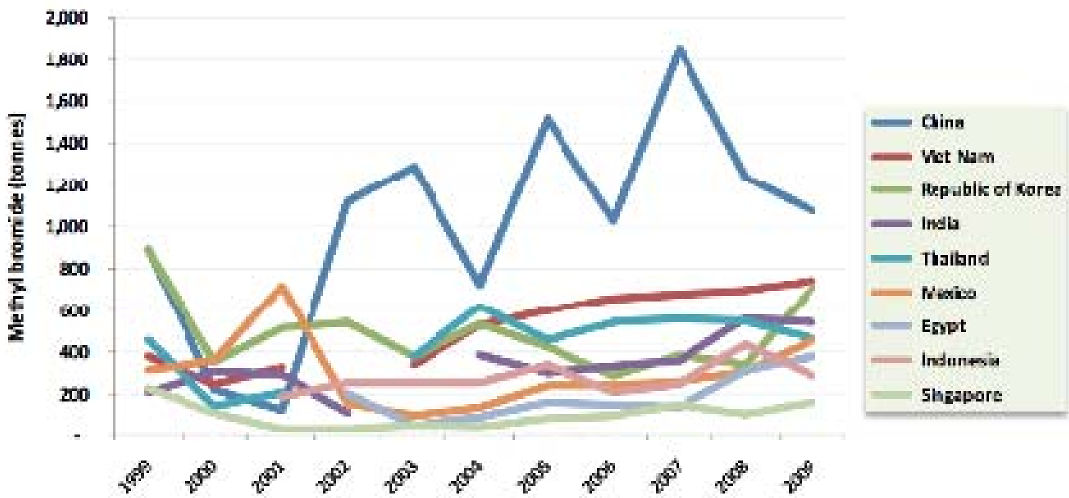


Figure 31 shows that 81% of A5 Parties consumed less than 10 tonnes of QPS, or provided no report in 2009, or had never reported consumption at all. Twenty-eight A5 Parties reported consumption of more than 10 tonnes in 2009. Three A5 Parties consumed more than 500 tonnes.

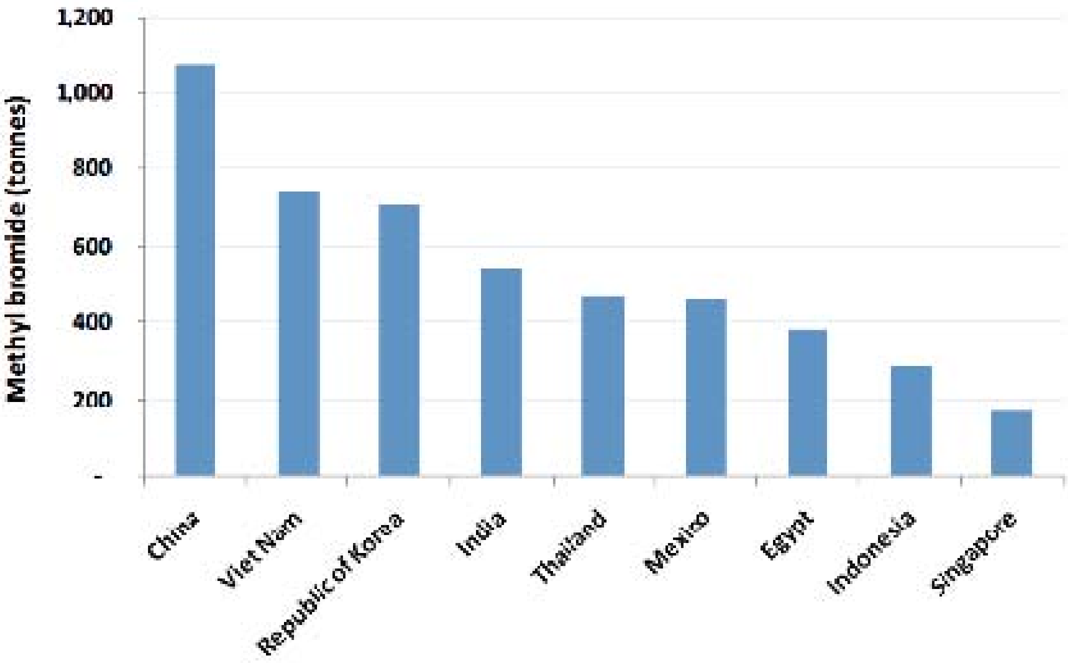
Figure 32 shows the consumption trend in the largest A5 consuming countries that consumed more than 100 tonnes of QPS in 2009. The consumption in 2009 ranged from 166 tonnes in Singapore, to 1,074 tonnes in China.

FIGURE 32. QPS CONSUMPTION TREND IN A5 PARTIES THAT REPORTED CONSUMPTION OF MORE THAN 100 TONNES IN 2009



Out of the total 147 A5 Parties, nine Parties (China, Vietnam, Rep. of Korea, India, Thailand, Mexico, Egypt, Indonesia and Singapore) accounted for 89% of the QPS consumption in 2009. In the A5 Parties, China was the largest consumer of QPS in 2009, followed by Vietnam, Republic of Korea, India and Thailand (Figure 32).

FIGURE 33. CONSUMPTION OF QPS IN A5 PARTIES THAT CONSUMED MORE THAN 100 TONNES IN 2009



China, Thailand and Indonesia decreased QPS consumption in 2009 compared to 2008, as indicated in Table 31. The other six A5 Parties increased consumption (Figure 32 and Table 31). Some other A5 Parties have reduced their QPS consumption in recent years and are no longer among the top nine A5 consumers. For example, Brazil reduced its QPS consumption from 368 tonnes in 2006 to 61.3 tonnes in 2009, which is a reduction of more than 80% over 4 years. Similarly, Chile reduced its QPS consumption from 114.8 tonnes in 2005 to 25.8 tonnes in 2009, which is a reduction of more than 75% over 5 years. Reductions in several LAC countries have contributed to an overall lower regional consumption.

6.9.6.2. Non-A5 QPS consumption

The Ozone Secretariat database showed 27 non-A5 Parties had reported consumption of QPS at least once in the period 1986 to 2009. A further 19 (51%) non-A5 Parties had never reported consumption of QPS during this period. The consumption of QPS reported by non-A5 Parties in 2009 totalled 5,433 tonnes.

The consumption in five non-A5 Parties that consumed more than 100 tonnes of QPS in 2009 is shown in Table 34. These five non-A5 Parties consumed 99% of the QPS in non-A5 Parties in 2009.

TABLE 34: CONSUMPTION OF QPS FROM 1999 TO 2009 IN NON-A5 PARTIES THAT CONSUMED MORE THAN 100 TONNES IN 2009

Year	Israel	USA	Japan	Australia	New Zealand
2009	2,182	2,099	697	502	271
2008	148	1,212	849	401	289
2007	210	2,930	1,107	288	170
2006	277	5,089	1,105	355	215
2005	331	2,931	1,166	358	126
2004	416	4,116	1,277	388	205
2003	501	3,722	2,845	440	141
2002	437	4,127	1,525	415	100
2001	337	3,079	1,408	468	51
2000	319	3,663	1,637	517	58
1999	225	4,038	1,450	425	60

6.9.6.3. Non-A5 QPS consumption bands

Figure 34 shows the number of A5 Parties in each QPS consumption band, according to their annual consumption reported for 2009.

FIGURE 34. NUMBER OF NON-A5 PARTIES IN SPECIFIC QPS CONSUMPTION BANDS IN 2009

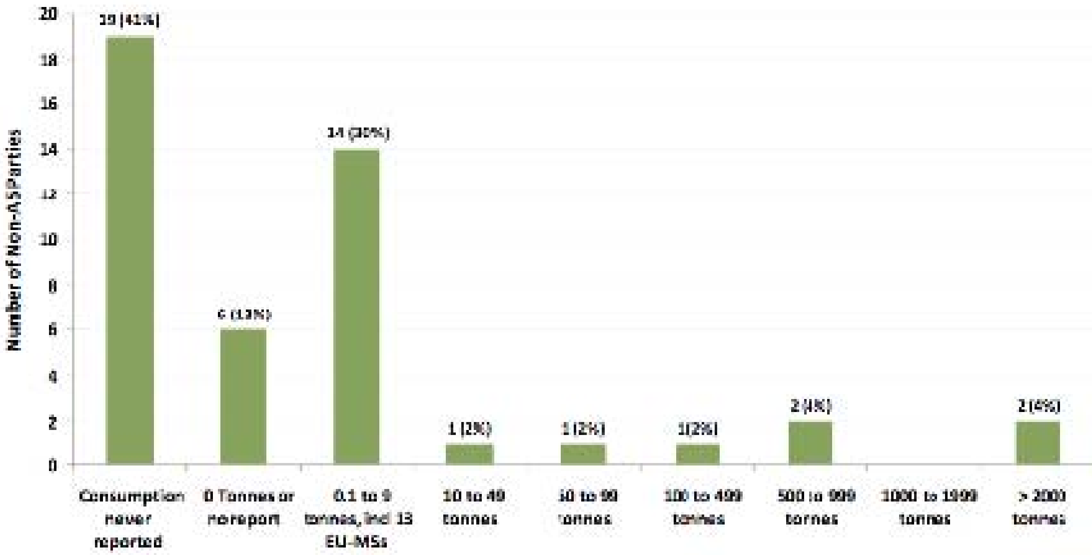
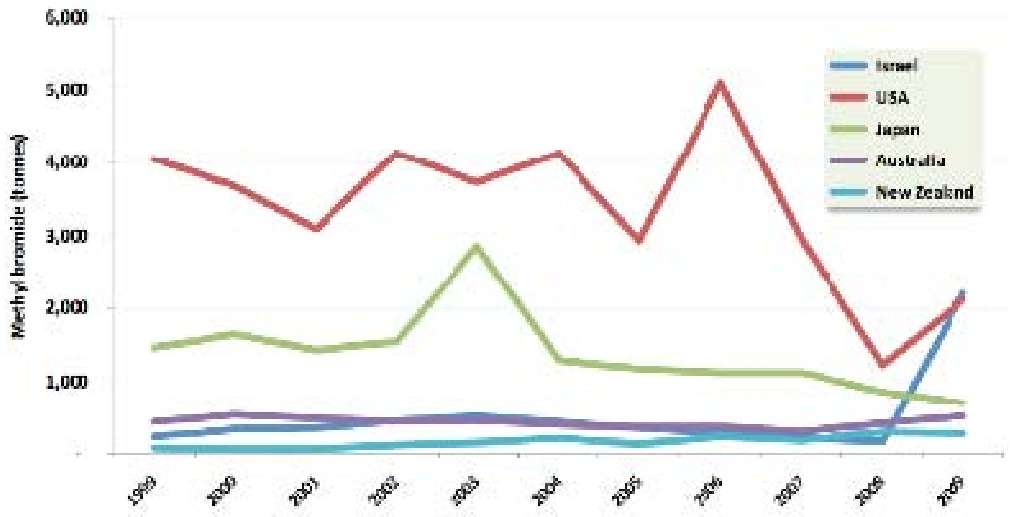


Figure 34 shows that 84% of non-A5 Parties consumed less than 10 tonnes of QPS, or provided no report in 2009, or had never reported consumption at all. The consumption reported by the EU of 52.7 tonnes in 2009 was included in the "50-99 tonnes" band, as the EU is a Party to the Montreal Protocol. The EU consumption of 52.7 tonnes was also divided between 13 Member States that had reported QPS in the past, and this number of countries added to the "0.1 to 9 tonnes" band since their average consumption was about 4 tonnes. The number of Parties shown in Figure 35 is therefore 46 in total.

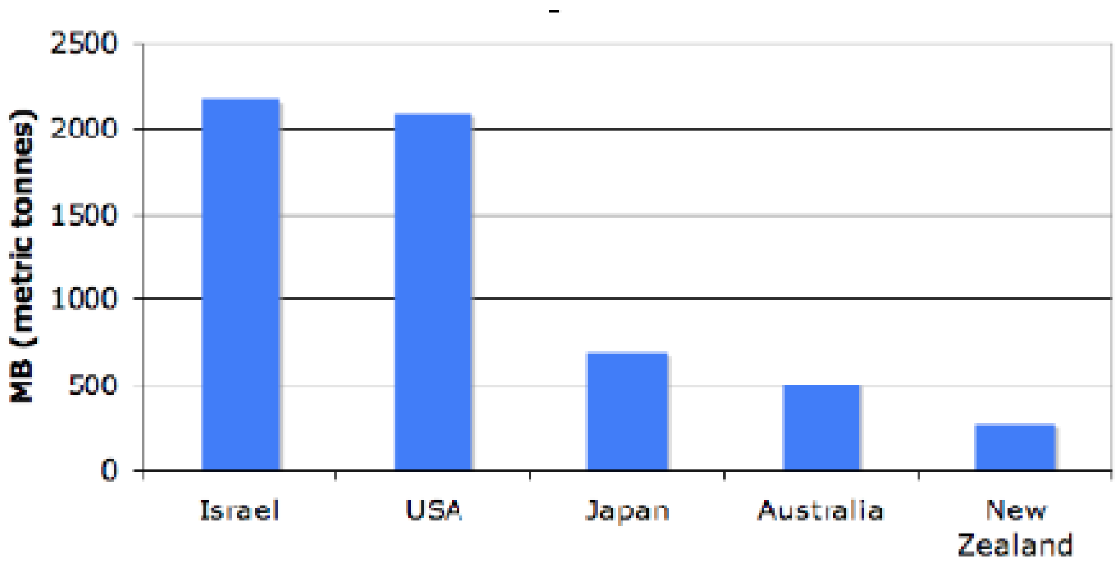
Figure 35 shows the consumption by the highest-consuming five non-A5 Parties each year from 1999 to 2009 that each consumed more than 100 tonnes of QPS in 2009.

FIGURE 35. TRENDS IN QPS CONSUMPTION IN NON-A5 PARTIES THAT REPORTED CONSUMPTION OF MORE THAN 100 TONNES IN 2009



Out of the 46 non-Article 5 Parties that reported QPS, these five non-A5 Parties consumed 99% of the QPS in 2009. Israel was the largest consumer (2,181.5 tonnes), closely followed the USA (2,099.3 tonnes) then followed by Japan (697.3 tonnes), Australia (502.3 tonnes) and New Zealand (271.0 tonnes) (Figure 36).

FIGURE 36. CONSUMPTION OF QPS IN NON-A5 PARTIES THAT CONSUMED MORE THAN 100 TONNES IN 2009



The consumption reported by Israel in 2009 (2,181.5 tonnes) was about 14-times larger than its consumption in 2008 (147.4 tonnes) (Figure 35).

The consumption reported by the USA in 2009 (2,099.3 tonnes) was 73% larger than in 2008 (1,212 tonnes), but about 60% lower than its maximum QPS in 2006 (5,089 tonnes).

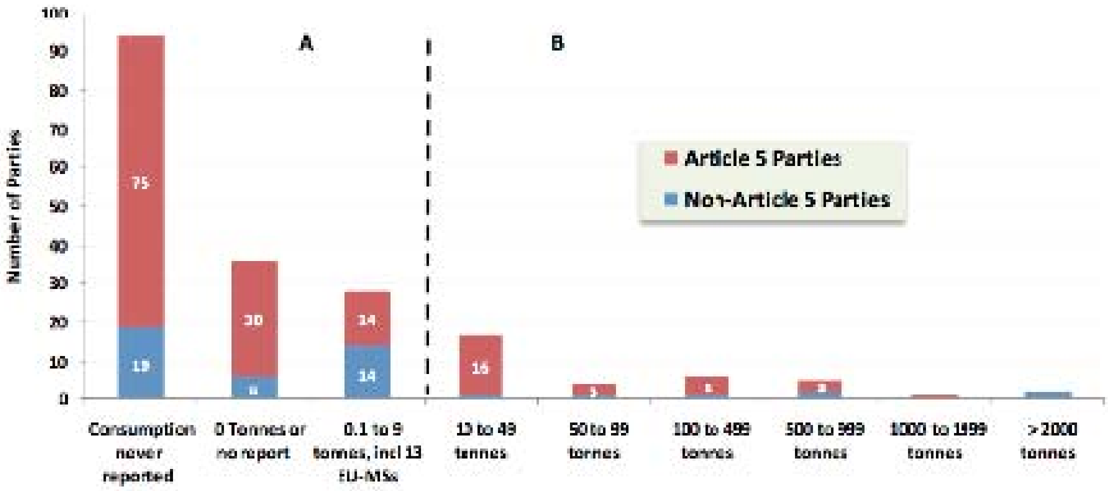
Japan's consumption in 2009 (697.3 tonnes) continued a steady reduction trend from peak consumption in the past 10 years of 1,637 tonnes in 2000. Conversely, both Australia and New Zealand have increased QPS in each year since 2007.

The EU reports consumption to the Ozone Secretariat on behalf of 27 Member States. The EU's consumption of 51.7 tonnes in 2009 was about 75% less than the previous year. The EU adopted legislation in 2008 and 2009 that banned consumption of methyl bromide including QPS from 19 March 2010.

6.9.6.4. Global QPS consumption bands

Figure 37 shows the number of A5 and non-A5 Parties in each QPS consumption band, according to their annual consumption reported for 2009.

FIGURE 37. NUMBER OF A5 AND NON-A5 PARTIES IN SPECIFIC CONSUMPTION BANDS IN 2009



The results in Figure 37 show that 158 Parties [16] (82%) were in the lowest three consumption bands, as they either consumed less than 10 tonnes of QPS, or they reported zero or provided no report in 2009, or they had never reported consumption prior to 2009. Thirty Parties (16%) reported QPS consumption of more than 10 tonnes in 2009. Of these, six Parties (3%) reported consumption of more than 500 tonnes.

6.9.7. Conclusions

Production of QPS was 8,922 tonnes in 2009, a small increase on 2008. QPS was produced mainly by Israel (2,182 tonnes), the USA (4,612 tonnes) and China (1,605 tonnes).

For the first time since reporting began more than 15 years ago, QPS consumption was greater, by 39%, than non-QPS consumption in 2009. QPS consumption was 11,308 tonnes and non-QPS was 8,148. This is primarily due to the large decrease in non-QPS

[16] 119 A5 Parties + 39 non-A5 Parties = 158 Parties. Total Parties = 193. 158/193 = 82%.

consumption over this period, together with a 26% increase in QPS consumption in 2009 compared to 2008.

Global QPS consumption was 11,308 tonnes in 2009, which was 26% more than in 2008 but close to the average for the past 11 years. A5 consumption was 5,433 tonnes and non-A5 consumption was 5,823 tonnes in 2009. Consumption in A5 Parties shows an increasing trend over the past 10 years, while in non-A5 Parties it has been decreasing overall.
Parties within the Asia group consumed more than 7,000 tonnes and accounted for 63% of global QPS consumption. Israel contributed to more than 91% of the net increase in consumption within the Asia group, which offset reductions in consumption made by China and seven other Parties within this group. Similarly, the "Western Europe and Others" group reduced consumption overall, mainly because the EU and USA implemented large reductions in QPS consumption in 2009, which offset relatively smaller increases in consumption by Australia, Canada and New Zealand. The New Zealand increase is use is solely due to an increase in log trade to China and India that requires mandatory pre-export fumigation.

Among A5 Parties, China was the largest consumer (1,074 tonnes) of the nine A5 Parties that consumed more than 100 tonnes in 2009. Some A5 Parties such as Brazil and Chile are no longer in the top nine as they have reduced consumption over the past 4-5 years.

Israel was the largest consumer of QPS globally in 2009. Israel's consumption of 2,182 tonnes was 14 times higher in 2009 than in 2008. Consumption in the USA was 2,099 tonnes, which was lower than the consumption reported in 73% larger than in 2008 but 60% lower than its maximum consumption in 2006. Five Parties (Israel, USA, Japan, Australia and New Zealand) accounted for 99% of the QPS consumption in non-A5 Parties in 2009. EU consumption (52.7 tonnes) in 2009 was about 75% less than in the previous year.

On the basis of the information provided by the Ozone Secretariat, the majority of Parties (158 out of 193 Parties or 82%) consumed less than 10 tonnes of QPS (28 A5 and non-A5 Parties), or they reported zero or provided no report in 2009 (36 Parties), or they had never reported consumption prior to 2009 (94 A5 and non-A5 Parties). Thirty Parties (16%) reported QPS consumption of more 10 tonnes in 2009. Of these, six Parties (3%) reported consumption of more than 500 tonnes.

In 2010, MBTOC estimated that four uses consumed more than 70% of the methyl bromide used for QPS in 2008: 1) Sawn timber and wood packaging material (ISPM-15); 2) Grains and similar foodstuffs; 3) Pre-plant soils use; and 4) Logs. On the basis of these estimates and currently available technologies to replace methyl bromide for QPS, TEAP calculated that 31% to 47% of global consumption in 2008 was replaceable in these four categories of use. In 2011, MBTOC will analyse the most recent data on QPS uses supplied by Parties to provide an estimate of the quantities of methyl bromide replaceable globally for the methyl bromide consumed for QPS in 2009.

6.10. Alternatives for sawn timber and wood packaging material

This section excludes logs and covers only quarantine treatments of wood that has been sawn into lumber and wooden packaging material derived from sawn timber. This material is mostly free of bark, but may include sapwood as well as heartwood. Sapwood is often present in lumber and can contain insects even in logs that have been debarked. For imports of lumber into some countries such as China and Korea do not require fumigation but inspect on arrival and fumigate if pests are detected; and other countries such as India require fumigation of lumber containing sapwood; and in Japan sapwood is categorized as logs and it is inspected and treated in import quarantine.

Sawn timber may be traded or made into pallets, dunnage and other packing material associated with either international or domestic trade.

6.10.1. Heat treatment

The only alternative treatment to methyl bromide treatment approved and accepted internationally under ISPM-15 for treatment of wood packaging materials (wood packaging material) is heat treatment, including kiln drying. A temperature of at least 56°C, core temperature, must be maintained for at least 30 minutes (IPPC 2006). The current revised version of the ISPM-15 standard (IPPC 2009) specifically encourages the use of heat where feasible in preference to methyl bromide, because of the ozone-depleting properties of methyl bromide.

There is substantial use of the heat treatment in many countries to meet ISPM-15. Many countries use heat exclusively to meet ISPM-15. Canada approves only heat for ISPM-15 suppliers and requires any methyl bromide treated packaging to be individually certified. In general, heat treatment requires a somewhat higher level of infrastructural support compared with methyl bromide fumigation, but has the advantage that a toxic gas is not used.

ISPM-15 requires that any wood packaging material stamped be treated to the required standard with the logo as evidence of the pallet having complied with the ISPM-15 standard. Where packing material such as pallets have not yet been certified, they may be treated to ISPM-15 standard in a heated enclosure of some kind. Pre-treatment stamping of pallets was understood to have occurred in situations where it may be expedient to treat the packaging material and the goods on the pallets together, such as in a loaded shipping container. This may preclude the use of heat, where heat-sensitive and dense goods are present, leaving methyl bromide as the only available alternative.

Kiln drying of sawn timber (lumber) exceeds the temperature thresholds and duration criteria defined in ISPM-15, thereby providing an alternative quarantine treatment to methyl bromide where insect and nematodes are pests of quarantine concern. Higher temperatures are required for control of fungi, but some timber (especially hardwoods) can be damaged by the high temperature treatment.

Canada (CFIA 2007) describes procedures for measuring and achieving ISPM-15 heat conditions with both green and dried wood. The Australian (AQIS) standard for heat treatment (AQIS 2009) provides procedures for measuring heat dosages to meet ISPM-15 and for the treatment of other commodities too.

6.10.1.1. Chemical alternatives

Fumigation is preferred when goods are present on wood packaging material that needs to be disinfested to meet the requirements of ISPM-15, and the goods are likely to be damaged by heat. The only officially-recognised chemical option at present is methyl bromide but Sulfuryl Fluoride, Methyl Iodide and Phosphine are under consideration.

A new ISPM is being drafted for the international movement of wood that will enable treatments to be approved that are already in use in the bilateral trade of wood and that have proven efficacy against specific pests.

6.10.1.2. Alternatives for wood pallets and other wooden packaging materials.

Alternative packaging methods avoid the need for methyl bromide fumigation or heat treatment. Plastic pallets (often made from recycled plastic) are commercially available and are used by many companies in the EC, the US and many other regions of the world. Cardboard pallets can be suitable for loads of about 3,000 kg, for example, and are available commercially in Australia, the EC, Kenya, New Zealand, the US and others. A detailed description of the environmental and economic costs or benefits of using pallets manufactured from different materials is not a topic for inclusion in this report.

Plastic, cardboard, plywood and particle board can also be used, instead of wood packing materials, for boxes, containers and staves which prevent goods moving within packed shipping containers. These materials are exempt the requirements of ISPM 15 (methyl bromide or heat treatment), which refers only to solid wood packaging materials. ISPM-15 excludes non-wood packaging (plastic, cardboard) and plywood, particle board, oriented strand board and similar processed wood that have been glued or pressed during processing (IPPC 2009).

As a side benefit, a reduction in the volume of new timber used for wood pallets would benefit countries where forest resources are under pressure. Kenya, for example, is estimated to use about 250,000 to 300,000 wood pallets per annum for tea exports alone. This volume of pallets comprises about 5,500-6,600 tonnes of cut timber, which require the felling or importation of about 8,330 - 10,000 tonnes of raw timber per annum (Rodwell 2007).

Demand for timber for pallets causes problems in Kenya where the tree cover is rapidly dwindling due to the demand for firewood (Rodwell 2007). However, in many Parties especially those that are Article 5 Parties, the added expense of using alternative materials to wood as well as in some cases lack of raw materials with which to make such pallets, places constraints on access to pallets that are not made of wood. The reuse of ISPM 15 compliant wood packaging is common.

6.10.2. Economic feasibility

APHIS (2003) suggests that in the US the use of heat treatment for meeting ISPM-15 is more cost effective than methyl bromide fumigation. The cost of treatments in the United States using methyl bromide without gas recapture was estimated to range between $1.82 (2003) and $2.34 per pallet (including cost of chemical and construction of fixed fumigation structure). The cost to fumigate using a tarpaulin structure ranged from $1.79 and $2.70 per pallet.

By comparison heat treatment was estimated to add $2.00 per pallet (Jabara *et al.* 2008). Estimates of the cost of plastic pallets vary widely from 3 to 6% more than wooden pallets (Mokhlesi and Lohrabesi 2009) to double the cost.

The economic impact in the US of using heat treatment to meet ISPM-15 have been assessed, using the economic model from the Global Trade Analysis Project (GTAP) (Jabara *et al.* 2007) for the case of two heat treatments. The authors found that ISPM-15 would have only a minor impact on US imports, and generally less than 1% change in import value.

Microwave heat treatment is likely to be more economically viable, particularly in a pass-through conveyor configuration designed to eradicate wood materials infected with pinewood nematode, this is because dielectric modalities such as microwaves heat polar molecules through the profile of the wood simultaneously (Hoover *et al*., 2010).

Methyl iodide is registered in some countries. It is also under consideration as a potential alternative to methyl bromide in ISPM-15 although at this time, like sulfuryl fluoride, it is not approved. Methyl iodide is more costly than methyl bromide on a weight-for-weight basis, plus the preferred delivery for space fumigation is to mix with CO_2 which is likely to add further cost. It can be expected that materials cost for the MI/CO2 system will be more expensive than methyl bromide. However, as the cost of chemical applied is usually less than 20-30% of the cost of fumigation, a significant increase in chemical cost does not translate directly to the same level of increase for the whole fumigation. Currently there is no published economic analysis for sulfuryl fluoride. It is known that the price of sulfuryl fluoride is higher than MB as weight basis, and the proposed higher dosage rate of SF required to achieve the efficacy to pests concerned in ISPM-15, is 3,200g.hr/m^3 compared to 800 g hr m^3 for methyl bromide at 15^{o}C.

6.10.3. Market penetration of heat treatments compared to methyl bromide

There is a global trend to use heat rather than methyl bromide to comply with ISPM-15 requirements.

A variety of facilities are in use to achieve the specified heat dosage for ISPM-15. They include timber kilns (present in many countries), hot water dipping e.g. Bangladesh (Kabir 2005), modified freight containers or similar enclosures with either hot water heating (China) or electrical or gas heating (Australia, Jamaica). Heat has been used in many Article 5 countries for many years (e.g. Morocco, Costa Rica, Colombia and Ecuador) and is made easier due to the fact that it can be integrated with kiln drying.

Heat treatment of wood packaging material to comply with ISPM-15 is well established in Article 5 countries. In Colombia for example, 156 heat treatment companies around the country are presently certified to provide this treatment and can treat on the average four million pallets per year. The technique has become widely available in just five years since the inception of ISPM-15 in the country. Even though the Colombian Institute of Agriculture certified two fumigation chambers for complying with ISPM-15 with methyl bromide treatment in 2009, these have so far been used only on one occasion, to fumigate an onion cosignement coming from the Netherlands (Arévalo and Cárdenas 2010).

Of the 626 companies registered in Mexico for treating wood packaging material for compliance with ISPM-15, 578 (92.3%) provide heat treatment and only 48 (7.7%) treat with methyl bromide. These are located throughout the country but 50% (309) are located in states that border the US and in combination can treat 4.8 million packaging units per month, the national total being 9.9 million units (García 2007).

Of the 183 companies registered in New Zealand for ISPM-15 only 19 (10.4%) of them continue to treat with methyl bromide (NZ MAF website 2010). As of March 2010, almost 300 companies in Japan conduct ISPM-15 treatments. Ninety-one percent of them use heat and 9% use methyl bromide to meet ISPM-15 requirements (Misumi, 2009).

In Argentina, only one facility is registered and authorised for methyl bromide treatment, but it has not been used for the past five years since costs and difficulty of operation do not make it a feasible option. Heat treatment is the preferred method of complying with ISPM-15, and at least 200 companies throughout the country are now authorised for heat treatment. Since an important consideration is transferring packaging materials to and from the treatment site at least cost, the availability in different regions of heat treatment facilities is most important. Owners of such facilities quoted costs, health and environmental hazards and others as factors that discourage them from using methyl bromide instead of heat.

Because methyl bromide is not presently available for QPS (as of March 2010) in the EU, and to encourage the use of as many alternatives to methyl bromide as possible for the treatment of wood packaging material, the EU published a manual of options and alternatives to achieve the objectives of ISPM-15 without using methyl bromide (Vermeulen and Kool 2006). The manual includes a description of the use of controlled atmospheres and sulfuryl fluoride as two potential alternatives to the use of methyl bromide.

6.10.4 Regulatory requirements and other drivers

If efficacy data meet the required level for ISPM-15 and sulfuryl fluoride is approved by the IPPC for use in ISPM-15 in 2012, a revised standard could be promulgated in 2013 providing it is agreed by the Parties to the IPPC. This would allow those countries where sulfuryl fluoride is registered such as Europe, Australia and the USA to use sulfuryl fluoride for the disinfestation of wood packaging material. A government could also list sulfuryl fluoride as an approved quarantine treatment for imports and domestic quarantine use if data satisfied their level of quarantine security but it would not be binding on other countries in the way ISPM-15 would be.

Many countries have not yet registered sulfuryl fluoride for any use. The high global warming potential may prevent further registrations of sulfuryl fluoride in some countries. Furthermore, companies that are under pressure to reduce their carbon footprint may also be reluctant to use sulfuryl fluoride.

The 2009 revision of ISPM-15 (IPPC 2009) did not recognize any alternative to methyl bromide except heat, but several potential alternatives to heat and methyl bromide are under evaluation. The Technical Panel on Phytosanitary Measures that advises the Standards Committee of the IPPC on technical evaluations on alternatives, reports that several potential alternatives have been submitted and are under evaluation. The evaluation panels have requested additional efficacy data for the potential alternatives to methyl bromide shown in Table 35. Species of *Agrilus planipennis* (Emerald Ash Borer), *Anoplophora glabripennis* (Asian longhorned beetle), *Bursaphelenchus xylophilus* (Pinewood nematode), various bark beetles, sawflies and many other forest pests are key pests that must be controlled to a very high level of quarantine security by any alternative.

TABLE 35: LIST OF POTENTIAL TREATMENTS FOR ISPM-15 UNDER IPPC EVALUATION

Sulfuryl fluoride
Sulfuryl fluoride and MITC mixture
Hydrogen cyanide
Microwave heating
Phosphine
Methyl iodide

Of the alternatives for ISPM-15 being considered, the data submitted for sulfuryl fluoride are sufficient to support Probit-9 efficacy for sulfuryl fluoride fumigation against *Anoplophora glabripennis* in wood packaging material and pinewood nematode. The Technical Panel on Phytosanitary Measures has sufficient information to support the 99.99683% (Probit-9) efficacy of a methyl iodide schedule against pinewood nematode with but not for *Anoplophora*. Phosphine data submitted are not yet sufficient to demonstrate efficacy against either of the two key pests. Although only two of many quarantine pests that have to be controlled by alternative treatments, effectiveness against these two pests would indicate potential as a quarantine treatment and indicate sulfuryl fluoride is worthy of additional effort.

The requirement for mortality data showing a high level of efficacy for wide range of pests is a major barrier to development and approval of additional treatments for ISPM-15. The standard also needs approval from all member parties. Details of current requirements for submission of potential alternatives are given in ISPM-28. Criteria for future ISPM-15 treatment submissions are being considered by Technical Panel on Phytosanitary Measures of the IPPC.

Recently, the Technical Panel on Phytosanitary Treatments (TPPT) on IPPC is recommending two sulphuryl fluoride temperature schedules (15^{o}C and 30^{o}C) for approval for ISPM 15 though with no recommendations for 20°C or 25°C) although this causes questions over the practicality of these schedules is questionable. TPPT also recommended microwave heating for approval as a heat treatment. The microwave treatment is not at any particular frequency, but must be completed within 30 minutes (60^{o}C for 1 minute), with a maximum heating up time of 30 minutes and maximum wood thickness of 20cm. The frequency rate used affects how fast the wood can be heated a higher GHz will reduce treatment time and increase throughput. The next meeting of the Commission of Phytosanitary Measures is March 2011 and both SF and microwave treatment are going to be evaluated and a decision made whether they are to be included in ISPM-15 or not.

Some National Plant Protection Organisations recognise other treatments for wood packaging material and similar products, instead of methyl bromide or heat treatments undertaken according to the treatment criteria contained in ISPM-15. These treatments may be post entry or prior to export and are generally based on bi-lateral agreements between countries interested in a specific trade. Australia, for example, requires off shore treatments of timber packaging and dunnage that have not been treated in accordance with ISPM-15 to be treated at specified dosages of several alternatives, including fumigation with sulfuryl fluoride, or ethylene oxide or treatment with heat, gamma irradiation or some timber preservatives (ICON 2009).

6.11. *Alternatives for logs*

There is active research in progress to develop alternatives for logs but gaining the required efficacy data is very difficult as laboratory rearing has not yet been achieved to the numbers required, most insects are seasonal, and the commodity is large and variable.

Methyl bromide is the most widely used fumigant for logs, the largest single commodity treated using methyl bromide. It does have some limitations i.e., limited penetration, particularly across the grain and into wet timber. Most arthropods associated with timber are quite susceptible to methyl bromide but much higher dosages are required to kill fungi (Rhatigan *et al.,* 1998). Green logs are problematic to treat due to the high moisture content (80%), presence of bark (very adsorbent), size and large volumes. Overall, methyl bromide is currently the best log fumigant that is registered and available.

Treatments of logs may need to be rapid, such as at point of export or import, to avoid charges and congestion at ports associated with occupying restricted port area for the treatment. Where quarantine treatments can be applied outside port areas, such as prior to export or in-transit, alternatives to methyl bromide that take a longer time can be used. Many pests of quarantine significance, which attack green wood, do not re-infest dry and debarked wood.

Kiln-drying of lumber kills insect pests some of which also may be of quarantine concern. Specific QPS alternatives for logs are discussed below, followed by discussion of some processes under development.

6.11.1. Reduction in methyl bromide dosage

Treatment specifications for logs have not been harmonised worldwide and schedules vary with country of import and target pest. This is because the quarantine security requirements are set by the importing country in accordance with their unique quarantine requirements—a right guaranteed by the World Trade Organization. Korea requires 25 gm^{-3} for 24h at 12-15°C (Yu *et al.* 1984), India 64gm^{-3} 11-15°C, China 120 gm^{-3} for 16h at 5-15°C, and

Malaysia requires 128 gm^{-3} for 24 hour exposure at the higher temperature of 21°C. Significant savings of methyl bromide could be achieved by reducing the fumigation rate in situations where the use can be shown to be excessive. Using New Zealand as an example, the consumption of methyl bromide by New Zealand could be reduced by 53 tonnes per annum by reducing the methyl bromide fumigation rate from 120 to 80 gm^{-3} for pine logs to China (Ken Glassey, pers. comm. 2010). Examination of the data generated in New Zealand show that the lower dosage of methyl bromide is effective for controlling the target pests.

However, permission to use the lower dose in commercial practice is determined by the importing country in according to the level of quarantine security demanded by that country to satisfy its unique quarantine requirements.

A new ISPM is being drafted for the international movement of wood, although its acceptance by the Parties to the IPPC will not necessarily result in a reduction in methyl bromide used. It is intended to include treatments that are already in use in bilateral trade and with proven efficacy against specific pests.

6.11.2. Phosphine

New Zealand has pioneered the use of phosphine for the in-transit fumigation of *Pinus radiata* logs destined for China. It is now routinely used as a quarantine and pre-shipment measure and has partially replaced methyl bromide for this purpose. However, phosphine in-transit can only be used to treat logs shipped below deck in the holds, which are about two-thirds of each shipment. This method is currently saving around 400 tonnes of methyl bromide annually (Ken Glassey, pers. comm. 2010).

One of the major disadvantages of phosphine when compared to methyl bromide is the long exposure time (up to 10 days) required, but this is overcome by applying the phosphine in transit. Considerable efficacy data has been developed in support of this methyl bromide alternative (Hosking and Goss 2005; Zhang 2003ab; Zhang and van Epenhuijsen 2005; Wang *et al* 2009; Wang and Goss 2010). However, efficacy data for the wood wasp *Sirex noctilio*, a quarantine pest of concern for India, has yet to be obtained to the level required for approval for trade with India. Another serious pest, the pine wood nematode, is not present in New Zealand.

The current dosage specification requires at least 200 ppm phosphine (v/v, 0.28 gm^{-3}) to be maintained for 10 days. Due to sorption of the gas by the logs (Zhang 2004) top-up of phosphine is required 5 days into the voyage to prevent the concentration falling below 200 ppm. In-transit tests have shown an even gas distribution throughout the loaded ship holds. High concentrations of CO_2 also occur within the ship holds during the fumigation period that may increase the insecticidal action of the fumigant.

Phosphine is typically produced in the reaction of aluminium or magnesium phosphide with water. There are some formulations of phosphine available in cylinders as technical grade, pure compressed gas or diluted with CO_2. The gas is highly toxic to insects and has remarkable penetration ability (Spiers 2003). Because the egg and pupal stages of insects respire slowly, they are generally more tolerant than the larval and adult stages, which respire relatively quickly. Phosphine is generally ineffective against fungi infecting timber.

Phosphine has long been used for the treatment of grain insects but repeated treatment of grain silos and poorly conducted fumigations has led to frequent development of phosphine resistance in stored grain pests in some countries (Zettler 1997, Collinson 1999). Such resistance is not an issue for one way commodities such as forest produce and extrapolation of data on dosage requirements from grain insects may not be relevant for forest produce.

Research in China and Japan has demonstrated that phosphine killed 10 species of forest insects of quarantine concern including cerambycids, scolytids and platypodids. Oogita *et al.* (1997) fumigated the cerambycids (*Semanotus japonica*, *S. japonicus*, *Callidiellum rufipenne*, *Monochamus alternatus*, the scolytids (*Phloeosinus perlatus*, *Cryphalus fulvus* and *Xyleborus pfeili*) and the platypodids (*Platypus quercivorus* and *P. calamus*)) with phosphine at concentrations of 1.0 and 2.0 gm^{-3} for 24 and 48h at 15°C and 25°C. *S. japonica* and *P. perlatus* eggs were killed at 2.0 gm^{-3} for 24 hours at 15°C, but larvae and pupae of all species were not killed at 2.0 gm^{-3} for 48h at 15°C. At 2.0 gm^{-3} for 48h at

25°C, all stages of *C. fulvus* and *X. pfeili*, except larvae of *C. fulvus*, were killed. The work concluded that more than 48h was required for complete mortality.

In New Zealand, two phosphine log fumigation trials were completed in 2009 (Wang *et al.* unpublished), using sea containers loaded with commercial export logs and field collected insect-infested logs. The initial dosage of aluminium phosphide in the treatment container was equivalent to 2 gm^{-3} of phosphine gas. Phosphine concentration was maintained at over 200 ppm v/v during the 10-day fumigation period with one to three additional applications of aluminium phosphide pellets. Penetration of the phosphine into export logs at an average moisture content of 59% and 79% to a depth of 80mm achieved an average exposure of 183 ppm.hr and 265 ppm.hr respectively in the two trials.

A total of 680 insects extracted from infested logs in the treatment chambers were dead after phosphine fumigation and the mortality rate was 100%. All the 561 insects extracted from the controls were alive. Insects included Cerambycidae; *Arhopalus ferus* (Mulsant) larvae, *Prionopolus reticularis* (White) larvae, Ichneumonidae; *Rhyssines* larvae (*Sirex noctilio* parasite) and Scolytidae; *Pachycotes pergrinus* (Chapuis) adults, *Hylastes ater* (Paykull) adults, Hylastes eggs, *Hylurgus ligniperda* (Fabricus) larvae, *Hylurgus* adults, and *Hexatricha pulverulenta* (Westwood) larvae.

This work confirmed laboratory trials carried out by Zhang (2004b) that included four replicates of 94-102 eggs of *A. ferus*, which were successfully killed by 200 ppm phosphine for 10 days. In another later trial, a further four replicates of 100-253 *A. ferus* eggs were killed at a mean of 260 ppm phosphine over seven days. The length of time required to complete treatments restricts its commercial acceptability.

Data are being collected on the efficacy of phosphine controlling wood pests in both New Zealand and Canada, in order to improve the usefulness of this alternative.

6.11.3. Sulfuryl fluoride

Data is being collected in the USA and China on the efficacy of sulfuryl fluoride for controlling wood pests as an alternative for the disinfestation of logs. Sulfuryl fluoride penetrates timber somewhat better than does methyl bromide (Scheffrahn and Thoms, 1993; Ren and Lee, 2010).

Sulfuryl fluoride is a similar fumigant to methyl bromide except that the fumigation temperature or concentration usually needs to be higher to achieve the same level of pest mortality for all stages including the egg stage. Sulfuryl fluoride is reported to have a large global warming potential (Papadimitriou *et al.,* 2008).

Sulfuryl fluoride has a long history of use for control of wood and structure pests. It has been sold for this purpose since 1961. Several quarantine authorities (New Zealand MAF, Australia AQIS and USDA-APHIS) at one time accepted treatment of timber by sulfuryl fluoride at 64 g m^{-3} for 16 hours at 21°C.

Sulfuryl fluoride is registered or licensed for use in many countries including the Australia, EU, Japan, US and Canada, and is one of the most promising equivalent replacements for MB for logs and sawn timber, having similar properties and exposure requirements, with significantly better penetration of wood (Scheffrahn *et al*., 1992).

Registration activities are in progress in China and India. Sulfuryl fluoride has been shown to be effective against adult bark and timber insects but its efficacy against eggs is reduced below 21°C, requiring increased application rates. Soma *et al*. (1996) have shown sulfuryl fluoride to be effective against seven species of wood borers and bark beetles, although egg stages were up to five times more tolerant than other stages.

Soma *et al.* (1997) found that to achieve 100% egg mortality of one species required a 24-hour dose of 100 g sulfuryl fluoride/m3 at 25°C. Barak *et al*., (2006) recommend a dose of 104 g m^{-3}, a temperature of 15.6°C and above and a CT (concentration x time) product of 1095 g-h m^{-3} for control of *Anoplophora glabripennis*, Asian longhorned beetle larvae and pupae. Ash logs infested with emerald ash borer, *Agrilus planipennis* were fumigated with SF at four dosages from 104 to 144g m^{-3} for 24 and 48 hours at 15.6 and 21.1°C. No adult emerged from fumigated logs and *ct*- products were a range of 3,329 – 5,466 g-h m^{-3} (Barak *et al*., 2010).

In direct exposure trials at 15°C, Zhang (2006) showed that burnt pine longhorn (*Arhopalus ferus*) adults were controlled by 24-hour exposure to 15 g sulfuryl fluoride m^{-3} while eggs required 120 g m^{-3}. In the same study, black pine bark beetle (*Hylastes ater*) adults and larvae were also controlled by 15 g sulfuryl fluoride/m3. A follow-up study (Brash et al. 2007) showed that black pine bark beetles were controlled by a 24-hour exposure to 7.5 g m^{-3} but burnt pine longhorn adults may require up to 30 g m^{-3} (because at lower rates a number of adults were classified as moribund but not dead). Zhang (2006) also showed that sulfuryl fluoride has potential to control fungi associated with trees and timber in New Zealand. Eight fungal cultures required at least 30 g sulfuryl fluoride m^{-3} for full control.

A recent submission was made by the manufacturer (Dow AgroSciences), IPPC 2007) to the IPPC for inclusion of sulfuryl fluoride in ISPM-15 for treatment of wood pests in wood packaging. According to the manufacturer, the recommended treatment schedule suggests high rates of sulfuryl fluoride are required for a 24-hour treatment at a recommended a *ct*-product of 3000 g-h m^{-3} and an initial dose of 175 g m^{-3} when treatment temperatures are 15–20°C. Higher temperatures (over 27°C) may be needed to obtain satisfactory control at lower dosage levels.

There is a perception that sulfuryl fluoride will not control egg stages of quarantine pests and will not work at common ambient temperatures. Dow AgroSciences believes that good efficacy on eggs is possible by adjusting exposure rates and/or times (Scott Boothey, pers. comm.). Sulfuryl fluoride is also perceived as likely to be more expensive than phosphine but Dow AgroSciences also points out (Scott Boothey, pers. comm.) that the exact price has not yet been determined. The high GWP of SF may also be concern, particularly at a higher dosage rate, to those wanting to reduce their carbon foot print. Combining sulfuryl fluoride with other fumigants is an approach with potential to overcome the resistance of eggs to sulfuryl fluoride alone.

6.11.4. Methyl isothocyanate/ Sulfuryl fluoride mixture

Research on alternatives for logs evaluating the efficacy of MI and MITC/SF mixtures has been completed in Japan and both treatments are under the process of inclusion under the relevant regulations. However, instructions or procedures for conducting gas measurements and safety devices to protect fumigators from gas exposure still need further work.

The mixed gas of MITC and SF was registered in Japan in 2004 for logs infested with forest insect pests. MITC does have high sorption characteristics and an odour (UNEP 2001). MITC used in mixture with CO_2 is effective against wood borers, bark beetles, and ambrosia beetles at 40-60 gm^{-3} for 24hrs at 15°C (Naito *et al.,* 1998); and it was found to be particularly effective against pinewood nematode (Soma *et al.,* 2001). Soma et al. (2004) obtained complete control of all life stages of a range of forest insect pests using two mixes - sulfuryl fluoride (30 g m^{-3}) with methyl bromide (15 g m^{-3}) and sulfuryl fluoride (15 g m^{-3}) with methyl isothiocyanate (15 g/m^3). The latter mixture has been registered for use in Japan on imported timber. After the completion of public hearings, it is expected that a sulfuryl fluoride/methyl isothiocyanate/CO_2 mix (30% methyl isothiocyanate, 30% sulfuryl fluoride, 40% CO_2) will be introduced into the Japan quarantine treatment schedules (TEAP 2008).

The proposed schedule is methyl isothiocyanate 33 g/m^3 and sulfuryl fluoride 33 g/m^3 for 10–14.9°C, methyl isothiocyanate 27 g m^{-3} and sulfuryl fluoride 27 g m^{-3} for 15–24.9°C and methyl isothiocyanate 21 g m^{-3} and sulfuryl fluoride 21 g m^{-3} for over 25°C (Soma *et al*., 2006).

6.11.5. Methyl iodide

Data are being collected on the efficacy of methyl iodide for controlling wood pests in the New Zealand, France and the USA, in order to assess the usefulness of this alternative for the disinfestation of logs.

In Japan, the developments of alternative chemicals to methyl bromide for imported logs has been carried out by the Ministry of Agriculture, Forestry and Fisheries, manufacturers and other bodies concerned with methyl bromide use. Methyl bromide use for logs is the largest use of this fumigant for plant quarantine in Japan.

Complete mortality of the pinewood nematode and the longhorn beetles, *Monochamus alternatus* and *Arhopalus rusticus*, were achieved at 84 g m^{-3} at 10°C, 60 gm^{-3} at 15°C, 64 gm^{-3} at 20°C, 48 g m^{-3} at 25°C respectively using methyl iodide 50% and carbon dioxide 50% (Kawakami *et al.* 2004). This mixture is now registered in Japan for timber treatment and is in the process of being included in the quarantine schedule. The limited amount of research that has been undertaken suggests it is no better than methyl bromide in controlling pathogens in wood and may be inferior (Schmidt and Amburgey 1997).

Naito *et al*., (2003) report results of a 24 h MI fumigation at 15°C against most life stages of nine species of forest insect pests. Egg stages were controlled by 5–10 g MI/m^3 and most larval and pupal stages (under bark, in xylem or in artificial diet) were controlled by 30 g MI/m^3. Complete mortality of all stages was achieved for all species except one at 50 g MI/m^3. Some xylem-dwelling larvae of one species (*Callidiellum rufipenne*) survived.
Soma *et al*. (2006) tested a MI regime that had been devised to control pine wood nematode for the control of two species of longhorn beetle (larval and pupal stages only). Fumigations were carried out for 24 h at 10, 15, 20 and 25°C using infested logs (100–200 mm diameter and 1 m long) under tarpaulin (51.2% loading; loading is the term referring to the

percentage of the volume within the fumigated space which is occupied by the goods being treated).

They obtained complete mortality of larvae and pupae of longhorn beetles using 84 g MI/m^3 at 10°C, 60 g MI/m^3 at 15°C, 48 g MI/m^3 at 20°C and 36 g MI/m^3 at 25°C. This study was followed up with an evaluation of MI on a wider range of forest insect pests, including some that were found in logs imported from Malaysia (Soma *et al*., 2007a).

Complete mortality of seven species was obtained, including all life stages (eggs, larvae, pupae and adult) of four species at 7.9–10.6°C using 60 g MI/m^3 for 24 h. This evaluation was carried out at semi-commercial scale (70–74% loading (v/v) under tarpaulin with a capacity of 5.4–6.0 m^3. Klementz and Brash (2010) conclude that MI shows high potential. Soma et al. (2005a) examined a range of MI doses at four temperatures for the control of pine wood nematode. Red pine (*Pinus densiflora*) naturally infected with pine wood nematode (Bursaphelenchus xylophilus) was cut into pieces (150 mm x 150 mm x 300–400 mm long and 13–24.7% moisture content) and fumigated for 24 h. Higher doses were required at lower temperatures. No surviving nematodes were observed on samples fumigated at 60 g MI/m^3 at 10°C, 40 g MI/m^3 at 15 and 20°C and 30 g MI/m^3 at 25°C. MI was sorbed (see section 2.1.5 for an explanation) by the wood during fumigation and the authors estimated the CT product for complete mortality was 450 g·h/m^3 at 10°C, 400 g·h m^{-3} at 15°C, 350 g·h m^{-3} at 20°C and 300 g·h m^{-3} at 25°C. Soma et al. (2005a) recommended 84 g MI/m^3 at 10–14.9°C, 60 g MI/m^3 at 15–19.9°C, 48 g MI/m^3 at 20–24.9°C and 30 g MI/m^3 at 25°C and higher. A follow-up tarpaulin study (Soma *et al*., 2006) using infected timber pieces of a similar size to the earlier study confirmed these recommendations when used with the higher (and close to commercial practice) loading of 50%.

MI has been tested as a quarantine treatment for solid wood packing material. Tubajika and Barak (2007) inoculated small wood blocks (25 mm x 25 mm x 10 mm) of birch, maple, poplar and red pine with *Ceratocystis fagacearum* – a fungal species commonly associated with wood degradation. The wood blocks were incubated for a minimum of 30 days prior to fumigation treatment. Three fumigants (MB, MI and sulfuryl fluoride (SF)), two fumigant concentrations and three exposure times were compared in a replicated lab experiment. The results suggest at least 48 h exposure to 240 MI g m^{-3} or 72 h exposure to 160 MI g m^{-3} is required for pathogen control (CT product of over 7800 g·h m^{-3}). MI performed as well as MB and better than SF.

Methyl iodide successfully killed oak wilt fungus at rates similar to methyl bromide (Tubajika 2006).

Methyl iodide is expected to be adopted by Japan as a quarantine treatment in the near future. Lack of registration in other countries for post-harvest uses severely limits its availability for quarantine treatment of forest pests in other countries.

6.11.6. Cyanogen

Cyanogen, sometimes referred to as ethanedinitrile or EDN, shows promise but is yet to be registered or used commercially. Its registration is pending in Australia. When naked *A. glabripennis* larvae were exposed to cyanogen at 4.4, 10, 15.6 and 21.1°C the *ct* for LD 99.5 l was for 3 hrs 282.49, 240.99,130.5 and 95.28 g m^{-3} respectively and 353.38, 221.82, 126.77 and 56.62g m^{-3} respectively for 6hrs (Ren *et al*., 2006). When treating naturally infested wood the main problem is high solubility in water, therefore moisture content in wood binds material to a large degree (A. Barak, pers. comm.). However, this high solubility can allow cyanogen penetrate through high moisture content timber. It was found effective against various termite species; larvae of *Monochamus alternatus* in a 24 hrs fumigation. All workers of *Cryptotemes acinaciformus*, *Cryptotermes brevis* and *Mastotermes darwinienis* were killed at 1.61, 3.0 and 2.3 g m^{-3} respectively. After a 6 hour exposure at 21+/- 2^{o}C, the LD99.5 values were 0.65 g m^{-3} against *Reticulitermes speratus* adults. A 6 hours exposure achieved $LD_{99.5}$ values against *Tomicus piniperda* and *Hyphantria cunea* adults at 4.64 and 0.63mg/l. a mortalilty of >96.5% was achieved against the pinewood nematode at 50 g m^{-3} at 4.1^{o}C for a one day fumigation. Another nematode Steinermena carposcapsae was killed at 40mg/l at 20^{o}C after a five hour exposure (Ren and Lee, 2009). The toxicity of cyanogen to insect pests and pathogens will be increased with increasing temperature, CO_2 and equilibrium RH (Hooper *et al*., 2003, Ren *et al*., 2006 and Desmarchelier and Ren, 1996).

It is not known if work is continuing with cyanogen for the treatment of logs as it appears to penetrate high moisture content timber well but may have a high sorption rate (Barak and Ducom pers. comm. 2010).

6.11.7. Heat

Heat treatment has been accepted as a quarantine treatment for logs and timber to be shipped to the USA and many other countries for many years (e.g. USDA 1996). The general specification requires the wood to reach a core temperature of 71°C for 60 minutes. Kiln drying of timber to a moisture content of less than 20% using temperatures over 70°C is often a commercial requirement but also has long been accepted as a quarantine treatment by most importing countries. Currently, 56°C core temperature for 30 minutes is required under ISPM-15 for wood packaging material.

Heat treatment of unprocessed logs is an approved risk mitigation measure for importation into the USA (Morrell 1995). Steam heat is a more effective quarantine measure than dry heat (USDA 1994; Dwinell 2001). Moist heat treatment is an integral part of log conditioning prior to peeling and has the additional benefit of eliminating quarantine pests. Moist heat treatment can be, if done to a level necessary for pest kill, an integral part of log conditioning prior to peeling veneers and has the additional benefit of killing any quarantine pests that might be present in the wood.

A considerable volume of literature addresses thermal mortality of insects and has been reviewed by Hosking (2002a). Jamieson *et al.* (2003) provides a good general summary of the literature on heat mortality of insects and fungi. A better summary of heat treatment applications for forestry produce is that of Dwinell (2001).

This literature suggests few if any insects can survive even short exposure (less than 24h) to temperatures above 50°C, but some fungi are more tolerant. Direct exposure of gypsy moth eggs (Hosking 2001) resulted in 100% mortality at the lowest temperature (55°C) and shortest exposure time (5min) tested. Fungi were more variable in their response to temperature and exposure time. Some fungi required exposures of up to 6 h at 57°C (Morrell 1995) while others were killed by exposure to 60°C for 10 min (Ridley and Crabtree 2001).

Heat treatment by steam has been shown to eradicate all tested fungi when 66°C is held at the centre of wood for 1.25 hour (Miric and Willeitner 1990; Newbill and Morrell 1991), but Dwinell (2001) reported that neither the APHIS-approved methyl bromide treatment for timber nor heat treatment up to 81°C killed all saprophytic fungal pathogens in imported hardwood pallets. Many fungal pathogens are also very tolerant of methyl bromide (e.g. see Rhatigan *et al.* 1998). Trials with heat treatment using steam are proposed in the USA (Ken Vick pers. comm. 2010)

6.11.8. Irradiation

Gamma irradiation is currently approved for the disinfestation of logs into Australia at a rate of 10 kGy (1.0 Mrad). However, its practical application must overcome a number of hurdles, not the least being the construction of large irradiators to handle logs and bulk wood products.

Irradiation is also limited by poor penetration into freshly cut logs, potential damage and dose-dependent degradation of wood products such as fibre board and paper, variation in effect on different insect groups, and very high dosages required to eliminate fungi (Morrell 1995).

No continuing work on irradiation treatment of logs is known to MBTOC.

6.11.9. Water soaking or immersion

Water soaking or immersion provides a way to control pests on imported logs. Immersion of some logs destined for plywood manufacture is a useful process as it improves the quality of the products. The storage of logs in water or under water spray has long been accepted as an effective treatment for terrestrial insects and fungi. Salt water immersion of logs for 30 days is an approved treatment for logs into Japan but contamination of waterways with bark is an issue. The upper surface of the logs above the water level is sprayed with an insecticide mixture such as dichlorvos as part of the pest management strategy (Reichmuth 2002).

The potential for use of water soaking for quarantine treatment of imported logs is limited by the large area of water required and the undesirable side effects of ponding large volumes of logs, making its application on a large scale unlikely.

6.11.10. Debarking

Bark removal has long been a key strategy in reducing contamination of logs and a way to reduce the risk of logs and sawn timber carrying certain insects and fungi of quarantine concern.

While debarking removes surface contamination and also bark and cambium, which are areas particularly prone to pest attack, it does not affect insects and fungi already in the wood (USDA 1992). Many countries require debarking of all imported logs. Because of the high cost, and the requirement by customers in major Asian markets that bark remain on logs, its application as a quarantine treatment is limited and frequently only carried out on high value logs.

6.11.11. Chipping and Grinding

This may be suitable for one of the methods to use in an eradication program after incursion of a tree pest, the effects of chipping and grinding for Emerald Ash Borer, *Agrelus planipennis* pre-pupae were examined. Roughly 8,700 pre-pupae were processed by horizontal grinder with a 2.5 or 10cm screen, there were survivals in chips processed with the 10cm, but not the 2.5cm screen (McCullough *et al*., 2007).

6.11.12. Microwaves

Microwaves are essentially a heat treatment using electromagnetic energy in the 10 – 30,000 MHz range. It seems unlikely that microwave irradiation has application in the treatment of logs because of the large quantities exported. Scaling up microwave technology to mitigate against quarantine risk in logs faces significant challenges.

No continuing work on microwave treatment of logs is known to MBTOC.

6.11.13. Economic feasibility

Treatments of logs may need to be rapid, such as at point of export or import, to avoid charges and congestion at ports associated with occupying restricted port area for the treatment. Where quarantine treatments can be applied outside port areas, such as prior to export or in-transit, alternatives to methyl bromide that take a longer time can be used. Many pests of quarantine significance, which attack green wood, do not re-infest dry and debarked wood.

Some types of logs that are primarily coniferous that are shipped in high volume, they have comparatively low value and they are shipped long distances. This trade is very price sensitive to changes in freight costs, exchange rates and treatment costs. In contrast, there is also a large trade in hardwood logs that has significant value to some countries of over $1billion and each log is valued at several thousand dollars when used for making veneer, for example. Therefore, the economic value that a new treatment brings to the log trade depends mainly on the type of log, its market destination and intended use.

Phosphine is less expensive than methyl bromide for the treatment of logs when it is applied at the point of export as an in-transit treatment: $0.93 per m^3 for logs exports from New Zealand to Japan, compared with $3.50 per m^3 for methyl bromide (Self and Turner 2008). The cost effectiveness of in-transit use of phosphine is dependent on the length of transit. Its use on shorter transit shipments would add significant costs (approximately $1,000 per hour (Self and Turner 2008)) to shipping due to delays. On longer transits phosphine can be more cost effective than methyl bromide. This is because, compared to methyl bromide, the dosage rate is lower, and it is faster to apply which reduces costly moorage time in the port. The sailing time is sooner as the ship avoids having to stay in port for at least 36 hours while the hold is fumigated and then vented. A fumigation technician is required for the voyage to add more fumigant, monitor for leaks and vent the holds. This method can only be used for logs stowed in the holds, which is normally about two-thirds of the cargo, and the balance of the cargo on deck must be fumigated with methyl bromide under tarpaulin on the wharf prior to export.

Sulfuryl fluoride is about 50% more expensive in the United States than methyl bromide due to sulfuryl fluoride's higher cost per unit of volume and a higher dose needed for the treatment (John Sansone, pers. comm. 2010). Most treatments of logs occur in temperate climates that have temperatures less than 25°C for much of the year which would make the treatment uneconomic in comparison with methyl bromide treatment. The recommended minimum temperature is 15°C. A gas monitor that operates on the thermal conductivity principle (Fumiscope®) is historically used for sulfuryl fluoride measurement at sites of fumigation for such as termite control. Any CO_2 present interferes with the reading for SF by a Fumiscope and a high level of CO_2 is generated from logs and WPM during fumigation. The CO_2 absorbent generally used for these monitors subsequently destroys sulfuryl fluoride. Therefore, an improved CO_2 absorbent or alternative gas monitor may be needed. Effective infrared (IR) gas monitors exist but are expensive.

Methyl iodide or methyl iodide plus CO_2 have similar application rates to methyl bromide but any premixing with CO_2 adds cost to the more expensive price of the chemical. Both treatments are under evaluation in Japan for the control of log pests. No commercial sized applications have been undertaken to verify the economics of log fumigation with methyl iodide.

The cost of cyanogen is unknown. Both heat treatment and irradiation of large volumes of logs are uneconomic. Heat is a technically feasible alternative but because of the energy required and the large volume of the unprocessed logs being shipped, it is rarely an economic alternative to fumigation.

Though the use of irradiation for decontaminating logs in export trade does not appear to be economically feasible at this time, it may be useful in managing pests on high-value forest products that cannot normally be heat treated or fumigated.

Due to a lack of infrastructure, increased cost, tariffs and customer requirements, conversion to sawn timber pre export may not be viable option in most cases. Conversion of logs to sawn timber that carries a lower quarantine risk is a technically feasible alternative, but would have significant trade implications. Some particular timbers and end uses may be unsuitable for conversion to lumber for technical and end use reasons. The current log trade in many cases relies on conversion to lumber and more highly processed products at the importing country. This provides employment in the importing country, as well as greater control over what the timber is converted to, but at the cost of greater quarantine risk.

Moving the point of conversion of logs from importing country to the exporter would have substantial economic implications. The trade from some countries with high labour costs and limited milling infrastructure may be lost to those that can provide lower cost conversion.

6.11.14. Market penetration of alternatives

The alternative must be effective against the pests of concern for the particular importing country and for the treatment to be economic. For instance, efficacy has yet to be proven to a quarantine level for wood wasps and pine wood nematode using phosphine, which holds up the market penetration of the use of in-transit phosphine.

The current market penetration for alternatives for logs is very small. Of the 58 million m^3 of logs imported into China, India, Japan and Korea in 2007, only 800,000m^3 (1.3%) was treated with phosphine. This volume could be increased to 8.9 million m^3 if all four countries receiving logs from the USA, Canada and New Zealand accepted phosphine fumigation of below-deck logs. Acceptance of phosphine as an alternative would potentially save about 1,200 tonnes of methyl bromide per year, even though it is still only about 15% of the global log trade.

Based on the 2008 trade statistics for logs imported by Japan, MBTOC estimated that Japan could replace about 500 tonnes of methyl bromide with methyl iodide, methyl iodide/CO_2 and/or methyl isothocyanate/sulfuryl fluoride mixture if those chemicals are approved in Japan by the Japanese government for the treatment of imported logs.

China has approved a specific treatment schedule for sulfuryl fluoride on logs for fumigation in Germany and other countries prior to export. Data on the use of sulfuryl fluoride under this treatment schedule are not available and the extent of the market penetration of sulfuryl fluoride for this use is unknown.

6.11.15. Regulatory requirements and other drivers

All countries have a chemical registration process that over time has become more rigorous and expensive, making it difficult to register new chemicals or new uses for existing ones. While it is easier to gain approval for the treatment of non-edible products such as logs and timber, it can still take between five to ten years for final approval of a new treatment. There is also a high probability of not being successful at the end of the process, after investing much time and money.

Acceptance of an alternative is also based on time and cost. As exported product may be competing with the domestic market or another exporting country, and therefore any additional treatment costs or delay may make the trade unviable.

A high level of efficacy is required for treatments to ensure that pests of quarantine concern do not establish in the importing country. History has shown that incursions of forest pests can cause billions of dollars of damage (e.g., the Asian longhorn beetle, the emerald ash borer) or even drive species to extinction (Chestnut blight and American elm blight).

Acceptance of alternatives requires negotiation between officials of the importing and exporting countries. Science and research finding play an important part in this process. However, due to a lack of technical personnel, funding, expertise or other resources the negotiations can take years to obtain market access for an alternative treatment. If a treatment is approved at the international level, an included in a standard such as heat for ISPM-15, the negotiation time can be reduced significantly.

Japan attributed several technical and regulatory reasons (Akio Tateya pers. comm. 2010) for its approximately 50% reduction in the consumption of methyl bromide for QPS in 2009 (542 tonnes) compared to 2006 (1,039 tonnes):

- A concerted programme by MAFF to improve gas retention in fumigation chambers;

- Reduction in dosage when the treatment can be carried out at higher temperatures, recirculation equipment is present and other criteria;
- On board fumigation using phosphine of non-food commodities, such as bamboo from Taiwan;
- Import of genetically modified crops that are less susceptible to pest infestation than crops that have not been genetically modified;
- A reduction in products that are subject to plant quarantine e.g. imported timber is subject to plant quarantine but not processed wood;
- On the basis of pest risk analyses following ISPM-2 criteria, a reduction in the number of pests classified in Japan as regulated quarantine pests;
- Reductions of imports to Japan due to tariffs imposed on raw wood exports by the exporting country e.g. Russia;
- Greater use of heat treatment for wood packaging material as heat treatment is less costly than methyl bromide;

Alternatives to methyl bromide have been registered e.g., for timber sulfuryl fluoride, methyl isothiocyanate, carbon dioxide and sulfuryl fluoride, and methyl iodide but they are not yet in use as quarantine treatments on processed timber.

6.12. Alternatives for grains and similar foodstuffs

Methyl bromide fumigation continues to be used for pre-shipment treatment of cereal grains where logistical constraints at point of export, or importing country specifications, preclude the use of phosphine. Phosphine is the principal accepted fumigant alternative to methyl bromide. Methyl bromide is also applied when it is specified by regulation, and/or for treatments against certain specific regulated quarantine pests. Methyl bromide fumigation may be the treatment of choice or the only approved and available treatment for the situations where a quarantine treatment is required.

There are different alternative treatments of choice for grains to meet appropriate QPS standards, depending on whether the treatment is officially required by national authorities for common and cosmopolitan insects that attack or are associated with grain in storage and transport (i.e., pre-shipment), or they are for control and elimination of specific regulated quarantine pests.

Export cereal grains, such as rice and wheat, are prone to infestation by a number of cosmopolitan grain pests that cause damage when in storage and are unacceptable to modern market standards. Most of the methyl bromide fumigations are pre-shipment treatments that target non-quarantine pests. These pre-shipment treatments are officially required by official regulations of some exporting countries or by official requirements of some importing countries. Examples of pre-shipment treatments have been reported previously (TEAP 1999, 2002; MBTOC 2002). Export cereal grains, similar products and associated packaging from some locations may also be subject to quarantine treatments against specific insect pests, notably Khapra beetle (*Trogoderma granarium*), *Prostephanus* species or contaminants such as specific snails (e.g. *Cochlicella* spp.) or seed-borne diseases such as Karnal bunt (*Tilletia indica*).

Many countries have strict quarantine regulations on grain and other durables originating from countries where Khapra beetle occurs. Typically, only methyl bromide treatment is specified against this quarantine pest, using double normal dosages for stored product disinfestation often with extended exposure period. For instance, cereal products from Khapra beetle areas for import into Australia require 80 gm^{-3} of methyl bromide for 48 hours at 21°C with an end point concentration at 48 hours of 20 gm^{-3} (ICON 2009).

6.12.1. Alternatives for quarantine treatments

The USDA PPQ Treatment Manual (USDA 2009) contains many treatment schedules specific to Khapra beetle and most involve fumigation with methyl bromide. Schedule T307a refers to various treatment schedules for commodities and transport vehicles found infested with Khapra beetle for post-entry quarantine treatment. Heat treatment at a high temperature and prolonged exposure (7 minutes at 65.5°C) is given as the only approved alternative to methyl bromide and can only to be used when specifically authorised by the APHIS.

Heat treatment is a good alternative to methyl bromide for controlling many stored product pests, including Khapra beetle. Despite its tolerance to temperatures of about 41°C, Khapra beetle is quite susceptible at higher temperatures, more so than some common storage pests such as *Rhyzoperta dominica*. There are old but good quality data to substantiate heat susceptibility of stored product pests in general. For instance, Husain (1923) studied heat disinfestation of wheat from Khapra larvae. Pupae of *T. granarium* were found to be the most heat tolerant stage, requiring 16 hours at 50°C or 2 hours at 55°C for '100%' kill, while other stages were eliminated in less than 2 hours (Mookherjee *et al.*1968). *R.* dominica requires in excess of 24 hours for complete kill at 50°C, 5 hours at 51°C and 10 minutes at 55°C. Battu *et al.* (1975) found LT95 for diapausing and non-diapausing larvae to be 7.4h and 3h respectively at 50°C. Lindgren *et al.* (1955) noted a slight dependence of time to complete kill at an ambient relative humidity. Treatment at high humidities extended the time. At 55°C, 75% RH, 95% mortality was obtained after 8 and 15 minutes with 4th instar larvae and pupae respectively. Wright *et al.* (2007) investigated heat treatment of *Trogoderma variabile*, showing it to have similar response to heat as *T. granarium*. The economic feasibility of heat treatments for grain and similar foodstuffs are discussed later in this report.

In the past, *T. granarium* was quite susceptible to phosphine e.g. Hole *et al.* (1976), which made phosphine a potential alternative to methyl bromide against this pest. However, with the frequent development phosphine resistance by *T. granarium* in the Indian subcontinent, phosphine is not currently an option for controlling this pest.

Some winter wheat fields in Texas were infected with Karnal bunt disease, *Tilletia indica*, in 2001. Karnal bunt was detected in Arizona in March 1996 and in Texas in 1997. The 2001 detection in Texas was significant because it occurred outside the quarantine area in Texas (J. Schaub pers. comm. 2010). When infected grain was harvested and transferred to storage bins, the bins and grain handling equipment became infected. Methyl bromide fumigation of emptied contaminated storage bins requires a high dosage (240 gm^{-3}) for 96 hours to meet quarantine standards. Steam heating to a point of runoff in bins also is an effective alternative to methyl bromide providing surface temperatures reach 77°C (Dowdy 2002).

Japan imports about 30 million tonnes of grain including wheat, maize and soybean. Methyl bromide is the fumigant of preference for treatment of these imports. There is no approved treatment schedule other than methyl bromide where granary weevil (*Sitophilus granarius*) is detected in the grain. This flightless pest, widespread in most countries, is a listed object of quarantine in Japan. The quantity of methyl bromide used for grains in Japan is larger than for any other category except whole logs (PPS 2007). Phosphine fumigation using aluminum phosphide tablets has been included in the plant quarantine treatment schedule in Japan (MAFF, 1971). The treatment with phosphine takes many days and is thus unsuitable where there is insufficient capacity at import ports to allow long holding periods. Methyl bromide treatments typically take less than 48h.

6.12.2. Alternatives for pre-shipment treatments

There are well known, standard processes for protection and disinfestation of stored grain in storage and transport. Grain and similar dry foodstuffs, either bagged or in bulk, can be delivered to an export point in a '*pest-free'* condition without recourse to methyl bromide fumigation (e.g. see MBTOC 2007). The choice of alternative is dependent on the commodity or structure to be treated, the situation in which the treatment is required, the accepted level of efficacy and the cost and the time available for treatment. Some alternatives (e.g. some fumigants, heat treatment) may be implemented as 'standalone' treatments to replace methyl bromide in certain situations. Others may be used in combination to achieve an acceptable level of control.

These processes, theoretically, can avoid the need for any further treatment against infestation at the export port. In practice, consignments may be brought to the export point in infested condition. Also, particularly in humid, tropical situations, there is often a high invasion pressure from pests at the export point. As a result, an insecticidal process (usually fumigation) must be used to ensure the grain meets the exporter's or importer's official regulations for lack of infestation.

In some cases, the pre-shipment treatment is used to disinfest ship holds or other conveyances before placing grain or similar commodities in the ship hold, in order to prevent infestation from contaminated holds during shipment. Alternatives to methyl bromide for pre-shipment fumigation of shipholds using phosphine were proposed on the basis of work undertaken in Canada (Field and Jones 1999).

Pre-shipment treatments in general are aimed at a lower standard of pest control than quarantine. While quarantine treatments lead to a commodity free of regulated quarantine pests, pre-shipment only requires the consignment to be "*practically free*" of pests. This lower level of security gives some wider choice of alternatives, with reduced requirements for efficacy testing.

Alternatives to methyl bromide fumigation for pre-shipment of cereal grains, including rice, vary with situation, particularly the required speed of action. In some export situations, there is sufficient capacity at the port, to allow slower acting alternative treatments to be used easily, with treatment times of 7 days or more for full effectiveness. Phosphine fumigation is in widespread use for this purpose, for both bagged and bulk consignments. Controlled atmosphere technologies have some usage at present (e.g. Clamp and Moore 2000), but have potential for much more widespread adoption. Direct application of pesticide to the grain will also will give pest-free grain to inspection standards, sometimes with a holding period before inspection to allow for action of the pesticide on the pests. Rapid acting pesticides for direct application include dichlorvos and cypermethrin. The use of methyl bromide alternatives is limited by various registration issues and also by market and end user requirements, some of which require 'residue-free' grain.

In many export situations, a high throughput is required, where there is limited space at the port for treatments and as demurrage costs on waiting vessels is high. Typical turnaround times for methyl bromide for a shipment can be 24-48 hours, a time that has to be accommodated in the organisation of the export consignment under pre-shipment treatment.

Sulfuryl fluoride fumigation is restricted by the availability and registration of the fumigant to only a few countries at this time. However, it is now used routinely as an alternative to methyl bromide for pre-shipment treatment of grain e.g., in Australia.

Some importing countries may specify fumigation at point of export as a pre-shipment treatment, with indications as to what treatments are acceptable. In cases where methyl bromide is specified as one treatment, phosphine fumigation may be specified as an alternative. However, several countries specify use of methyl bromide as the only acceptable QPS treatment of imported grain from specified exporters.

Treatment of bulk or bagged grain in ships with phosphine after loading may potentially replace some current pre-shipment uses of methyl bromide. However, this may be interpreted as falling outside 'pre-shipment' and may not meet regulatory requirements of some exporters and importers who require grain to be practically pest-free before loading. Phosphine treatments may be conducted at the dockside, in lighters or barges prior to loading a ship, or in the ship after loading and before sailing. In suitable ships, in-transit phosphine treatment gives an effective post-export treatment.

The International Maritime Organisation recommendations on safe use of pesticides in ships and shipping containers describe the safe use of both phosphine and methyl bromide at port and in-transit (IMO 2008ab). The Organisation specifically recommended that cargoes should not be fumigated in ships with methyl bromide prior to sailing due to the risks resulting from the difficulty in ventilating the cargo effectively (IMO 1996). As an alternative to methyl bromide, for safety and efficacy reasons, in-transit treatment with phosphine is restricted to specially-designed bulk carriers, tanker-type vessels and other ships where the holds are gastight or can be made so (Semple and Kirenga 1997). In addition, equipment must be installed to circulate the phosphine through the cargo mass (Watson *et al.* 1999). The circulation equipment ensures that the gas penetrates throughout the load and can be aired from the load prior to unloading.

In-transit treatment of bulk grain is in widespread use, potentially avoiding the need for methyl bromide treatment prior to shipment where import and export regulations permit. USDA APHIS estimates that of the 95 million tonnes of wheat and corn that the U.S. exported in 2009, 66.9 million tonnes were transported under in-transit fumigation with phosphine.

6.12.3. Economic feasibility

Methyl bromide fumigation was used widely in the past to fulfill requirements for pre-shipment treatment of grain. In general, other processes are cheaper and more convenient and methyl bromide use for this purpose has decreased to the stage where it is typically used only in situations where the rapid action of methyl bromide confers technical and economic benefits.

Use in 1992 for QPS treatment of grains and similar foodstuffs was estimated to be about 7,000 metric tonnes (TEAP 1997). In 2005, this annual consumption for this purpose was estimated to be about 1,700 tonnes (TEAP 2009). This significant reduction, brought about largely by the replacement of methyl bromide by phosphine, is indicative of the cost competitiveness of phosphine compared with methyl bromide.

Although heat is technically feasible, its use is limited by the high cost of heat treatment facilities that are able to heat grain moving at fast handling speeds, such as when loading or discharging, compared to the costs of facilities to implement other alternatives. Small scale heat disinfestation facilities for bulk grain, operating at a relatively slow speed of tens of tonnes per hour throughput, are commercially available.

6.12.4. Regulatory requirements and other drivers

Transition to phosphine for the pre-shipment of grains has been driven largely by economic consideration. Increasing health regulations associated with avoiding worker exposure to methyl bromide are likely to further encourage use of alternatives.

Methyl bromide treatment of grains for quarantine purposes continues to be often the only accepted and convenient treatment in many cases. There appear to be no drivers away from this situation, in the absence of measures to curtail methyl bromide use for QPS purposes.

6.12.5. Emerging or potential alternatives for grains and similar foodstuffs

6.12.5.1. Pre-shipment treatments

Alternatives that act at least as fast as methyl bromide would be welcomed in many export situations, as these would minimise delays handling the export consignment with associated costs and grain handling limitations.

At this time there are no agreed, widely available and approved pre-shipment treatments that will match the treatment speeds of large consignments that can be achieved with methyl bromide fumigation, though there are some in the regulatory approval process in a few countries. The fumigants sulfuryl fluoride, cyanogen and carbonyl sulphide, and synergised ethyl formate all have potential to give similar treatment times and throughputs to methyl bromide (MBTOC, 2007), although these are not registered in most countries. Methyl iodide also has potential for this use.

6.12.5.2. Quarantine treatments

Microwave technology used in laboratory tests was reported as effective in controlling Karnal bunt (*Tilletia indica)* teliospores in 10 seconds compared to 96 hours using methyl bromide (Ingemanson, 1997). Scale up to large quantities of grain is problematic.

Alternative treatments to methyl bromide are needed for various snails of quarantine significance (e.g. *Achitina fulica*, *Cernuella* spp. *Theba pisana*). Methyl bromide fumigation is usually the only approved quarantine measure for these pests when associated with grain shipments. Other processes, including HCN and CO_2 fumigations, may be more effective (e.g. Cassells *et al.,* 1994), but are not approved and not registered.

Phosphine is not accepted for controlling *Sitophilus* species because the pupal stage of *Sitophilus granarius* (a regulated quarantine pest for Japan) could not be killed completely at the dosage rates and fumigation conditions used in commercial quarantine fumigation (Mori and Kawamoto, 1966). On the other hand, sulfuryl fluoride has higher efficacy against pupal stages of several stored product insects, although the egg stage is the most tolerant (Furuki *et al.* 2005; Bell *et al.,* 2003). Fumigating with a mixture of phosphine and sulfuryl fluoride gas kills all stages of *Sitophilus* species, using the good properties of both fumigants. Tests with mixtures of phosphine and sulfuryl fluoride were conducted in Japan and a sequential fumigation that consists of a sulfuryl fluoride fumigation for 24 hours and a phosphine fumigation for 48 hours was decided to be effective to eliminate all stages of Sitophilus species (Misumi et al., 2011).

6.12.5.3. Carbonyl sulphide

Fumigation with carbonyl sulphide has been recommended for control of insects in stored products, durable commodities and structures (Desmarchelier 1994; Zettler *et al*., 1997; Wright, 2001).

Carbonyl sulphide (COS) is a major sulphur compound naturally present in the atmosphere at 0.5 (± 0.05) ppb and is a colourless gas (Wright, 2000) with a typical sulphide odour. The average total worldwide release of carbonyl sulfide to the atmosphere has been estimated at about 3 million tons/year, of which less than one third is related to human activity (Hazardous Substances Data Bank, 1994). It is also present in foodstuffs such as cheese and prepared vegetables of the cabbage family. Traces of COS are naturally found in grains and seeds in the range of 0.05-0.1 mg kg^{-1} (Wright, 2000; Navarro, 2006). The compound is naturally present in the environment as part of the natural global sulphur cycle, occurs naturally in food and breaks down rapidly, with a high turnover (Obenland et al. 1998; Caddick 2004; Bartholomaeus and Haritos 2005). Plants are able to metabolise carbonyl sulphide and synthesise it (Protoschill-Klrebs and KesseMIer 1992; Feng and Hartel 1996).

The use of COS as a fumigant for the fumigation of durable commodities and structures was patented worldwide in 1992 by CSIRO, Australia and registration is being sought in both Australia and New Zealand. COS has been trademarked in Australia as COSMIC®. BOC Limited has an agreement with CSIRO for its manufacture and worldwide distribution. It has good penetration action, and commodity sorption is generally less than that of either methyl bromide or methyl iodide (Schneider *et al*., 2003). Carbonyl sulphide has similar efficacy on a w/w basis against insects as methyl bromide, and faster efficacy than phosphine (Caddick 2004). It does not react as fast as methyl bromide with grain, and is thus easier to retain at higher concentrations. Where tolerant egg stages must be controlled, it is beneficial to extend the exposure time.

Carbonyl sulphide has a low boiling point of minus 50.2°C with a vapour pressure of 9412mm Hg and is readily gasified at room temperature, Therefore it can be applied directly into the grain bulk where it is dispensed into the intergranular air space. This method of application provides simple, safe, fast application and even gas distribution in the silo (Ren, 2007). This compares to MB, which has a boiling point of 3.7°C, and therefore should be applied using a heated vaporiser to distribute the fumigant and minimise residues.

COS does not show any reaction with a variety of materials including hard and soft timbers, paper, iron, steel and galvanized sheet, PVC, polyethylene, and brick applied with high concentrations at high temperature and relative humidity (Wright, 2000). However, to avoid corrosion on copper, Ren and Plarre (2002) suggested that COS for direct use as a fumigant must be manufactured to minimise hydrogen sulphide contamination (to <0.05%, v/v), or the fumigant scrubbed of H_2S before application on site. Sorption studies with higher moisture content commodities, such as wheat at 18% moisture content, show a rapid loss of COS, by hydrolysis to H_2S and carbon dioxide, at rates that would make COS fumigation impracticable (Wright, 2000) and can result in a strong sulphur smell. This characteristic may make it unsuitable for fumigation of products such as export logs that have high moisture content within the fumigation enclosure and may result in ephemeral smells after treatment.
While COS is flammable with a range of 12 % - 28,5 % v/v , this is well below the 2% or less suggested for fumigation of grain with standard precautions related to dilution.

6.12.5.3.1. Efficacy

COS at practical concentrations from 10 to 40 g m^{-3} has been shown to be effective on a wide range of postharvest pests in all stages, including mites, at exposure times between 1-5 days at temperatures above 5°C (Desmarchelier, 1994). Amongst the tested pests, *Sitophilus oryzae* (L.) was found to be the most tolerant species to COS. All developmental stages including eggs could be controlled at 20 g m^{-3} with 5 days of exposure at 30^{o}C (Weller *et al*., 2001). Research on COS in Australia, Germany and the USA revealed that the egg stage was the most tolerant to the fumigant, however, the effective exposure period was half that of phosphine. Eggs of weevils were more tolerant of carbonyl sulphide fumigation than adults when fumigated with 25 g/m3 at 30°C (Weller and Morton 2001). COS shows some efficacy at temperatures above 5ºC, , but for effective treatment fumigation should only be conducted when the temperature is 15°C or above.

Short exposure times at 25°C have been investigated for treatment of surface insects on tropical fruits and flowers (Chen and Paull 1998). Avocados, mangos and papaya tolerated a 1% (26.5g m^{-3}) treatment of carbonyl sulphide for 7, 3 and 16 h, respectively. Red ginger inflorescences were less tolerant of carbonyl sulphide than fruit, being able to withstand 1% (26.5g/m^3) for less than 2 h. Lemons can tolerate a 70 g m^{-3} treatment for 8 h without reduction in market quality (Obenland *et al*., 1998). Fumigation of nectarines with 80 g/m^3 carbonyl sulphide for 2 h at 21°C intensified peel colour, delayed fruit softening and did not adversely affect fruit quality (Aung, 2001). Phytotoxicity studies conducted on 12 species of cut flower have shown that phosphine is least toxic followed by carbonyl sulphide, methyl bromide and hydrogen cyanide. Carbonyl sulphide at the rate of 15 g m^{-3} for 5 hours is very effective in controlling the target pests and caused phytotoxic damage to only two out of 12 treated cut flower species. Although phosphine (0.25 g m^{-3} for 5 hours) was least toxic to the treated cut flowers, it was not as effective in controlling the target pests (Weller and van Graver , 1998).

6.12.5.3.2. Phytoxicity

Seed germination in wheat, oats, barley and canola was not affected by COS fumigations (Wright, 2000). However, there are contradictory reports in the literature on negative effects of COS on germination of cereals except sorghum and barley, off odours in walnuts, in milled rice, and colour change in soybeans (Navarro, 2006). There has not been any adverse effect found on quality of bread, noodles or sponge cake (wheat flour), on malting and brewing characteristics of barley, or on the oil content/colour of canola (Ren et al., 2000).

6.12.5.4. Conclusion

Currently, phosphine is the fumigant of choice for grains due to its low cost, availability, versatility in application, ease of use, and global acceptance as a residue free treatment. However, major stored product insects have already developed strong resistance against phosphine in some countries and unfortunately resistance is spreading throughout the world. COS may provide an alternative in some circumstances.

6.13. Alternatives for pre-plant soils use for propagative material and nursery uses

6.13.1. Treatment of soil with methyl bromide to control pest incursions

Pests that are accidentally introduced to an area where they are not known to occur is called an 'incursion'. When an incursion of a pest occurs, such as a soil pest, disease or weed, it is important to implement a control measure as soon as possible to prevent the pest spreading. During this time, the pest is under "*official control*" and it is considered a quarantine treatment. If the spread stays restricted, the pest may stay under official control until such time that the pest is eradicated which is the ultimate goal.

Methyl bromide has been selected for many years by phytosanitary organisations to treat incursions. Treatment of soil to eliminate officially-recognised quarantine pests, either in soil transported as a substrate or treated *in situ*, is consistent with the Montreal Protocol's definition of a QPS use. Examples include:

- Soil or substrate that is either imported or exported as a commodity (to grow plants in) was sometimes fumigated with methyl bromide as a quarantine measure in Malaysia[17];
- Soil *in situ* was fumigated for controlling and containing quarantine pest, such as the pale potato cyst nematode *Globodera pallida,* which is a quarantine pest in the United States. Occurrence is limited to the State of Idaho. The movement of plant materials from the State and designated quarantined areas within the State are restricted by State Regulations[18]. In 2007 and 2008, a total of 217 tonnes of methyl bromide were used to control incursions of the potato cyst nematode (TEAP 2009);
- Soil fumigated with methyl bromide in Australia prior to 2006 to control and eliminate branched broomrape, which is an exotic quarantine pest (parasitic plant) that has a limited distribution within the country.

If the pest/disease/weed spreads rapidly then it may lose its official control status. In that case methyl bromide use is no longer considered a quarantine treatment. Methyl bromide can still be used providing an exemption is granted for this use under the CUE process e.g.,

[17] TEAp, 2009 (QPSTF Report) and MBTOC survey sof MB uses 2009 qnd 2010 Some of Malaysia's total QPS consumption of 5.05 tonnes in 2007 and 0.5 tonnes in 2009 was reported to have been used for treatment of soil as a substrate
[18] Federal Register Vol 73 No. 177, Sept 11, 2008; USDA 2007. Regulations 301.86 to 301.89

Israel use for broomrape prior to 2010. However, the CUE approval takes longer than one year during which time the pest can spread, and therefore methyl bromide is not an ideal solution for the initial control of a pest incursion.

Alternatives are being sought to replace the use of methyl bromide where it is known to not be fully effective in controlling pests or in cases where there are restrictions on its use. MBTOC is unaware of studies which report directly on the relative efficacy of alternatives to methyl bromide to manage pest incursions. However, fumigants used to the disinfest soil as a result of work in the non-QPS sector can provide guidance on the suitability of alternatives for controlling pest incursions (See chapter 4). For example, methyl iodide for the treatment of soil pests can be a viable option to replace methyl bromide in areas where methyl iodide is registered. Methyl bromide was not totally effective in controlling branched broomrape incursions in Australia alternatives to methyl bromide are now used to manage the incursions (Faithful and Maclaren, 2004). In the US, fumigants designated for use for preventing incursions are permitted to be used at rates higher than those specified on the label. This designation opens up the opportunity for the temporary use of non-MB soil fumigants to control pest incursions.

6.13.2. Treatment of soil with methyl bromide to control pests in propagated plants

Methyl bromide can also be used to control pests, diseases and weeds in soil to meet official certification standards. Treatments of soil-in-situ against endemic pests on nursery plants to meet certification standards was about 25% of the QPS consumption reported by non-Article 5 Parties (TEAP 2010). The USA is the only Party that classifies 'soil-in-situ' use of methyl bromide for certification as a QPS use. All other Non-Article 5 Parties classify such treatments as normal soil use that would require an annual CUE approval, if alternatives to methyl bromide are not available.

The treatments with methyl bromide in the US target only nematodes that are found in strawberry nursery runners, forest nurseries, turf grass, bulbs, ornamental plant nurseries and seed potatoes. The US maintains a QPS exemption for use of MB for these uses complies with 'Federal Register Rule' (FR68). This Rule covers only '*plants for planting'* that are '*moved from one distinct locality to another*' and for '*official quarantine requirements specifying that the underground portions of the propagative material must be free from quarantine pests*'. The Rule only applies to propagative material to meet official quarantine requirements of the destination to which such material in transported. However, the quarantine pests present at the source must not be present at the destination, in order to be consistent with the intent of the FAO definition of 'Quarantine' and the definition used in the Montreal Protocol.

The limited data available (Horner 1999, De Cal *et al*. 2004, Mann *et al*. 2005) indicates that methyl bromide fumigation of the soil and other fumigant alternatives cannot guarantee the soil is entirely free of pathogens, especially fungal pathogens**..** In addition, soil disinfestation with methyl bromide, whilst often being an effective tool for minimising disease levels on nursery stock, does not guarantee a reduction in disease levels to zero, but only to a low and undefined level.

Although QPS methyl bromide has not been reported for fungal pathogen control, the prospects of control to the standard required for certification appear limited. Horner (1999) showed that root material infested with *Phytophthora fragariae* could still survive MB:Pic/70:30 fumigation when placed at depths of 12 to 30cm in soil and, moreover, that these infested roots could still cause both root and crown root symptoms. They also showed that alternative fumigants, e.g. chloropicrin or 1,3-D/Pic produced similar results to the MB/Pic treatments. De Cal *et al.* (2004) isolated *P. cactorum* (in up to 7% of plants), *Fusarium* (3%), *Pythium* (2.5%), *Verticillium* (0.2%) and *Colletotrichum* (0.2%) from strawberry runners produced in soils disinfested with methyl bromide. In these examples, disease levels were higher than would normally be expected to meet certification standards for disease tolerance (usually <1% of plants affected).

Similarly, Mann *et al*. (2005) showed that hot-gas MB (100%, 60 g m^{-2}) did not eradicate consistently buried inoculum of *Fusarium oxysporum, Rhizoctonia solani, Rhizoctonia fragariae* or *Sclerotium rolfsii* placed at depths of 10, 20 and 40cm in a clay-loam soil, particularly at soil depths of 40 cm. Another study showed that injected MB:Pic (30:70, 50 g m^{-2}) did not eradicate buried inoculum of *Phytophthora cactorum, F. oxysporum, R. solani, R. fragariae* or *S. rolfsii.* Survival was generally low, mostly at depths of 20 and 40 cm in soil and was higher when samples were taken further away from the injection point for methyl bromide.

In spite of methyl bromide being used for the QPS applications above, iodomethane is seen as an alternative for these uses , particularly in locations where it is already registered for soil-in-situ (nursery production) in the USA. Further trials are being conducted to evaluate lower rates with barrier films (Mike Allen, Arysta, pers com. 2010).

Other alternatives, particularly combinations of existing alternatives including the 3 way system (1,3-D, Pic and metham), and 1,3-D/Pic are being widely adopted to replace use of MB for critical uses. Some have been used to replace methyl bromide for the production of certified plant nursery material. MBTOC notes that many countries have phased out methyl bromide and alternatives are now used for production of certified plants.

The use of substrates also offers another alternative method to methyl bromide which avoids the need for soil fumigation with any chemical to grow crops. Thus, several industries in some countries (ornamentals, cucurbits, tomatoes) have adopted soilless production to avoid the need to grow crops in soils that can harbour endemic and exotic pathogens and pests.

6.14. Alternatives for fruit and vegetables

6.14.1. Introduction – Quarantine and pre-shipment treatments

The vast majority of horticultural products globally are harvested and placed on the market without any postharvest treatment. However, a minority of the trade in horticultural products enters the market only after a treatment has been carried out on the harvested product that aims to kill any pests that are of concern. Such treatments can be important for reducing the risk of accidentally transferring pests present in the export country but not in the importing country. These treatments may be applied either pre-shipment, in-transit or on arrival depending on the phytosanitary requirements of the importing country.

Postharvest insect control treatments applied to horticultural commodities may include physical treatments (such as cold, heat, controlled/modified atmospheres, removal, irradiation, radio/microwave frequencies, pressure/vacuum), fumigation treatments with either Generally Recognised As Safe (GRAS) compounds (i.e. ozone, ethyl formate), or higher risk fumigants (i.e. methyl bromide, phosphine, sulphuryl fluoride, carbonyl sulphide, cyanogen) or insecticidal dips. Some postharvest practices currently used, such as coolstorage, can be utilised as a disinfestation treatment (or part thereof) if efficacy can be demonstrated. In addition, computing power and visual and spectral systems have now reached the point where insects can be detected "in line" (during packing), and thus fruits with insects might be excluded during packing.

An assessment in 2009 by MBTOC of the data on QPS consumption of methyl bromide reported to the Ozone Secretariat by Parties showed that 158 Parties (82%) either consumed less than 10 tonnes of QPS, or they reported zero or provided no report in 2009, or they had never reported consumption prior to 2009. Thirty Parties (16%) reported QPS consumption of more than 10 tonnes in 2009, and of these six Parties (3%) reported consumption of more than 500 tonnes (see Section 6.9.) Despite the exemption for methyl bromide for QPS, many countries have been seeking alternatives to methyl bromide for QPS because of their concerns for human health, occupational safety and environmental damage when methyl bromide is used (Kostyukovsky *et al.* 2002; Hansen *et al.* 2005).

6.14.2. Selection of alternatives to methyl bromide

The type of alternative treatment to methyl bromide that can be applied to kill insects on horticultural products tends to be specific to individual crops, cultivars, pests, markets and even growing regions. Alternatives to methyl bromide should be cost-effective, practical to apply within the logistics chain, and sufficiently effective against a wide range of insects.

This therefore requires a much higher level of knowledge that methyl bromide on the type of treatment, pests, products and how and where these fit into the supply chain for each market. New solutions are also being increasingly targeted to be "soft" solutions that leave no residues, and in some cases even reduce agrichemical residues that were applied pre-harvest.
Restrictions on residues are increasing in many markets and there has been renewed interest in utilising postharvest disinfestation treatments that do not leave residues, to control pests that have previously been controlled by residue-contributing preharvest measures, and even to decrease residues after harvest (e.g. water blasting or hot water treatments). Non-chemical disinfestation may become a marketing advantage (healthy fruit) and a valuable alternative to methyl bromide (Chevin *et al.* 2000).

Certain quarantine treatment technologies such as irradiation are not universally accepted, which slows their adoption. Other treatments such as heat or cold can be faster to implement since they are not chemicals that require registration. Area-wide pest management programs lower pest levels before harvest and improve the quarantine security provided by any postharvest treatments. These lead to "Systems Approaches" which capitalize on cumulative pest mortality from multiple control components to achieve quarantine security in an exported commodity. Standardized phytosanitary measures and research protocols are needed to improve the flow of information when countries propose to trade in a regulated commodity (Follett and Neven 2006).

6.14.3. Organic produce

Since the late 1990s there has been a strong and steady growth in the sales of organic foods. Data detailing the volume of accredited organic products have to rely on unofficial reports because of failure of official trade data to distinguish between organic and conventional products. Organic foods typically command a price premium over conventionally produced foods because of higher production costs and the tendency for demand to exceed supply. For fruit and vegetable markets in the EU, a price premium between 20-40% is common. Strict quarantine requirements put on organic products by importing countries like Japan, Korea, Taiwan, the USA and Australia mean that if insects are found, consignments are treated with methyl bromide, which cancels the organic status of the product. Alternative treatments that meet organic certification as well as phytosanitary requirements are necessary to develop supply chains for organic products.

6.14.4. Pests that restrict market access

Market access pests are those that can occur on the exported part of the plant and whose presence can result in market access restrictions. The pests that occur on the horticultural crops at harvest can be grouped in the following broad groups: thrips, scale insects, mites, mealybug, caterpillars, aphids, weevils, beetles, bugs, hoppers and psyllids. Most of these pests are surface dwelling, therefore readily exposed to disinfestation treatment. However, and some are internal pests that require an effective postharvest disinfestation treatment to penetrate the commodity.

Treatment efficacy can vary with the susceptibility of the target species/life stage, the treatment application method and the environmental conditions that prevail before, during and after treatment.

All quarantine pests can cause market access restrictions; however, often non quarantine pests cannot be readily identified from their quarantine pest relatives, and thus also cause difficulties when intercepted. Eggs and juvenile stages of pests (especially thrip, mealybug and mites) are often intercepted and unidentifiable, and therefore quarantine regulators must assume that they are the quarantine species and treat accordingly. In the future, rapid identification using molecular markers may offer a solution to this problem. Also, although dead pests should not be a quarantine concern, it is often difficult to determine if eggs, pupae and sessile insects are alive or dead.

6.14.5. Market requirements

Each importing country has its own quarantine pest list and different phytosanitary requirements. This includes the requirement for import permits, phytosanitary certificates, additional declarations and/or treatments and also any other relevant export information and documentation.

Maintenance, and even more so expansion of access to markets, requires a substantial commitment to research and development. It generally takes a number of years to develop an effective and robust disinfestation treatment, and commercialisation requires commitment and co-ordination of industry bodies, commodity packing houses, technical providers, fumigators, exporters, regulator bodies and researchers. Finally, market opportunities, actionable pests, residue limits and politics can change on a year-to-year basis and therefore there is a constant effort is required to remain current across all these factors.

6.14.6. Economic impact of alternatives

Although the cost of a replacement for methyl bromide for QPS is an important consideration, there are few published studies.

Aegerter and Folwell (2000) analysed the economic aspects of alternatives to methyl bromide for use in selected fresh fruit: apples, sweet cherries, nectarines, peaches and plums. Partial budget scenarios for each commodity were developed to determine the methyl bromide treatment costs which established a benchmark scenario to compare to the alternative treatment scenarios of each commodity. Irradiation was the only alternative identified that was available for all the fruit in the study. Cost increases for all fruit treated with irradiation ranged from two to 14 times methyl bromide costs. Controlled atmosphere storage for apples had cost increases of 122% over methyl bromide costs. Costs for regular cold storage of apples were 93% of the benchmark cost. However, the reduced costs of suppressing the pests resulted in a marketing window of only four months since four of the eight-month limit on commercial cold storage would be needed for disinfestation.

6.14.7. Process for developing of disinfestation treatments for market access

The National Plant Protection Organisation of the individual countries has the responsibility of negotiating with the overseas authorities responsible for control of imports and biosecurity to determine new or improved conditions of entry for products and the removal of unjustifiable phytosanitary barriers to trade. Negotiating access to new markets is a lengthy process involving many steps and often takes 5-10 years.

The process by which a new postharvest disinfestation treatment is developed usually involves the following key stages:

- Efficacy against a range of life stages of target pest/s found on exported commodity (time and/or dose response trials) to determine effective treatment parameters and the order of tolerance for each life stage tested;
- Tolerance of the fresh produce to a range of the treatment parameters that have been demonstrated to cause a high level of pest mortality;
- Acceptability of the treatment in the target market (includes compliance with residue limits if a Maximum Residue Limit (MRL) has been established);
- Collection of efficacy data for protocol negotiation (and registration/residue analysis if required);
- Protocol negotiation;
- Industry investment in treatment facilities, logistics and infrastructure;
- Commercialisation of the treatment.

It is important to note that some importing countries require disinfestation research to follow a more intensive and formal experimental procedure. For example, Japan requires more traditional extensive disinfestation research to demonstrate Probit 9 (99.9967% pest mortality) level mortality based on the following steps:

- Life stages found on fruit at the time of harvest;
- Cultivar chemical/fumigant sorption test;
- Susceptibility of each life stage found on fruit at harvest to treatment;
- Identification of the cultivar associated with the lowest mortality;
- Large-scale mortality test (0 live out of 30,000 of most tolerant life stage);
- Confirmation trial using semi-commercial treatment equipment;
- The quality, and hence marketability, of the commodity after exposure to the treatment;
- Gas penetration, sorption and desorption under standard disinfestation treatment; and
- Residue analysis of the commodity.

Markets such as Australia and Taiwan have a newer "Systems Approach" that is based on quantitative pest risk analysis, which includes:

- Mode of trade
- Volume of trade
- Probability of infestation at each step of the pathway:
    - Probability of pest being on fruit at harvest;
    - Probability of pest being viable (as opposed to dead or parasitized);
    - Likelihood that clean fruit are contaminated during picking and transport to the packhouse;
    - Probability of viable pest remaining on fruit during packing;
    - Likelihood that clean fruit are contaminated by pest during processing in packhouse;
    - Likelihood that pest survives palletisation, quality inspection, containerisation and transport to market;
    - Likelihood that clean fruit are contaminated by pest during palletisation, quality inspection, containerisation and transport to market.
- Probability of entry, establishment and spread in the destination country
- Assessment of the environmental, social and financial consequences if the pest were to enter, establish and spread in the destination country.

If the final probability remains below an 'acceptable allowable limit', then after being through a defined process, the commodity is allowed entry.

Maintaining market access for horticultural products is highly complex requiring both short- and long-term planning. Good communication and information exchange is a prerequisite to success and effective utilisation of resources, based on integrated approach between many teams specialised in different scientific disciplines who collaborate with industry representatives that are specialised in sourcing local produce and selling it in different export markets.

Previous MBTOC and TEAP reports have summarised existing and potential alternatives for methyl bromide for QPS. Similar to these previous reports, this chapter relies mainly on published reports from relatively few laboratories (5-6 laboratories based mainly in

Australia, New Zealand and the United States) that have published most of the information on alternatives to methyl bromide for QPS. Consistent with previous reports, Section 2 in this chapter reports mainly on research to develop alternatives to methyl bromide for QPS, and Section 3 summarises alternatives to methyl bromide that have been approved by regulatory authorities.

The following postharvest pest control treatments are mainly for pre-shipment use, but their use also for quarantine is not precluded if they have been found acceptable for this purpose by the relevant competent authorities. It is unlikely that there will be a single disinfestation treatment to cover all horticultural products. Some combination treatments are described, as these often shorten treatment duration and can reduce product damage compared to single treatments. However, combination treatments tend to be more expensive and they may require more extensive documentation to meet export protocol requirements.

Increasingly markets are demanding residue-free fresh produce. Effective non-chemical treatments are preferable to chemical treatments, which have the potential of leaving unacceptable active ingredients. Non-chemical treatments also have the advantage of maintaining the organic status of commodities after treatment.

6.14.8. Cold treatment

Cold storage is used for the majority of fresh produce to extend its postharvest life and can effectively control many pest species. An advantage of cold treatments is that they can be applied in transit. However, evidence of compliance with insecticidal, in-transit requirements of the importing country can be difficult to produce for compliance purposes. Cold treatments are generally not suitable for tropical and subtropical fruit as they are more susceptible to chilling injury. However, some cold-sensitive commodities can be preconditioned at temperatures near to the chilling threshold to enhance tolerance to a subsequent disinfestation cold storage treatment.

Freezing has rarely been tested as a disinfestation treatment as the process is well known to damage fresh commodities. However, the ability of a short pulse of freezing temperatures to shorten the cold storage period necessary to achieve effective disinfestation was tested by Chervin *et al.* (2000). Packham's pears and Pink Lady apples were not damaged when exposed to less than one day at -5°C followed by controlled atmosphere (1 to 2 kPa oxygen) and cold storage at -1°C for 2, 4 or 6 weeks. The impact of these conditions on leafroller larvae mortality was not reported.

Hansen *et al.* (2007) exposed diapausing (overwintering), diapause-destined, and non-diapausing codling moth larvae to 1.1°C in 'Fuji' apples. All non-diapausing larvae were dead within 12 weeks, diapaused-destined larvae were controlled by the seventh week, yet more than half of the original populations of diapausing larvae were still alive after 11 weeks. Diapaused-destined larvae were younger than the non-diapausing larvae, which may have made them more susceptible to cold. Because larvae normally diapause outside the fruit, cold storage would not be applicable for controlling larvae in this physiological state.

In general, the order of susceptibility for some market access pests on produce from most susceptible to most tolerant (indication of the number of days required for ~99% mortality at $0^{o}C$) is: mealybug (18-30) < lightbrown apple moth (34-76) < leafrollers (46) = codling moth (66-152) < mites (26% @ 90 days). It is important to note that effective lethal times are generally more for pests on fruit than for the same pest/life stage off fruit. Cold storage is generally a long treatment and depends on the susceptibility of the species and life stage to low temperatures.

Some fruit can be stored for many weeks before export. A 5 to 6-week air cold storage period at 0-1^{o}C has the potential to cause high mortality rates (≥ 99%) for the most cold tolerant life stages of mealybug (Dentener 1990; Waddell 1996b; Hoy 1997) the leafroller *Cnephasia jactatana* (Whiting 1998c, 2000) and lightbrown apple moth (Waddell 1996a). However, a further week or two of cold storage in CA would be required to cause equivalent mortality of the other leafroller species (Whiting 1996, 2000). Storage at 0-1^{o}C for 42 days caused 99.8% mortality of onion thrips in the absence of fruit (Yokoyama 2000).

6.14.9. Heat treatments

Heat is an environmentally acceptable but energy-intensive treatment. Applied treatments range from 40 to 50^{o}C for minutes to hours. Heat treatments are usually required to bring the core temperature of the largest fruit in the coolest part of the treatment chamber to the specified temperature and hold it for the required time. The temperature, duration and application method must be precise and uniform to kill pests without damaging the commodity.

Heat treatment is suitable for controlling internal and external pests, as the treatment penetrates in to the commodity. Heat treatments can be applied as hot water or hot air. Hot air treatments can be applied as a high relative humidity ("vapour heat") or low relative humidity heat treatment (HTFA).

Postharvest treatments using hot air or water can control insect pests on a range of crops (Jones 1995; Lester 1995; Dentener 1997) but can also damage fruit (Lay-Yee 1997). Damage is a particular problem when the target pests are inside the fruit or under the calyx, as longer treatment durations and higher temperatures are required than those necessary to kill surface dwelling pests (Lester 1995; Whiting *et al.* 1997). Although heat alone may be unsuitable for many highly perishable products such as leafy vegetables (UNEP 1998), a number of studies have shown its potential for use on more heat-tolerant commodities (Collin *et al.* 1997; Schirra *et al.* 2005; Finkelman *et al.* 2006; Hoa *et al.* 2006).

For more susceptible commodities, conditioning treatments prior to heat treatments can increase their tolerance to subsequent heat treatment (Hara 1997). However, any conditioning treatment needs to be thoroughly investigated, as the tolerance of the pest to heat treatment may also be enhanced thereby reducing its usefulness as a disinfestation treatment.

Methyl bromide treatments can damage some commodities, especially plant material in transit. For this reason, alternatives were investigated to control quarantine pests on plant material. Cuthbertson *et al.* (2009) investigated the ability of both the egg and pupal stages of the South American leafminer (*Liriomyza huidobrensis*) to survive submersion in water heated to temperatures of between 40 and 50°C for varying periods of time. Large reductions in egg viability were recorded. However, the treatments also resulted in unacceptable levels of damage to the host plant material. Pupae were killed in water at

44°C for 20 min. Pre-treatment of insect and plant material at either 5 or 20°C for 24 h before submersion in the hot water did not significantly alter the pests' ability to survive the treatments. The potential of hot water treatments to be used as an alternative to methyl bromide for plant material in transit requires further evaluation.

6.14.9.1. Hot air

Most of the hot air disinfestation research carried out use a high temperature forced air (HTFA) system (low relative humidity) system that overcomes the problem of water condensing on the surface causing commodity damage, which can occur when the vapour heat treatment is used.

The cost of heat treatments has been reported to be 6-7 times more than that of methyl bromide fumigation (USEPA 1996). In fresh produce industries, hot air treatments have been developed over many years for both tropical and subtropical fruit products. HTFA treatments have been developed and are operating as quarantine pre-shipment treatments in the Pacific region (Williamson & Williamson 2003; Waddell *et al.* 2004). Many heat treatments have been approved by regulatory authorities for disinfesting fruit flies.

An HTFA treatment is used to disinfest produce in the Pacific Islands for export to New Zealand. The standard treatment is a minimum core temperature 47.2°C for 20 min. This treatment was approved in 1994 for papaya exported from the Cook Islands; in 1996 for papaya exported from Fiji; in 1998 for papaya exported from Tonga; in 2001 for litchi exported from New Caledonia and for eggplant and mango exported from Fiji; in 2004 for papaya, eggplant and breadfruit exported from Samoa;, and recently for papaya, citrus and eggplant exported from Vanuatu. Additional crops have been approved for export to New Zealand from the Pacific Islands using heat treatment for fruit fly disinfestation, for example avocado, tomato and chilli. However, these are rarely if ever used because of the detrimental impact of the treatment on product quality.

The high capital setup costs, long treatment time, technical difficulty in achieving even product temperature, and the "batch" nature of the process restricts the use of this method for high volume horticultural exports.

The United States has approved HTFA treatment for citrus, mango and papaya (USDA 2001). Citrus from Hawaii exported to the US mainland is treated with forced air 47.2°C for 4 hours against fruit flies. Citrus from Mexico exported to the US is treated with forced air, 44°C for 100 minutes against fruit fly. Also, tangerine can be disinfested of fruit flies with forced air at 45°C for 3.5-4 hours (Shellie & Mangan 1995).

6.14.9.2. Vapour heat

Vapour heat treatment uses air saturated with water vapour whereby heat is transferred by the condensation of water vapour on the cooler fruit surface. It is mainly used for the disinfestation of fruit flies on subtropical fruit (Lurie 1998). The vapour heat treatment specification for most products is 44.5°C for 8.75 hours and then immediately followed by cooling.

Commercial facilities operate in many countries including Australia, the USA, Thailand, Taiwan, Philippines (Paull & Armstrong 1994; Jacobi *et al.* 2001). The USDA has approved vapour heat treatment for bell pepper, some citrus, eggplant, mango, papaya, pineapple, squash, tomato and zucchini. Vapour heat treatments for vegetables have been developed experimentally for tomato, bell pepper, bitter melon (Brecht 1994), cucumber and green beans (Armstrong 1994).

6.14.9.3. High temperature control atmospheres

As with cold treatment, combining high temperature with controlled atmospheres can decrease the severity of the treatment (time or temperature) while maintaining high pest mortalities (Whiting 1995b, 1999).

The relative mortality responses of leafrollers to a wide range of HTCA treatments have been identified (Whiting 1992b, 1995a; Hoy 1998; Whiting 1999). These studies showed that lightbrown apple moth (*Epiphyas postvittana*) was more tolerant of treatment than the leafroller species such as brownheaded leafroller (*Ctenopseustis obliquana*) and tolerance increased with larval maturity. A 6-h HT (40^{o}C) or HTCA (2% O_2, 5% CO_2, 40°C) was lethal to brownheaded leafroller but not to lightbrown apple moth. Combining HTCA with cold storage was necessary to kill lightbrown apple moth.

A controlled atmosphere/temperature treatments system (CATTS) has been effective in disinfesting cherries from codling moth. The system uses 1% O_2, 15% CO_2 in combination with 45-47°C and is more effective than high temperature alone (Nevin & Mitcham 1996; Nevin & Drake 2000). While no longer necessary for codling moth control on summerfruit, CATTS may have utility against other summerfruit pests. The CATTS system using 60% CO_2, 40% N_2 at 35^{o}C for an 8-hour exposure may be a suitable quarantine treatment to control western flower thrips, melon aphid, fifth instar codling moth and pupae of omnivorous leafrollers.

6.14.9.4. Hot water treatment

Hot water treatment generally involves immersing a batch of fruit in heated water for a specified time at a specified temperature. Short but high temperature hot water treatments were shown to be an effective non-chemical method for controlling fungal pathogens in citrus without human health risks associated with the chemical fungicides. The research was carried out because of increasing concern with the use of such fungicides, particularly in the diets of children, as well as concerns with widespread occurrence of fungicide-resistance isolates, with environmental problems associated with the disposal of water used in packing operations, and with the limited number of fungicides available to control rots in citrus (Irtwange 2006). The researchers postulated that the same temperatures that were used to control the fungi may also control insects on the surface of the citrus.

Longer treatments are required for internal pests such as fruit fly, to heat the whole fruit (Lurie 1998), but such longer duration treatments are likely to damage many crops. Generally, hot water treatments are more effective at the same temperature than hot air treatments, because of faster heat transfer in water and the more uniform heating of the fruit by use of high water flow, and therefore hot water generally costs less to apply (Waddell 1993). Hot water treatments also have the added advantage of reducing residues, pathogens and may remove other contaminants as well as washing off dead insects.

To minimise fruit damage and capital cost, hot water treatments should be as short as practical. The presence of air bubbles on the surface of some fruit types (especially summerfruit) or under sepals or in open cavities can provide thermal shelters for insects that substantially increase the time to kill insects. One approach to removing air bubbles is to use water jets to tumble the fruit while they are passing through the water (McLaren

1997, 1998, 1999), or to use vacuum treatments (RM McDonald and LE Jamieson unpublished).

Hot water treatments have been used commercially for persimmons and asparagus. In persimmons the key pests are leafrollers and mealybugs, but because of the nature of the calyx and disorders such as calyx cavity, there are many other "hitchhiker" insects such as slaters, centipedes, snails and spiders. Some reduction in fruit quality can occur in the fruit, primarily skin cracking. A hot water treatment of 3.6 min at 54°C was reported to be effective at disinfesting persimmons of twospotted mites (*Tetranychus urticae*). A lower temperature treatment (47°C for 67 minutes) was also effective for controlling longtailed mealybug (*Pseudococcus longispinus*) and lightbrown apple moth (*Epiphyas postvittana*) without damaging the fruit (Lester 1997b).

For asparagus, a hot water treatment followed by rapid cooling to avoid damage is used to kill thrips and remove aphids. There are also claims that the appearance of the spears is improved and the shelf-life extended. The process has been in use for more than 10 years avoiding hydrogen cyanide or methyl bromide fumigation on arrival in the import markets. Hot water treatment (49°C for 20 minutes) is used commercially to disinfest Hawaiian lychee and longans of tephritid fruit flies. This treatment has been shown to be effective against koa seed worm and litchi fruit moth, which are native to Australia (Follett & Sanxter 2001). Hot water treatment is an alternative to hot air treatment for crops such as mango with treatments of 46.1°C for 65-90 minutes depending on the variety, shape and weight of the fruit (Shellie & Mangan 2000).

6.14.10. Controlled and modified atmospheres

6.14.10.1. Controlled atmosphere cold storage

Coolstorage can be applied in combination low oxygen and/or high carbon dioxide atmospheres and this is referred to as controlled atmosphere (CA) cold storage. When cold storage is combined with controlled atmosphere, the time to cause high pest mortality can be further reduced (i.e. leafrollers – Whiting *et al.* 2000) in most cases, but not always (i.e. greedy scale insects - Jamieson *et al.*2009a; Whiting *et al.* 2003). Specific controlled atmosphere facilities need to be utilised for this treatment.

Scientists not only look for new treatments but also ways to minimise the dosage of methyl bromide in order to reduce the environmental damage caused by this gas as much as possible. Navarro *et al.* (1999) showed that the addition of CO_2 halved the amount of MB required to kill larvae when compared with MB without CO_2. The amount of methyl bromide could be reduced still further at elevated temperatures.

Neven (2005) used a combination of short-duration high temperatures under low oxygen, elevated carbon dioxide atmospheric environment to control codling moth in sweet cherries, *Prunus avium* (L.). The two treatments developed are a chamber temperature of 45°C for 45 min and a chamber temperature of 47°C for 25 min under a 1% oxygen, 15% carbon dioxide, -2°C dew point environment. Both these treatments were shown to provide control of all life stages of codling moth while preserving commodity market quality. The third and fourth instars of codling moth are equally tolerant to CATTS treatments and are the most tolerant immature stages to these treatments. The results showed that low levels of oxygen were more important than elevated carbon dioxide in achieving high levels of insect mortality. Large-scale efficacy trials of both treatments resulted in 100% mortality of 5,000 third instars of codling moth in each treatment. These treatments may be used to provide quarantine security in exported sweet cherries where codling moth is a quarantine concern and fumigation with methyl bromide is not desired.

The ability of cold storage to control pests can be improved when cold storage is combined with controlled atmospheres. The more cold tolerant species include codling moth, mites, apple leafcurling midge. The most cold tolerant life stage of codling moth was the fifth instar larvae programmed for diapause, which required between 66 and 152 days of storage at 0.5°C for 99% mortality. There is not much information on efficacy of cold storage against mites.

Some mite species (e.g. twospotted mite) enter a diapausing state over winter and these are very tolerant to cold storage. Over 200 days is required for high mortality of diapausing two-spotted mites at 4°C, while at 0°C only 26% mortality was recorded after 90 days at 0°C. Mortality after 90 days of storage can be increased to 71% if CA is combined with cold storage at 0°C. A cold storage period of 25 days reduces the emergence rates of apple leaf-curling midge adults to 27%. However, cold storage will not be an option for a stand-alone mitigation treatment to reduce apple leaf curling midge infestations to below phytosanitary levels. A CA cold storage period of 59 days has potential to kill adult wheatbug (Waddell 1988).

The efficacy of standard cold storage (SCS) and controlled atmosphere cold storage (CACS) against armoured scale insects depends on the species of scale insects that is targeted and the assessment criteria that are used. Armoured scale insects are immobile except for their short duration crawler stage, and assessment of whether scale insects are alive or dead is a challenge. Some researchers assess a discoloured scale insect body as dead, while others wait until the scale insect body is dried up until it is classified as dead. Morgan (1967a) reported the first instar black caps stage of *Quadraspidiotus perniciosus* as being most tolerant to cold temperatures, requiring 110-140 days for complete mortality at 0°C, with CA storage having no apparent increase in efficacy (Chu 1992). Waddell *et al.* (1989) found that complete mortality of a mixture of armoured scale species on kiwifruit was achieved in 56 days, while Whiting (2000a) found that 81.4 days was required for 99% mortality of a similar composition of species on kiwifruit. Recently, using a combination of physical characteristics and a biochemical enzyme-based test to classify live and dead scale, Jamieson *et al.* (2009a) found that 40 and 49 days at 0°C were required to achieve 99.5% mortality of greedy scale on kiwifruit, using the biochemical test and physical characters as assessment criteria, respectively.

Australian pome fruit exports to northern America and Japan are rejected if they contain lightbrown apple moth (*Epiphyas postvittana*) or codling moth (*Cydia pomonella*) respectively. A warm CA disinfestation treatment (72 h at 28°C at 0, 1 or 2 kPa), followed by varying lengths of cold storage (5 weeks, 10 weeks or 6 months), was tested by Chervin *et al.* (1999). Four cultivars were studied: Packham's Triumph pears; Royal Gala, Fuji and Pink Lady apples. Consumer panels found that fruit subjected to the 2 kPa warm CA treatment and cold storage were as acceptable as untreated fruit. This is an important finding as previously published results for a harsher treatment described treated fruit (especially Pink Lady) as being less acceptable than untreated fruit. Some advanced ripening was observed for treated Packham's Triumph pears. After 5 and 10 weeks cold storage, treated Royal Gala apples were generally firmer than the controls. Insects were also subjected to the 2 kPa warm CA treatment. The most tolerant life stage (MTS) of lightbrown apple moth was the sixth instar with an LT_{95} of 37 days cold storage (0.5°C) after the 2 kPa warm CA treatment. Comparison with previous research suggests that the 2 kPa warm CA treatment approximately halved the time required in cold storage for effective control of late instar lightbrown apple moth. An LT_{95} of 81 days was achieved for fifth instar codling moths (considered to be the MTS) and this may need to be reduced for export to Japan. Preliminary observations suggested that there may not be a substantial difference between the mortality response of non-diapausing and pre-diapausing codling moth larvae to the warm CA followed by cold treatment.

6.14.10.2. Ambient controlled atmosphere treatments

CA treatments at ambient have been used for many years to prolong the storage life of many commodities and to control pests, in particular in grains and nut crops. Research has demonstrated its efficacy against pests for fresh commodities (Mitcham 1997). In general, the most effective CAs at ambient were below 1% O_2 and above 20% CO_2 for insect control.

Most insecticidal treatments using CA require long exposures. For example, six days were required to control flower thrips (*Thrips obscuratus*) on kiwifruit flowers at 2% O_2, 18% CO_2, 20°C (Potter *et al.* 1994) while carbon dioxide concentrations of >30% at 20°C were shown to kill onion thrips (*Thrips tabaci*) on onions after at least 24 hours of fumigation (Page 2002). These long treatment times may not be acceptable for some markets as they miss the period of highest market prices. In addition, prolonged exposure to low O_2 and/or high CO_2 has a detrimental effect on some fresh fruits.

6.14.10.3. Heated controlled atmosphere treatments

Codling moth, *Cydia pomonella* (L.), and oriental fruit moth, *Grapholita molesta* (Busck), are serious pests of apples (*Malus* spp.) grown in the United States and other countries. In countries where these species are not found, there are strict quarantine restrictions in place to prevent their accidental introduction. The treatment used in by Neven and Rehfield-Ray (2006) consisted of hot, forced, moist air with a linear heating rate of 12°C/h to a final chamber temperature of 46°C under a 1% oxygen and 15% carbon dioxide environment.

They found that the fourth instar of both species was the most tolerant to the treatment, with equal tolerance between the species. Efficacy tests against the fourth instar of both oriental fruit moth and codling moth using a commercial CA temperature treatment system chamber resulted in >5,000 individuals of each species being controlled using the combination treatment. Confirmation tests against codling moth resulted in mortality of >30,000 fourth instars. These treatments may be used to meet quarantine restrictions for organic apples where fumigation with methyl bromide is not desirable.

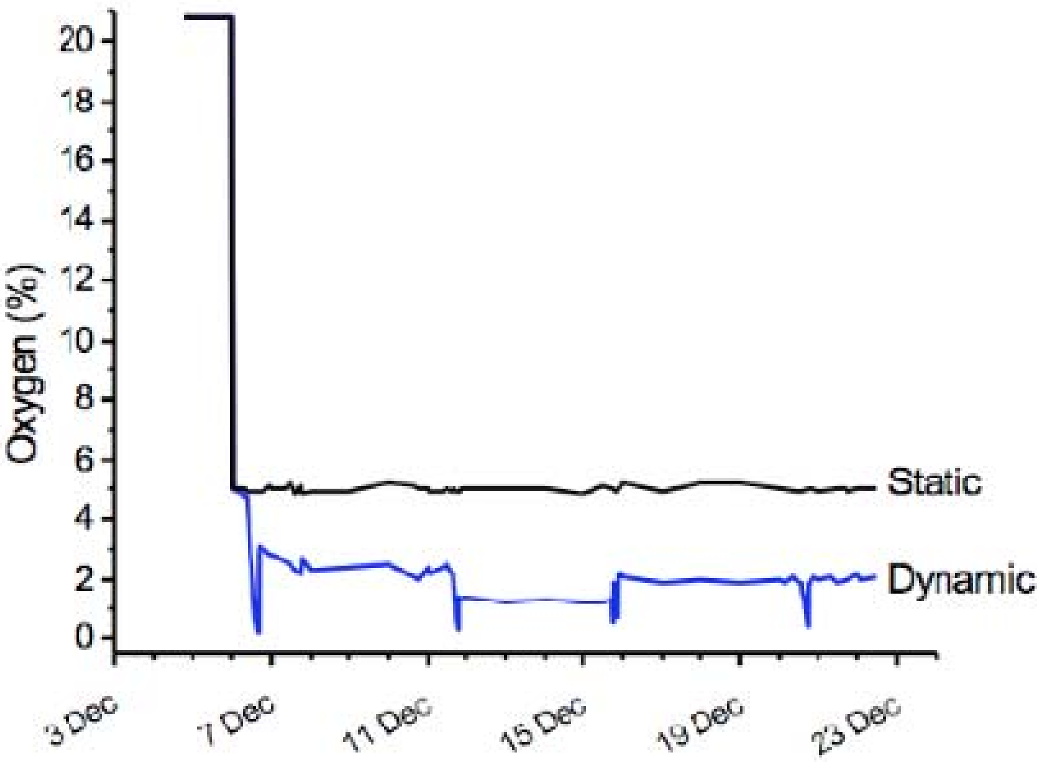
Non-chemical quarantine treatments, using a combination of short duration high temperatures under low oxygen, elevated carbon dioxide atmospheric environment were also developed by Neven and Rehfield-Ray (2006) to control western cherry fruit fly, *Rhagoletis indifferens* Curran, in sweet cherries, *Prunus avium* (L.). The two treatments developed used a chamber temperature of 45°C for 45 min and a chamber temperature of 47°C for 25 min, both under a 1% oxygen, 15% carbon dioxide, -2°C dew point environment. Both these treatments were shown to provide control of all life stages of western cherry fruit fly while preserving commodity market quality. No specific egg or larval stage was the most tolerant to either CA temperature treatment system treatment. Efficacy tests for both treatments resulted in 100% mortality of > 5,000 western cherry fruit flies in each treatment. With further research, these treatments may provide quarantine security for exported sweet cherries where western cherry fruit fly is a quarantine concern and fumigation with methyl bromide is not desired.

Shellie *et al.* (2001) exposed 'Bing' cherries to 45 or 47°C in an atmosphere of 1% oxygen with 15% carbon dioxide (balance nitrogen). Heated cherries had similar quality to non-heated or methyl bromide fumigated cherries. The results suggested that 'Bing' sweet cherry tolerated heating in an atmosphere of low oxygen containing elevated carbon dioxide at doses that may provide quarantine security against codling moth (*Cydia pomonella*) and western cherry fruit fly (*Rhagoletis cingulata*).

6.14.10.4. Dynamic CA/Ultra low oxygen

CA treatments are usually managed according to a pre-determined oxygen level that is maintained throughout storage irrespective of different fruit responses that can exist in different seasons, cultivars and harvest times. A recent development in CA research is dynamic CA, which has been investigated with the support of various industries such as apples. Dynamic CA/Ultra low oxygen (ULO) is a process whereby the oxygen level is matched to the physiological state of the fruit and the atmosphere is changed based on feedback from the fruit response, which is set just above the low oxygen stress point (Figure 38). This allows the minimum oxygen that gives the best quality fruit with minimum risk of injury to the fruit. With the advent of these more "advanced" CA protocols that run at significantly lower O_2 concentrations (i.e. $\leq$ 1% O_2 compared with 2-3% for standard static CA conditions), there is the potential that greater insect mortality may be achieved during cold storage and/or as pre-treatment at ambient or higher temperatures (Dentener 2002).

FIGURE 38. OXYGEN PROFILE DURING DYNAMIC CONTROLLED ATMOSPHERE (CA) STORAGE COMPARED WITH STANDARD STATIC CA CONDITIONS



Liu (2007) determined the impact of ULO treatment on western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) on broccoli at 1°C. Complete mortality was achieved in 5 days at 0.003% oxygen. Oxygen level affected the insecticidal nature of the ULO treatment. At a 10-times higher oxygen level of 0.03%, the 6-d treatment killed ~85% of thrips, and 10-d treatment killed all thrips. The 5-d ULO treatment with 0.003% oxygen was successfully tested on iced commercial broccoli of several cultivars without any noticeable negative effects on shelf-life and postharvest quality. The ULO treatment provided a safe and effective alternative to methyl bromide fumigation for postharvest control of western flower thrips on exported broccoli.

6.14.11. Removal

There is a range of techniques that can be used to remove insects from fruits physically. A significant advantage of treatments that remove insects compared with those that simply kill insects is that absence of insects on arrival in overseas markets means that the product line is much more likely to pass official phytosanitary inspection.

6.14.11.1. Brushing

Use of rotating brushes during packing (generally prior to quality checking and grading) is a common practice in most fruit crops. This is carried out either on dry brushes or with lightly wetted brushes. Such treatments remove dirt and other material from fruit, and in doing so they also remove exposed pests such as thrips, mites, beetles and Collembola

(Stevens 1997). However, they will not remove insects and mites that are well protected by either their structure e.g. scale insects or insects within cocoons fastened to the surface, or because they are protected by coverings or location in crevices or structures of the fruit e.g. under calyx.

6.14.11.2. Water blasting

There have been a number of developments of water blasting (or high pressure water washing) systems for fruit products. These can be carried out for longer durations (10-20 seconds) over rotating brushes, or for very short times without brushes. It appears from published information that the first water blasting of fruits was developed in South Africa in the 1970s by L.J.K. Theron (Honiball 1979). This was then taken up by other countries and further research was published in the USA (Walker 1996, 1999).

6.14.11.3. Moderate pressure high volume

Moderate pressure / high volume water systems were developed successfully for citrus to dislodge scale. These washers been used in a number of countries including the USA, Israel and South Africa. Walker *et al.* (1999) used the FMC Freshgard 4000 system (FMC Corporation, Riverside, CA) to remove California red scale (*Aonidiella aurantii*). The washer consists of eight banks of two manifolds per bank to which nozzles are attached (total of 16 manifolds). The banks are 12.7 cm apart, and the nozzles in each bank are 17.8 cm apart, with the nozzles 21.6 cm above the brushes. They found that the optimum treatment was 325 psi for ≅ 20 seconds. Higher pressures resulted in unacceptable external damage to the fruit.

Rush Heath developed a similar system for apples but operating at significantly lower pressure (<120 psi), and more than 30 units are operating. This system is patented in the USA (http://www.freepatentsonline.com/5775348.pdf). The system operates at 50-120 psi for 10-15 seconds over rotating brushes. This treatment was first developed for disease reduction and cleaning up apples in Washington State (Bai *et al.* 2006).

An apple washing treatment using moderately-pressurised water is applied to nearly all apples exported from New Zealand. It achieves up to 90% removal of mealybug as well as reductions in woolly apple aphid (WAA), scale, leafcurling midge, mites, leafrollers and a range of hitchhikers such as weevils and spiders, without causing apple damage (Walker J Plant and Food Research New Zealand *pers com.* 2005). Recent work has aimed to standardise this treatment and the target is 80-120 psi for 13-17 seconds over rolling brushes (Rogers 2006).

Although water blasting is generally carried out using cold water, the value of killing and removing mould spores and insects using hot water and additives was examined in Hood River, Oregon in 2001 (Bai *et al.* 2006; Hansen *et al.* 2006; Neven *et al.* 2006; Spotts *et al.* 2006).

6.14.11.4. High pressure water washer

A high-pressure apple washer was developed in New Zealand that oriented fruit and sprayed them with a much shorter (generally 0.5 to 1 second) higher pressure water treatment. Each fruit was individually rotated and sprayed with jets of water from three directions to remove any pests that might be on the fruit (McDonald RM 1999: NZ Pat. 314528 "Washer"). The washer removed the random element in previous washer designs that rely on a prolonged period of semi-random movements of fruit.

Research in New Zealand in the 1990s examined the use of water washers on apples, kiwifruit and avocado (Whiting 1998ac; Jamieson 2000). This research used water under high pressure (400-2000 psi). The fruit were rotated accurately, thus ensuring a great accuracy of coverage and pest removal efficacy. Use of high pressures (500 and 800 psi for 1 or 2 seconds) was shown to remove a substantial proportion of lightbrown apple moth and mealybug removal from apples, despite artificially high infestations (Whiting 1998a). Scale insects proved difficult to remove from kiwifruit, even at 2000 psi with a hot water drench (55-65°C) for 30 seconds before water blasting(Whiting 1998b). While useful for disinfestation, this high pressure system that rotates fruit is technically more challenging and tends to have lower throughput and higher capital and running costs, than other more simple fruit washers.

One crop where higher pressure low volume treatment has proved to be successful is avocado (Woolf 1998, 1999; Jamieson 2005). This work was targeted at removal of leafroller egg rafts, the key quarantine pest for export to Australia. However, it was also very effective at removing all crawling insects (leafrollers, thrips and mites (Jamieson 2000). Optimum treatment was 1 second with two fruit rotations, and a pressure of ≅ 800 psi. Water blasting is also very effective in removing pine pollen (*Pinus radiata*) from the base of fruit, and spray residues. Two packhouses have been running water blasting for the last decade, others have recently installed units. Nearly all packhouses will have units by 2011 as it is now a requirement for avocados entering the USA.

6.14.11.5. Air-blasting

Air blasting has been used in the past on green kiwifruit for insect removal (primarily mites, John White, pers. comm.). Any current commercial use is not known. A key limitation is that large compressors are expensive. An additional challenge is that efficacy of the air-flow decreases rapidly with distance, more so than for water blasting. Thus, differences in fruit size and orientation will have more impact on insect removal.

6.14.12. Irradiation

Various forms of irradiation have been investigated as disinfestation treatments. The three major forms are gamma irradiation, electron beam, and x-ray. Gamma irradiation is generated from radioactive isotopes, which causes public concern with the safety of isotope transport, long-term storage and facility location. Electron beam irradiation does not use radioactive material, and therefore does not have the same public concerns. Gamma irradiators have better penetration and can treat packaged or bulk products, while electron beam accelerators more effectively treat products in thin layers (2-5 cm thickness). X-ray irradiation has better penetration than electron beam. However, the technology using X-rays is a recent development for disinfestation and published reports more limited than for research based on gamma and electron beam.

Irradiation has been shown to be the most efficient and least damaging method to treat some fruit (Hallman 1998; Hallman & Thomas 1999). Generally, doses from 0.05 to 0.2 kGy are sufficient for quarantine security, but the exact dose varies with the insect being targeted. The USDA-accepted treatment dose for fruit flies is 75-150 Gy. However, other insects, such as moths, require a dose of ~250 Gy (Corcoran 2001). At these doses the insects are not necessarily killed but will not continue development (Morris & Jessup 1994). In these cases, evidence of exposure to irradiation is required to satisfy phytosanitary inspectors that the insects although alive are sterile and present no biological risk.

The advantage of irradiation is that the treatment is fast, residue-free and fruit can be treated in the final packaging. Three challenges exist with using irradiation as a quarantine treatment. Firstly, compared with other treatment options the capital costs of irradiation are high, which means treatments must be made in a few central locations. Secondly, irradiation can render the pest stages sterile, rather than dead, leaving the government or quarantine inspector uncertain as to whether the insects were exposed to irradiation, whether all the insects were treated, or whether the pest entered the commodity following irradiation.

Thirdly, irradiation does not have regulatory approval as a food treatment in all markets and has poor consumer acceptance in some, although this is changing and may be less of an issue in the future. In the past, consumers have been concerned with food safety issues relating to irradiated products.

A number of studies have investigated the potential of irradiation as a disinfestation treatment of plant products (Halfhill 1988; Jessup 1990; Johnson 1990; Heather 1991; Miller & McDonald 1996; Follett & Sanxter 2000; Follett 2004; Gochangco *et al.* 2004; Gould & Hallman 2004; Hallman 2004; Hamidah *et al.* 2004; Shafqat *et al.* 2006; Follett 2007; Wall 2007). Research has indicated that many types of fresh fruits and vegetables can tolerate the radiation doses required for quarantine purposes.

USDA-APHIS-PPQ approved irradiation of imported product as a phytosanitary treatment for 11 species of fruit fly and for mango seed weevil, regardless of the host product, at doses of between 0.1 and 0.30 kGy. In addition, Food Standards Australia New Zealand (FSANZ) approved irradiation at 0.15 -1.0 kGy for pest disinfestation of some fresh tropical fruits.
USDA-APHIS-PPQ also approved irradiation quarantine treatments including Surebeam® electron beam and x-ray irradiation to disinfest Hawaiian tropical fruits for export to a number of countries. The US mainland has approved imports from Hawaii, Thailand, India and Viet Nam and is the lead country in terms of acceptance of this technology. The schedule requires a minimum dose of 250 Gy and a maximum of 1,000 Gy, with documented dose mapping for each commodity, fruit size and box configuration. Additionally, irradiated commodities are to be safeguarded after treatment to ensure that they do not become re-infested (Dowdy 2005).

MAF NZ approved in 2004 the import of irradiated fruit into New Zealand. The import of mango, papaya and litchi from Australia is approved following exposure to a minimum dose of 150 Gy for fruit fly host material and 250 Gy for other regulated arthropod pest species. Similarly, imports from the US are approved for papaya only at a minimum dose of 150 Gy.
Examples of research illustrate the work that contributed toward regulatory acceptance of irradiation as a quarantine treatment. Adamo *et al.* (1996) showed ionizing radiation could be used as an alternative to methyl bromide to control the Mediterranean fruit fly (Medfly) in oranges. The effect of irradiation on the chemical composition of the fruit was also determined. At doses of 300, 400, 500 and 700 Gy, ionization was lethal to all life stages of Medfly, without producing unfavourable changes in the chemical composition of the fruits.

The advantages of the technique over chemical methods are that penetration of the energy is uniform and deep, guaranteeing disinfestation even in the centre of the fruit, but without undesirable residues characteristic of chemical treatments. It can be used on fruits which are already wrapped, thereby preventing recontamination. It is recommended that a minimum dose of 300 Gy is used to guarantee fruits pest-free for quarantine purposes.

Oriental fruit moth (*Grapholita molesta*) is a pest of many rosaceous temperate fruits, including apples and stone fruit in much of the world. However, some areas are free of the pest, and shipments of fruit hosts from infested to non-infested areas may be regulated. Current quarantine treatments for oriental fruit moth include methyl bromide fumigation and cold storage for several weeks. Cold is not tolerated by many hosts of oriental fruit moth. Hallman (2004) examined the potential of irradiation as a quarantine treatment against the pest under ambient and hypoxic storage conditions because some hosts of oriental fruit moth create hypoxic atmospheres inside the fruit where the pest resides. Hypoxia is known to lessen the impact of irradiation. In ambient atmospheres, no adults emerged from 58,779 fifth instars (the most radio-tolerant stage present in fruit) irradiated with a target dose of 200 Gy (195-232 Gy measured). In atmospheres low in oxygen that had been flushed with nitrogen, 5.3% of adults emerged from 44,050 fifth instars irradiated with a target dose of 200 Gy (194-230 Gy measured), but they died at a faster rate than control adults and without laying eggs. A dose of 232 Gy (the maximum recorded when 200 Gy was targeted) was recommended to disinfest any fruit of oriental fruit moth under ambient and hypoxic atmospheres.

Lester and Barrington (1997) examined the potential of irradiation as a quarantine treatment for eggs and larvae of the leafroller *Ctenopseustis obliquana*, a pest of fruit in New Zealand. They found that 1-day-old eggs were more radio-sensitive than 5-day-old eggs, requiring 55.9 Gy and 269 Gy for 99% mortality, respectively. Effective disinfestation of *C. obliquana* could be achieved with a dose as small as 70.1 Gy, which would inhibit any oviposition by adults developing from irradiated 1-day-old and 5-day-old eggs, and 1st, 3rd and 5th-instar larvae. Further quarantine security for these life stages could be achieved with a dose of 150 Gy which would inhibit adult emergence, or 215 Gy which would inhibit larvae from entering pupation. As these doses are unlikely to damage host fruit, gamma irradiation provides a potential alternative to methyl bromide fumigation.

Neven and Drake (2000) irradiated Bing and Rainier sweet cherries at 300 Gy, followed by storage at 1°C for 0, 7 or 14 days. Irradiated cherries had better overall quality than methyl bromide-treated cherries, which suggested that irradiation had potential as an alternative quarantine treatment to methyl bromide.

6.14.13. Radio frequencies and microwaves

Radio-frequency (RF) and microwave energy are sources of heat that involve the application of electromagnetic energy at 10-30,000 MHz. Because of the congested bands of radio-frequency and microwaves already being used for communication purposes, regulatory bodies have allocated five frequencies for industrial, scientific and medical applications: 13.56, 27.12, 40.68 MHz in the RF range and 915 and 2,450 MHz in the microwave range.

Both hot air and hot water systems have been used to control pests in a number of subtropical and tropical fruits. However, because of the heat-sensitive nature of fruit, a small deviation from the required parameters can result in either product damage or insect survival (Armstrong 1994). It is important to develop effective means to deliver thermal energy uniformly to every part of the fruit where insect pests may reside, to shorten treatment time and minimize thermal impacts on the fruit quality. RF heating has the advantage of fast core heating of fruits because of direct interaction between the RF energy and the fruit tissue to raise the centre temperature quickly, especially for large fruits. Pilot-scale RF systems have been used in research on postharvest insect control in fruits and nuts and have been suggested for control of market access pests (Andreuccetti *et al.* 1994; Hallman & Sharp 1994; Nelson 1996; Ikediala *et al.* 1999; Tang *et al.* 2000; Wang *et al.* 2001; Wang 2002; Birla *et al.* 2004; Mitcham *et al.* 2004; Mitcham *et al.* 2005).

At some wavelengths being studied, insects can be selectively heated without adversely heating the fruit (Schneider *et al.* 2003). By oscillating the voltage RF, heating can deliver lethal energy to insects and microbes without disturbing or damaging the host material. Researchers in the USA have patented this novel approach. RF Biocidics in California is developing and commercializing this technology. The RF heating system takes advantage of the high electrical conductivity of arthropod pests and the generally low electrical conductivity of the host commodities. The advantage of lower frequencies in terms of the type and efficiency of RF interactions with different materials has been demonstrated. Research using RF has focused mainly on food safety, but it has also proven effective for insect control. The technology is considered ready for use on dry food and grain products but more research is required for fresh produce application. Both RF and microwave treatments leave no chemical residues on commodities and have no known impact on the environment (Ikediala *et al.* 1999; Wang *et al.* 2001).

RF and microwave treatments to control pests on various commodities have mainly focused on control of beetles and moth larvae. Treatments at 27 or 2,450 MHz at temperatures between 43 and 55°C for 30 s to 5 min have been reported to control specific pests (Nelson & Payne 1982; Tang *et al.* 2000; Wang *et al.* 2001; Lagunas-Solar *et al.* 2007; Birla *et al.* 2008a). For internal pests, RF has been used in combination with water immersion to obtain uniform temperature increases in both the core and surface of the commodity (Ikediala 2002; Tiwari 2008). In New Zealand, Dentener *et al.* (2000ab) showed that RF treatment at 40.68 MHz caused high levels of insect mortality for a range of apple pests (inside and outside fruit). Unfortunately, the treatment was associated with fruit damage. Further preliminary trials with improved electrode plate configuration indicated that fruit quality issues could be addressed (Dentener P HortResearch unpublished data).

Birla *et al.* (2005) reported that heat treatments significant changed the volatile flavour profiles of Navel and Valencia oranges, even when there was no significant difference in the other quality parameters. The reduction in process time due to RF heating helped to retain many of these volatile compounds (a positive impact) in comparison with conventional hot water heating. The treatment used RF to raise the temperature of the fruit held in saline water from 19 to 48°C, and then held them for 15 min at 48°C. This treatment would meet quarantine security without impairing the quality of the treated oranges. However, taste tests to determine market acceptability of treated oranges need to be carried out to determine the commercial acceptability of the treatment.

Wang *et al.* (2006) explored the application of RF in conjunction with conventional hot water treatment to develop feasible heat treatments. Treatment parameters were selected based on minimum time-temperature conditions required for 100% mortality of fifth-instar codling moth. The treatments included pre-heating of infested or uninfested apples in warm water at 45°C for 30 min. The pre-heated apples were then heated to 48°C in a hydraulic fruit mover placed between two parallel plate electrodes in a 12 kW, 27.12 MHz pilot scale RF system. RF-treated apples were transferred to a 48°C hot water bath and held for 5, 10, 15 and 20 min before being hydro-cooled in ice water for 30 min. The mortality of codling moth in the infested apples was assessed, and the quality of the other apples evaluated by measuring weight loss, firmness, colour, soluble solids content, and titratable acidity after 0, 7, and 30 days of storage at 4°C. The results showed that the treatment at 48°C for 15 min was the most practical and effective both for insect control and apple quality.

To examine a potential alternative to MB fumigation, Hansen *et al.* (2005) infested 'Bing' sweet cherries with a codling moth larva, submerged them in water at 38°C water for 6 minutes pre-treatment, then exposed them to various temperatures generated by RF and held at that temperature for different times: 50°C for 6 minutes, 51.6°C for 4 minutes, 53.3°C for 0.5 minutes, and 54.4°C for 0.5 minutes. Insect mortality was evaluated 24 h after treatment and the fruit quality was evaluated after 7 and 14 days of storage at 1°C. No larvae survived the 50 and 51.6°C treatments. Fruit colour of non-infested cherries was darkened as temperature increased. Stem colour was severely affected after 7 days storage, even in a warm water bath of 38°C for 6 minutes, as was fruit firmness using the same treatment. Fruit quality loss increased after 14 days of storage, compared to after 7 days of storage. The amount of pitting and bruising of cherries increased with temperature and again this increase was more evident after 14 days of storage.

Ikediala *et al.* (2002) exposed 'Sweetheart' sweet cherries (*Prunus avium*) immersed in 0.15% saline water to RF energy. The dielectric and ionic conductivity properties of the immersion water and that of fruit were matched to obtain a relatively uniform temperature distribution within and among fruits during RF heating. With immersion in saline water of 0.15% NaCl, the mean temperature of the water and that of the cherries differed by <=0.6°C, while the maximum temperature variation within and among fruits determined within one minute after RF treatment was completed was less than ± 1.0°C of the target temperatures of 48 and 50°C. The saline water immersion technique helped to reduce variation in temperature within and among fruits which was characteristic of hot air treatments. More than 99% mortality of the 200-400 codling moth (*Cydia pomonella*) larvae or 589-624 eggs was obtained at 50°C when treated for between 7 and 10 minutes (heating 2-5 minutes and holding 5 minutes). Most quality parameters analysed were better, or were comparable with methyl bromide fumigated fruit. Saline water immersion treatment in RF may be used to overcome the problem of slow conventional hot air or water heating, as well as the non-uniformity of temperature associated with electromagnetic heating in air, when developing alternatives to methyl bromide for quarantine treatment of fruit.

6.14.14. Pressure treatments

Pressure techniques (mainly below barometric pressure – vacuum) have been investigated as a means for pest control on commodities for many years.

A new pressure-based method for rapid and effective insect and mite control that combines pressure, controlled atmosphere and volatiles, is under development by the University of California and Plant & Food Research in New Zealand. The method is known as 'metabolic stress disinfection and disinfestation' (MSDD) and is a novel concept whereby physical and volatile treatments are combined to disinfest plant products. The MSDD treatment is applied in a closed chamber and involves a rapid sequence of alternating pressure above and below barometric pressure cycles, creating mechanical forces using CO_2 as ballast to remove further ambient and cellular oxygen, causing a reduction of cellular pH acidosis in the fruit. This first phase of the MSDD treatment is referred to as the physical phase, at the end of which a second phase (volatile phase) is applied at reduced pressure, whereby a low concentration of a volatile chemical is introduced.

Research has shown that MSDD is effective in controlling microbial and arthropod pests without detrimental effects on the commodity, and the process is rapid, effective and applicable to a range of commodities (Lagunas-Solar *et al.* 2006). The treatment takes short periods of time (hours rather than days). However, as this technique remains in the development phase, further research will be required before its commercial value can be assessed.

Hulasare *et al.* (2003) studied the effect of low pressure on the mortality of eggs of *Rhagoletis pomonella* (apple maggots) in apples by exposing apples infested with the maggot to a low pressure of 25 mm Hg at 25°C. Mortality of all life stages increased with increasing temperature. The eggs were the most tolerant among the developmental stages, requiring pressures as high as 300 mm Hg for 100% mortality at 30 and 37.5°C. A practical treatment of 2-5 days can be achieved with 75 mm Hg at a typical ambient temperature of 22.5°C, but cooler temperatures required several more days for substantial mortality. Low pressure may therefore be a viable alternative to methyl bromide for the postharvest treatment of fresh fruit.

6.14.15. Fumigation Treatments

Fumigation is a widely used treatment employed to eliminate pests from a range of commodities including fruits and vegetables. During fumigation, a chemical with a high vapour pressure is introduced into a closed space and maintained at a certain level for a minimum time. CT (concentration x time) product values are determined by the length of time required for the chemical to permeate the material, and the minimum dosage required to eliminate the target organism(s).

6.14.15.1. "Generally Recognised As Safe" fumigants

A 'Generally Recognised As Safe' (GRAS) status for a compound is determined by the US Food and Drug Administration. GRAS compounds are considered safe for use with human food (Anon 1993a). The advantage of treatments utilising GRAS compounds is that they are already accepted by the USDA-APHIS-PPQ after a series of strict criteria have been satisfied. GRAS substances may therefore be excluded from mandatory premarket approval by the United State Food and Drug Administration (Hallagan & Hall 1995) when used on produce to control pests.

6.14.15.1.1. Ethyl formate

Ethyl formate is a plant volatile. It is classified as a GRAS compound and therefore considered safe for use in conjunction with food (Anon 1993a). Residues of ethyl formate break down to formic acid and ethanol. Ethyl formate is flammable and explosive when mixed with air at concentrations required to kill pests, but formulations in CO_2 reduce this risk significantly. Ethyl formate is currently registered in Australia, Switzerland, Italy, United Kingdom, United States, Germany, Canada and New Zealand. VAPORMATE™ (16.7 wt% ethyl formate dissolved in liquid CO_2) is registered and used through other regions.

Ryan *et al.* (2003) tested VAPORMATE™ against a range of insects. Adult mealybug and adult two spotted mites were controlled using 10-20 g/m^3 of ethyl formate for 2 - 4 h at 20^{o}C. A 2-h exposure to 5 g/m^3 showed promise against western flower thrips on flowers. Larvae of lightbrown apple moth and larval/cocooning stages of apple leaf curling midge were killed by a 6-hour exposure to 10 and 40 g/m^3 ethyl formate respectively (Page 2004; van Epenhuijsen 2005). Mites can be controlled by exposure to 99-132 g/m^3 ethyl formate for 1 h or a 2-6 h exposure to 20 g/m^3. Ryan *et al.* (2003) also reported that treatment of 35 g/m^3 ethyl formate at 18^{o}C caused 98% mortality of onion thrip adults on onions. However, eggs were more tolerant to the fumigation (van Epenhuijsen 2007). Mortality of 98-100% of scale insects and mealybug was obtained after a 2-h exposure to 142 g VAPORMATE/m^3 at 20°C (Jackman 2008).

Zhang *et al.* (2003ab) found that lettuce was damaged by VAPORMATE™ at the rate of 180 g/m^3 particularly when exposed for more than 2 hours. However, the recommended label rate is 120 g/m3 for 1 hour which is not reported to have any phytotoxic effects (K. Harder, BOC Gases pers. comm.). Moreover, liquid ethyl formate seems to be more phytotoxic than when in its vaporised state so vaporising Vapormate™ before applying to the fumigation chamber could help prevent phytotoxicity. Bananas can tolerate 6 h of exposure at 20 g/m^3 (Ryan *et al.* 2003), and onions can tolerate 60 g/m^3 without damage.

Kiwifruit were exposed to VAPORMATE at 3.7-6.5 times (523-885 g/m^3) the rate for controlling scale insects (142 g/m^3) and not surprisingly there was a reduction in fruit quality (Jackman 2008). The impact of lower rates on kiwifruit after storage has not been investigated. However, there was no evidence of any phytotoxic reaction to VAPORMATE™ on the kiwifruit at the rate of 142g/m^3 when checked 24 hours after fumigation (Jackman 2008). VAPORMATE™ uses CO_2 as a carrier gas for ethyl formate. However, it is unlikely that the CO_2 carrier gas had any impact on kiwifruit quality as kiwifruit can tolerate up to 80% CO_2 for at least 24 h (Brigati *et al.* 1989).

VAPORMATE™ rates and times recommended by BOC Ltd are 120 g/m^3 for 1 hour to control aphids (*Naonovia ribisnigri*) on lettuce, 160 g/m^3 for 1 hour to control onion thrip (*Thrips tabaci*) on onions, 70, 30, 60 g/m^3 for 2 hours to control western flower thrip (*Frankliniella occidentalis*) on sweet pepper, cut flowers, and callas respectively; 420 g/m^3 for 6 hours to control mites (*Oligotetranychus* sp.), mealybugs (*Dysmicoccus* sp.) and scale insects (*Asplidiotus* sp.) on bananas and pineapples; 250 g/m^3 for 1 hour to control western flower thrip, grape mealybug (*Pseudococcus maritimus*), omnivorous leafroller (*Platynota stultana*), twospotted mite (*Tetranychus urticae*) on grapes and strawberries; 640 g/m^3 for 1 hour to control adult pacific spider mite (*Tetranychus pacificus*) on grapes; and 140 g/m^3 for 6 hours to control oleander scale (*Aspidiotus nerii*) and longtailed mealybug (*Pseudococcus longispinus*) on kiwifruit. These treatments are recommended to be applied at temperatures >15^{o}C.

New Zealand Food Safety Authority is processing (as of October2009) a change to the registration of VAPORMATE™ to that any uses will result in no residues of ethyl formate in the fruit. The intention of this change is unclear since ethyl formate is a natural plant volatile that is already present in fruit.

6.14.15.1.2. Ozone

Ozone (O_3) is a naturally occurring compound that provides protection from the negative effects of ultraviolet light (UV). It is a colourless or bluish gas, heavier than air with a characteristic odour of electrical sparks. It can be generated by electrical discharges in air, and is currently used in the medical industry to disinfect medical equipment of micro-organisms and viruses. It is also used for reducing colour or odour and for removing taste, colour and environmental pollutants in industrial applications (Horvath *et al.* 1985; Kim *et al.* 1999).

Ozone is classified as a GRAS compound and recently there have been increased efforts to develop and use ozone as a postharvest disinfestation tool in the USA. Ozone readily decays into oxygen free radicals, $O^{\cdot}$, and molecular oxygen, O_2. The occupational exposure limits (OELs) of ozone are 0.1 ppm in an 8-h day, and 0.3 ppm for a 15-min exposure. The free radical oxygen is an extremely strong oxidising agent that destroys the membranes in plant and animal cells, causing death. Ozone degrades within minutes to hours depending on temperature, humidity, presence of organic material, and other co-existing pollutant gases. It can also be destroyed instantly by discharging it through a catalytic converter, and this feature would be very valuable for ensuring safe fumigations. Its subsequent breakdown to oxygen eliminates concerns with its handling, storage and disposal that can be concerns of operators using conventional pesticides.

Recently, small, energy-efficient high-output portable ozone generators with ducted outputs have been commercially developed, generating sufficient concentration and volume to treat large volumes such as sea containers. Such units have the potential to provide an overnight treatment for a container while consuming a modest amount of electricity.

Ozone has been shown to be effective against stored-product pests. It is a poor penetrant and consequently is principally a surface decontaminant. Using ozone in conjunction with controlled atmospheres, high temperatures, vacuum conditions or carbon dioxide may enhance the efficacy of ozone against insects (Leesch & Tebbets 2002; Hollingsworth & Armstrong 2005) and increase penetration of ozone into commodities. A 30-minute treatment of ozone at 200 ppm in 100% CO_2 at 37.8°C killed 48 and 98% of mealybug and adult thrip respectively (Hollingsworth & Armstrong 2005). A 1% ozone enrichment of air kills most living material within 24 h (Knight & Mavengere 2005). Ozone treatments targeting beetles, weevils, moths and fungi have ranged from concentrations of 5 to 50 ppm for 3 - 5 days (Erdman 1980; Akey 1982; Mason *et al.* 1997; Strait 1998).

Ozone has the potential to cause damage to fresh produce and for this reason, concentrations of less than 50 ppm should be investigated. Ozone may need to be used in combination with cold storage if treatment times exceed eight hours. Reduced airflow is thought to severely decrease ozone efficacy. Humidity may also play a role in ozone efficacy. Ozone was six times more toxic at high than low relative humidity (Margosan *et al.* 1997; Margosan & Smilanick 2002) .

6.14.15.1.3. Ethyl acetate

Ethyl acetate is a naturally occurring compound that is well known as an insecticide. Like ethyl formate, ethyl acetate is also classified as a GRAS compound and therefore considered safe for use in conjunction with food (Anon 1993a).

Application of ethyl acetate at 94-120 g/m^3 caused an estimated 82.7–91.1% mortality of onion thrip eggs. Unpublished research indicates that an 8-h exposure to ethyl acetate at 5000 ppm (at 25^{o}C or 38^{o}C) kills fifth instar lightbrown apple moth larvae on apples with no phytotoxic damage to fruit. Ethyl acetate may by less phytotoxic than ethyl formate (van Epenhuijsen 2007).

6.14.15.1.4. Ethanol

Ethanol is a GRAS compound that applied as an immersion has been shown to control both diapausing and non-diapausing forms of twospotted mites (*Tetranychus urticae*) (Dentener 1998) and cause high mortality of lightbrown apple moth (*Epiphyas postvittana*) on apples when applied as a vapour (Jamieson 2003).

Postharvest ethanol treatments can have beneficial effects on fruit physiology, such as enhancing the sensory quality of apples (Berger & Drawert 1984), reducing astringency of persimmons and bananas (Kato 1990; Esguerra *et al.* 1993), delaying ripening of tomatoes (Saltveit & Sharaf 1992), reducing postharvest decay of citrus and stonefruit (Yuen *et al.* 1995; Margosan *et al.* 1997) and controlling scald (a calcium deficiency) in apples (Scott *et al.* 1995).

6.14.15.1.5. Acetaldehyde

Acetaldehyde is a volatile that is produced naturally by fruit, like ethyl acetate and ethanol. It was found to be toxic to western flower thrips (*Frankliniella occindentalis*) on strawberries when fumigated at a dose of 2% for 4 hours at 21^{o}C. This treatment resulted in some injury to the fruit calyx but not when combined with CA (1% O_2, 50% CO_2). Fumigation of lettuce using 2% acetaldehyde controlled aphids after a 3-hour exposure (Aharoni *et al.* 1979).

6.14.15.1.6. Essential oils and volatile organic compounds

The fumigant activity of a large number of essential oils and essential oil components extracted from aromatic plants was evaluated on cut flower quarantine pests *Bemisia tabaci*, *Frankliniella occidentalis* and *Liriomyza huidobrensis* (Kostyukovsky *et al.* 2002). The most active compound had similar insecticidal qualities as methyl bromide against major insect pests of dry stored food. A concentration of 10 and 20 g/m3 and exposure time of 2 and 4 h, respectively, were sufficient to obtain 100% mortality of adult *B. tabaci* and *F. occidentalis*. A 50-60 g/m3 concentration for 2 h killed *L. huidobrensis* larvae.

Lacey *et al.* (2009) tested the effects of volatile organic compounds (VOCs) emitted by the endophytic fungus *Muscodor albus* on codling moth adults, neonate larvae, larvae in infested apples, and diapausing cocooned larvae in simulated storage conditions. Fumigation of adult codling moth with VOCs produced by *M. albus* for 3 d and incubated in fresh air for 24 h at 25°C resulted in 81% corrected mortality. Four- and 5-d exposures resulted in higher mortality (84 and 100%, respectively), but control mortality was also high due to the short life span of the moths. Exposure of neonate larvae to VOCs for 3 d on apples and incubating for 7 d resulted in 86% corrected mortality. Treated larvae were predominantly first instars, whereas 85% of control larvae developed to second and third instars. Exposure of apples that had been infested for 5 d, fumigated with *M. albus* VOCs for 3 d, and incubated as described above resulted in 71% corrected larval mortality. Exposure of diapausing cocooned codling moth larvae to VOCs for 7 or 14 d resulted in 31 and 100% mortality, respectively, with negligible control mortality. Our data on treatment of several stages of codling moth with *M. albus* VOCs indicate that the fungus could provide an alternative to broad spectrum chemical fumigants for codling moth control in storage and contribute to the systems approach to achieve quarantine security of exported apples.

6.14.15.2. Non GRAS fumigants

6.14.15.2.1. Phosphine

Phosphine is the common name for phosphorus hydride (PH_3). It is a colourless, flammable gas with a boiling point of −88°C at standard atmospheric pressure. Pure phosphine is odourless, but "technical grade" phosphine has a highly unpleasant odour like garlic or rotting fish, because of the presence of substituted phosphine and diphosphine (P_2H_4).

Phosphine forms explosive and self-flammable mixtures with air at concentrations exceeding 18,000 ppm. Phosphine has good penetration properties, can be removed rapidly by aeration after treatment (Bond 1984) and has a low degree of sorption by most commodities (UNEP 1998), thus leaving negligible residues. In the atmosphere, once exposed to natural light, phosphine quickly decomposes into phosphate (Horn *et al.* 2003).

However, phosphine is highly corrosive to some metals (e.g. copper) which can cause problems when the fumigated materials contain copper e.g. electrical circuits in a flour mill. It can be applied using traditional metallic phosphide pellets or by the more recent cylinder gas application methods.

Most reports concerning the efficacy of phosphine fumigation have used the metallic phosphide pellets to fumigate a number of materials of plant origin including flowers (Williams 1998), fruits and vegetables (Wolfenbager 1995; Soma 1997; Soma *et al.* 1997; Soma *et al.* 1999; Hasan & Reichmuth 2004; Soma 2004), stored products (Cangardel & Fleurat-Lessard 1976; Fields & Jones 1999; Watson *et al.* 2003) and wood products (Dwinell 1997). Fumigation with 0.5 – 4.5 g/m^3 phosphine (from metallic pellets) for 12-96 h at ambient temperatures can be effective against a wide range of insects The efficacy of phosphine applied as metallic pellets is reduced at lower temperatures and therefore its use below 10°C is not recommended. However, pure phosphine can be used at cool storage temperatures and be effective at concentrations that do not damage fresh produce.

Phosphine fumigation using the form of aluminium phosphide, calcium phosphide, or zinc phosphide pellets, yields phosphine on contact with atmospheric water. This reaction is temperature-dependent and the fumigation is normally conducted at ambient temperature. These pellets also contain other chemicals that produce ammonia that help to reduce the potential for spontaneous ignition or explosion of the phosphine gas. They may also contain other agents, such as methanethiol, to give the gas a detectable smell, which helps to warn users and bystanders of its presence (Wikipedia 2006).

Most reports concerning phosphine have been on the use of metallic phosphide pellets to fumigate stored grains, seeds and dried fruit (Bell 2000), while some treatments have been carried out on fresh produce including cut-flowers. A dosage of 0.3 g/m3 phosphine for

4.5 h gave complete mortality of *Myzus persicae* and some mortality of larvae of *Strepsicrates ejectana*. Fumigation for 6 h with 1.4 g phosphine/m3 killed all pupae and most larvae of *S. ejectana*. Most of 19 species of cut flowers showed no sign of damage either immediately after fumigation or 7 days later. Similarly, Karunaratne *et al.* (1997) concluded that phosphine has the potential as an insect disinfestation fumigant for king protea, tulip, and kangaroo paw at 4000 micro l/litre for 6 h without affecting vase life or causing damage. In other trials, Weller and Graver (1998) and Williams (1995) concluded that phosphine needed to be combined with other treatments to be an effective method for controlling pests on cut-flowers. Williams *et al.* (2000) reported that the phosphine cylinder gas formulation $ECO_2FUME^®$ (phosphine with CO_2 as a carrier gas) was recently registered for a 15-h treatment of cut flowers.

Trials have indicated that phosphine fumigation usually resulted in satisfactory mortality of insects, but the quality of treated fruit could be reduced either because of the presence of ammonia in the phosphine (phytotoxic) or the relatively high fumigation temperature of over 15°C (Horn & Horn 2004). In response to the problems encountered with fumigation using metallic phosphine, two types of cylinder phosphine gases that do not contain ammonia have been developed and commercialised by Cytec Industries Inc (2005).

$ECO_2FUME^®$ is a cylinder gas mixture of 2% phosphine and 98% CO_2. Phosphine is the active ingredient and carbon dioxide is used as a propellant and flame inhibitor. The gas mixture can be directly released into storage for fumigation. Fumigation using ECO_2FUME is safe and convenient (Cytec Industries Inc 2005), but it could be considered expensive as it contains only 2% phosphine.

$VAPORPH_3OS^®$ is a cylinder gas of 100% pure phosphine. $VAPORPH_3OS^®$ is designed for use in conjunction with Cytec-approved blending equipment (i.e. The Horn Diluphos System) to dilute pure phosphine safely with air, therefore greatly reducing the cost of fumigation (Cytec Industries Inc 2005). The Horn Diluphos System (HDS) invented by Fosfoquim S.A., Chile, is an automated system that allows the direct dilution of pure phosphine (i.e. $VAPORPH_3OS^®$ from Cytec) with air to below the combustion limit, allowing the injection of a phosphine–air mixture into an enclosed space to fumigate with concentrations up to 10,000 ppm phosphine without risk of ignition (Horn *et al.* 2003). The HDS is a mobile unit designed to allow easy transportation to different sites. Only a nitrogen cylinder, a phosphine cylinder and an electrical supply are required to operate the system. Application of HDS for fumigation of fresh fruits and vegetables in cooled fumigation chambers, cooling chambers or controlled atmosphere chambers at low temperatures between -1.5 and 15°C has been patented (United States Application 20050265892; Horn *et al.* 2005).

Trials conducted on the fruit fumigation showed that cylinderised phosphine can effectively kill all stages of insects using 1400 ppm at 0-6°C in 48-72 hours and a residue level below the maximum residue limit of 0.01 mg/kg (Cavisin *et al.* 2006). For treatment of exported cut flower and foliage in New Zealand, a shorter fumigation time of 4 hours is in commercial use with $ECO_2FUME^®$ under vacuum conditions.

There are few published reports on the efficacy of pure phosphine fumigation on fresh products. Thrip were controlled using 250 ppm phosphine for 18 h (Liu 2008). The postharvest quality of lettuce, broccoli and strawberries was not affected by phosphine concentrations of 500 and 1000 ppm. A preliminary trial to fumigate fresh fruits (apple, nectarines, pears, grapes and plums) at -0.5 to +1°C using the HDS indicated that 36-72 h fumigation with 1500 ppm phosphine showed complete mortality of all insects tested at all developmental stages (eggs and larvae) without causing damage to the fruit (Horn *et al.* 2005).

Pure phosphine has been used in Chile for the last five years to fumigate apples, plums, peaches, citrus, pears, grapes, kiwifruit, cherry, nectarine, persimmons, avocados, quince and apricots, where over 6000 fumigations have been conducted in certified chambers. The HDS/VAPORPH$_3$OS technology was reported to be effective in controlling obscure mealybug (*Pseudococcus viburni*); codling moth (*Cydia pomonella)*; eulia (*Proeulia* spp*.)*; fruit tree weevil (*Naupactus xanthographus)*; Mediterranean fruit fly (*Ceratitis capitata)*; fruit flies (*Rhagoletis* spp., *Bactrocera* spp., *Anastrepha* spp*.)*; Chilean false red mite (*Brevipalpus chilensis)*; and *Thrips* spp. (Horn & Horn 2004). The data supporting these claims are in confidential technical reports that are not in the public domain.

Preliminary trials in New Zealand showed good potential for low-temperature phosphine fumigation against horticultural pests: scale insects (*Hemiberlesia rapax* and *Aspidiotus nerii*), lightbrown apple moth (*Epiphyas postvittana*) and codling moth (*Cydia pomonella*) (Brash 2008; Wimalaratne *et al.* 2009). Insect resistance to phosphine is an emerging problem, particularly in developing countries. Resistance has occurred primarily because of poor sealing and non-compliance with minimum exposure times (Bell *et al.* 1998). Therefore, it is considered important to use the correct exposure and application technology to avoid development of resistance (UNEP 1999).

6.14.15.2.2. Carbonyl sulphide

Carbonyl sulphide (COS) was developed in Australia as a grain fumigant. The compound is naturally present in the environment as part of the natural global sulphur cycle, occurs naturally in food and breaks down rapidly (Obenland *et al.* 1998; Caddick 2004; Bartholomaeus & Haritos 2005). Plants are able to metabolise carbonyl sulphide and synthesise it (Protoschill-Klrebs & KesseMIer 1992; Feng & Hartel 1996). It has good penetration action, and commodity sorption is generally less than that of either methyl bromide or methyl iodide (Schneider *et al.* 2003).

COS has similar efficacy against insects as methyl bromide, and faster efficacy than phosphine (Caddick 2004). Fumigation with COS has been recommended for control of insects in stored products, durable commodities and structures (Desmarchelier 1994; Zettler *et al.* 1997; Wright 2001). COS fumigation has been reported to be effective against a wide range of pests at concentrations <50 g/m^3 and exposure times of 1-5 days (Desmarchelier 1994; Zettler *et al.* 1997). However, a 2-h fumigation of carbonyl sulphide at 80 g/m^3 failed to control codling moth eggs and red scale (Aung 2001). Eggs tended to be more tolerant of COS fumigation than adult weevils, when fumigated with 25 g/m^3 at 30°C (Weller & Morton 2001). Since the activity of COS is highly dependent on temperature, COS fumigation is recommended at 15°C or above.

Short fumigation periods using COS at 25°C have been investigated for the treatment of surface insects on tropical fruits and flowers (Chen & Paull 1998). Avocados, mangos and papaya tolerated a 1% treatment of COS for 3, 7, and 16 h, respectively. Red ginger inflorescences were less tolerant of COS than fruit, being able to withstand 1% for less than 2 h. Lemons tolerated exposure to 70 g/m^3 treatment for 8 h without reduction in market quality (Obenland *et al.* 1998). Fumigation of nectarines with 80 g/m^3 COS for 2 h at 21°C intensified peel colour, delayed fruit softening and did not adversely affect fruit quality (Aung 2001). Phytotoxic studies conducted on 12 species of cut flower have shown that phosphine is least toxic followed by COS, methyl bromide and hydrogen cyanide. COS at the rate of 15 g/m^3 for 5 hours is very effective in controlling the target pests and caused phytotoxic damage to only two out of 12 treated cut flower species. Although phosphine (0.25 g/m^3 for 5 hours) was least toxic to the treated cut flowers, it was not as effective in controlling the target pests (Weller & van Graver 1998).

6.14.15.2.3. Cyanogen

Cyanogen (C_2N_2; ethanedinitrile) was discovered by CSIRO in 1994 and is being developed as a fumigant for control of insects (including eggs), mites, nematodes, fungal spores, bacteria, viruses in agriculture, stored foodstuffs and medicine. It occurs naturally in the environment and is not an ozone-depleting substance or greenhouse gas. Ninety percent of cyanogen residues are ammonia, with the remaining 10% consisting of other naturally occurring compounds (Smith *et al.* 2005). Cyanogen is systemic in plants. It can be used as either a solution or a gaseous application with an inert carrier gas. Cyanogen has a workplace 8-h exposure limit of 10 ppm, which compares favourably with other fumigants, 5 ppm for methyl bromide and 0.3 ppm for phosphine (Dowsett & Ren 2005).

Field tests have shown that cyanogen is an effective fumigant against timber pests (Dowsett & Ren 2005; Park *et al.* 2006; Ren *et al.* 2006) and shows better penetrative characteristics than methyl bromide (Caddick 2004). Exposure for 6 h to cyanogen at 1.4 - 11 g/m^3 at 21 - 25^{o}C kills five species of timber pests (Dowsett & Ren 2005). MBTOC was not aware of any publications on the effect of cyanogen on perishable commodities and their pests.

6.14.15.2.4. Methyl iodide

Ryan *et al.* (2007) noted the importance of aeration after fumigation in order to preserve sufficient levels of the cellular protectant glutathione which helps to reduce the phytotoxicity of fumigants. Lemons were treated with methyl iodide at 28 gm^{-3} for 2 h at 21°C then were aerated for 2 or 24 h at 30°C. Total and oxidized glutathione concentrations were determined enzymatically immediately after aeration and after 3 weeks storage at 5°C. Total glutathione content was substantially reduced in comparison to controls after fumigation and 2 h aeration, but recovered considerably during a 24 h forced aeration. After 3 weeks storage, fruit subjected to 24 h aeration had glutathione levels equivalent to those of the controls, while those given a 2 h aeration had lower levels of total glutathione. This is the first demonstration of recovery of glutathione concentrations in a fresh commodity after methyl halide fumigation. Also, after 3 weeks storage, phytotoxicity in fruit given a 2 h aeration was high whereas fruit given a 24 h aeration had less injury. Fruit aerated at 30°C had less injury than those aerated at 21°C, suggesting that fumigant removal was temperature dependent.

6.14.15.2.5. Aerosol sprays

Aerosol sprays containing pyrethrin, permethrin and or dichlorvos are available for postharvest application. Pyrethrum aerosols are regarded as safe chemicals, have short application time, are relatively cheap, and are effective against a range of surface pests. Pyrethrum is only effective on contact with the pest and breaks down easily in sunlight.
Permigas™ (active ingredient pyrethrins, permethrin, piperonyl butoxide) is registered for used against aphids in capsicums (1.2 g/m^3 for 4-6 hours) and tropical armyworm in kumara (2 g/m^3 for 4-6 hours). Insectigas™ with 5% dichlorvos and Pestigas (active ingredient pyrethrum) are also commercially available.

Floragas™ containing pyrethrins and permethrin is registered for use against aphids and thrips on cut flowers. When protea flowers were treated in an enclosed chamber for 12 h with a combination of pyrethrin (Pestigas™) and dichlorvos (Insectigas™), both propelled by CO_2, the combination was more effective than either of the gases used alone (Wood & Wood 1991).

6.14.15.2.6. Insecticidal dips/inline spray

Contact pesticides can be applied quickly and easily as a postharvest chemical dip or an inline, low volume spray application. Pyrethrum products are effective against a broad range of insects. They have low toxicity to other animals and a short half-life, and are regarded as an environmentally friendly alternative to many other insecticides used postharvest, such as Dimethoate. Residues need to remain below MRL limits for export markets.

There are also health and safety concerns with insecticidal dips including environmental concerns with disposal and potential costs of registration. In a situation where there is no non-chemical alternative, these chemical treatments may warrant further investigation. In New Zealand postharvest pesticide applications have been investigated for pests and/or diseases of kiwifruit, avocado, apple, asparagus.

6.14.15.3. Combination treatments

Treatments are often combined in order to enhance the efficacy, reduce exposure time or reduce product damage. However, compared to single treatments combination treatments tend to be more expensive and they require more extensive documentation to satisfy phytosanitary inspectors.

A high-temperature CA treatment (2% O_2, 5% CO_2, 40^{o}C) followed by seven weeks of cold storage was considered to have potential for controlling leafrollers and lightbrown apple moth (LBAM) without damaging apples (Whiting 1999). This treatment has not been commercially adopted for a variety of reasons, including cost of implementation and the fact that the incidence of leafrollers on apples in New Zealand has reduced significantly over the last decade. Chervin *et al.* (1999) investigated a low oxygen treatment (2% O_2) at 28^{o}C for 72 h, prior to storage at 0.5^{o}C for control of LBAM and codling moth on apple and pears. A mortality of 95% was achieved after cold storage of 37 days or 81 days for LBAM and codling moth, respectively.

A process for removing or killing California red scale (*Aonidiella aurantii*) from citrus fruit as a postharvest treatment was evaluated by Fuester *et al.* (2004). The process subjects the fruit to vacuum steam and a vacuum that physically removes red scale from the fruit. The treatment kills scales that are not removed from the fruit. Different numbers of cycles and steam temperatures were compared for efficacy in removing scale from lemons or killing those that remained. Multiple (two to three) cycles removed up to 96% of first moult scales on the fruit, but they, were much less effective in removing other stages, especially those that had advanced beyond the second instar. However, it was extremely effective in killing the scales remaining on the fruit. Although this process does not eliminate cosmetic damage caused by scale presence, it might be used in combination with high-pressure washers currently used in packing houses to allow importers and exporters to meet the most stringent quarantine requirements. Because of its killing power, this technique could be tried on other insects and commodities to see whether it can be substituted for certain uses of methyl bromide.

Physical manipulations generating cycles of expansion and compression forces were combined with low vapour concentrations of natural disinfecting chemicals to disinfect and disinfest simultaneously and rapidly fresh agricultural products (Lagunas-Solar *et al.* 2006). Lethality in various fungi, plant and human pathogens and in all biological stages of selected arthropods was demonstrated with fresh fruits and vegetables. The combined process modifies the respiratory metabolism, affects biological structures, causes displacement of the O_2/CO_2 gaseous equilibrium and induces chemical toxicity at the cellular level. In aerobic microbes, oxygen metabolism is rapidly disrupted, causing biocidal effects. In larval, pupal and adult insect stages, irreversible structural damage of the tracheal system prevents the formation and causes the elimination of air reserves. In arthropod eggs, damage in essential structural features and dehydration of the chorion affect their ability to diffuse and use oxygen. The MSDD process is rapid (< 4 h), effective (100% insect controls, > 5 log(10) microbial reduction), reproducible, practical, economically competitive and applicable to large volumes of commodities. It causes minimal or no sensory/functional effects in host commodities. If developed commercially, it can be a single alternative to a broad spectrum of postharvest pesticides for disinfection and a likely alternative to methyl bromide fumigation or to irradiation for the post-harvest control of arthropods.

Combinations of non-chemical postharvest treatments were investigated by Tabatabai *et al.* (2000) as alternatives to methyl bromide fumigation for postharvest control of lightbrown apple moth (LBAM, *Epiphyas postvittana*). A combination of a warm controlled atmosphere pulse (1.2 kPa oxygen at 29°C) followed by cold storage (0°C) resulted in high level mortality of pupae (the most resistant stage). Effects of rearing temperature were tested by measuring the stress resistance of pupae originating from two field populations (from Victoria, Australia, 500 km apart) using three levels of stress (low, medium and high), each involving 48 h under controlled atmosphere at 29°C followed by 3, 9 or 27 days at 0°C. No differences in resistance to stress were observed between the two populations at low- and medium-stress levels (60 and 80% mortality, respectively) or high levels (100% mortality), and larval rearing temperature (14, 19 and 25°C) did not influence the subsequent stress resistance of pupae. Finally, the effects of age and weight on resistance to stress were investigated. Younger pupae (2-3 days old) had relatively higher resistance to disinfestation stress, while pupal weight (controlled for age) had no effect. These results suggest that disinfestation by the combined stresses may be effective over a range of environmental conditions and for different populations of LBAM.

One treatment currently used as an alternative to methyl bromide for fumigating cut flowers is a 2 h exposure period consisting of a 10 s burst of Pestigas (pyrethrum with carbon dioxide as a carrier gas) to agitate insects followed after 10 minutes by a 10 s burst of Insectigas (dichlorvos with carbon dioxide as a carrier gas) as the main killing agent (Williams and Muhunthan 1998). However, the current Pestigas/Insectigas schedule is not fully effective against all pests encountered in flowers. Extending the fumigation period from 2 h to 4-6 h and increasing the dosage of dichlorvos from 0.1 gm^{-3} to 1.7 gm^{-3} improved the range of pests controlled but did not kill all eggs of *Tetranychus urticae* and left some larvae of *Epiphyas postvittana* and *Strepsicrates ejectana* moribund (making small twitching movements and unable to feed). Assessment of several alternatives identified phosphine as the most promising fumigant because of its effectiveness against insects and its low phytotoxicity. Large scale trials are being carried out in a commercial fumigation chamber using Pestigas followed by Phosfume (phosphine with carbon dioxide as a carrier gas). Phosphine appears suitable for registration for fumigation of cut flowers.

Results obtained in 6-h fumigations with phosphine at 1.0-1.4 gm^{-3} were at least as good as those obtained in 6-h fumigations with dichlorvos at 1.7 gm^{-3}.

Low temperature storage combined with sulphur dioxide slow-release pads caused 100% mortality of omnivorous leafroller (*Platynota stultana*) 2nd-instar (the most tolerant stage to low temperature storage) after 3 weeks of exposure in table grapes (Yokoyama *et al.* 1999). Temperatures in packed grape clusters decreased from ambient to 2°C within ~2 days after placement in storage. Sulphur dioxide concentrations in the grape clusters ranged between 0.2 and 1.0 ppm during the 1- to 6-week storage period. The combination treatment incorporates existing packing house facilities and has potential to be used as an alternative to chemical fumigants such as methyl bromide to control pests of regulatory concern in exported table grapes.

6.14.15.4. Systems approach

Schneider *et al.* (2003) reported on the value of integrating pre-plant management activities and post-harvest processing when developing overall procedures to minimise the impact of insects from the field to the final packaging.

In Chile, *Brevipalpus chilensis* is a primary pest of wine grapes and of economic importance as a quarantine pest on table grapes, kiwifruit, clementines, lemons, mandarins, custard apples, figs and persimmons. Its likely presence requires mandatory methyl bromide treatment for commodities exported to the USA and other countries (Gonzalez 2006). Stone fruit were also found to carry female *B. chilensis* hidden in the pedicel cavity at very low population densities and a few eggs were deposited down in the cavity also (less than 0.3% of fruits infested with females). The miticide dicofol was effective for controlling mites in the vineyards, and newer acaricides such as abamectin, acrinathrin, bifenthrin, propargite and spirodiclofen have also shown to be effective. With the view to reducing the use of methyl bromide treatments for table grapes exported to the USA, and documented evidence of control of this quarantine pest in the field, the Systems Approach was proposed by Chile as a condition of entry without the need for methyl bromide fumigation.

Williams *et al.* (2000) treated oranges infested with larvae of Queensland fruit fly (*Bactrocera tryoni*) for 16-h at 20°C with an initial phosphine concentration of 0.98 gm^{-3}, which resulted in 96.4% mortality of fly larvae. Although the level of mortality was significant it was insufficient to meet the mortality requirements for interstate (99.5%) or export trade (99.9%). Exposure times, temperatures and phosphine concentrations were all increased in subsequent fumigations. In the final series of fumigations with export grade Washington Navel oranges the exposure time was 48 h at 23 or 25°C, using an initial phosphine dosage of 1.67 gm^{-3}. The concentration was topped up to about 0.7 gm^{-3} after 24 h. No adverse effects on the oranges were observed, and a mortality of 99.998% was achieved with > 48 000 larvae exposed. This would meet requirements for interstate trade in Australia and possibly also some international trade, particularly if incorporated as part of a Systems Approach.

6.14.16. Existing alternative treatments to methyl bromide

The previous section focused mainly on potential replacements for methyl bromide for QPS by highlighting some of the key research activities that are underway for some pests on selected fruit, vegetables and cut-flowers. This section summarises treatments that have been approved for commercial use by various phytosanitary authorities globally.

MBTOC (2002) recorded more than 300 alternative quarantine treatments for perishable commodities that had been approved by a National Plant Protection Organisation (national quarantine authorities) (MBTOC 2007, p.300) for some particular quarantine situation. It provides examples of alternative quarantine treatments and procedures that have been approved by national quarantine authorities for the list of fresh fruit and vegetables are listed in Table 36.

Approved alternatives include cold treatments, various types of heat treatments, heat + controlled atmospheres, pesticide dips or sprays, wax coating, pest removal (e.g. by brushing), alternative fumigants, irradiation, crop production in areas free from quarantine pests, the systems approach, and inspection procedures. Examples for particular perishable commodities are summarised in Table 36.

Technical descriptions of these alternatives can be found in previous MBTOC reports (e.g. MBTOC 2002, pp.273-318; MBTOC 2007, pp.306-315). For most of the commodities listed in Table 36, two or more different types of alternatives have been approved by various quarantine authorities for specific quarantine situations. Cold, heat and irradiation treatments appear to be applicable to the widest range of commodities at present.

There is a wide variety of pests of quarantine significance, varying according to origin and country of destination, that are controlled by these approved treatments. These include fruit flies, mealybug, thrip, aphids, mites and other pests (Table 36). In many cases, the approved treatments apply to a particular situation, i.e. a particular commodity with particular pest(s) from a particular country or region and a particular quarantine concern of the importing country (MBTOC, 2007). Each approved treatment may be applicable to just one or several species of fruit fly, for example. However, in some cases an approved treatment covers many species, such as ‘external feeders’ and ‘insects’, as shown in Table 36.

Although a number of treatments have been approved, actual use of these treatments is not well documented (MBTOC 2007, p.300). The extent to which a specific treatment has been commercially implemented was not determined. However, some of the approved treatments listed in Table 36 may not be used at all in commercial practice, while others are used to a significant extent. For example, the Systems Approach required for Hass avocado exported from Mexico (Michoacán region only) to the USA appears to be well used, according to FAO statistics (http://faostat.fao.org). Mexico exported a total of about 310,260 tonnes of avocado in 2007 (value $US 620 million), and much of this was imported by the USA, indicating that this quarantine procedure is used for a significant volume of product. An APHIS document also reported on the efficacy of the Mexico/Michoacán avocado procedure in commercial practice (which does not use MB), stating that “*In 6 years of experience, the surveys, inspections, and fruit cuttings have not detected the presence of any insect pests in the importation of Mexican Hass avocados*” (APHIS 2004, p.8).

Alternative treatments for perishable products may be carried out in the country of origin, or in-transit in some instances, or in the importing country as outlined below. However, for reasons of practicality, fumigation with methyl bromide may at present be the only available treatment in lieu of destruction or rejection of the consignment if inspection at the port of entry reveals pests of concern.

6.14.17. Treatments in the country of origin

Some of the approved alternative methods, notably Systems Approaches, pest free areas and pre-export inspection requirements, can only be carried out in the country of origin. For some important quarantine pest species such as fruit flies and codling moth, some importing countries require that perishable commodities undergo a mandatory treatment or procedure prior to export. Exporters sometimes prefer to carry out quarantine treatments in the country of origin for economic reasons. The cost of materials and labour for quarantine treatments can be lower in the exporting country, particularly if the destination country is a non-A5 country with higher labour costs or high charges for port demurrage. Quarantine MB fumigations in the Philippines, for example, were reported to be $US 20–80 if carried out prior to export compared with $1,500–2,000 if carried out in destination countries (MLF 2004).

In many cases, fixed facilities are needed for carrying out treatments e.g. heat, cold, controlled atmospheres, and it can be cheaper for the exporters to locate and operate the facilities in the country of origin than in the importing country, i.e. it is more efficient to treat all the commodity at the point of origin than to treat the commodity after it has been dispersed to several different ports. Taiwan, for example, has four vapour heat treatment facilities and pack houses which have been approved by the Australian quarantine authorities for mangoes exported to Australia, while the Philippines has five registered treatment facilities for mango (AQIS 2009). For certain treatments such as methyl bromide and heat there is a product quality penalty, however, for treating perishables before transit because the earlier treatment significantly reduces the shelf life of the treated commodity compared to treatment after transit. On the other hand, cold treatments and controlled atmospheres can improve the shelf-life and quality of perishable commodities (such as flowers and fruit) if carried out prior to export.

For perishable products, pest control based on pre-harvest practices, as part of the Systems Approach as described in ISPM No. 14, must include cultural techniques leading to pest reduction, they must have an agreement on the area of any pest-free zones, and be subject to inspection in order to receive certification. In these cases, regulatory approval depends on a number of factors including knowledge of the pest-host biology, evidence of commodity resistance to the pest, trapping and field treatment results, monitoring of pests and diseases, and careful documentation.

6.14.18. In-transit treatment

In some cases the approved alternative treatments (e.g. cold, controlled atmospheres) are allowed to be carried out while commodities are being transported to their destination in a truck, shipping container or ship hold that has the relevant equipment. The quarantine authorities in the USA, for example, have approved the equipment installations in a number of ships and in hundreds of shipping containers for in-transit cold treatments (CPHST 2009a, 2009b). For example, citrus shipped from Spain to the US treated by cold treatment in transit.

6.14.19. Treatments on arrival in the importing country

When products arrive in an importing country and are found to need a quarantine treatment, methyl bromide tends to be the prevalent treatment in a number of countries, due to logistic issues such as a lack of rapid pest identification facilities and lack of alternative treatment facilities at ports of entry. Quarantine authorities in the USA, for example, have approved a total of about 116 quarantine treatment facilities for imported products in 28 states (primarily for methyl bromide fumigation). This total includes seven heat treatment facilities[19] located in five states, and eight cold treatment facilities located in only one State (APHIS 2008 ab). So in many US states, only methyl bromide and phosphine facilities appear to be available at present for carrying out quarantine treatments on imported perishable products (APHIS 2008ab).

TABLE 36: EXAMPLES OF ALTERNATIVE NON-MB QUARANTINE TREATMENTS APPROVED BY SOME NATIONAL QUARANTINE AUTHORITIES FOR FRESH FRUIT AND VEGETABLES (LISTED BY COMMODITY) FOR SPECIFIC QUARANTINE SITUATIONS INVOLVING PARTICULAR IMPORTING AND EXPORTING COUNTRIES

Perishable commodities	Examples of alternative quarantine treatments or procedures						
	Cold	Heat	Chemical	Irradia-tion	Pest free areas	Inspect-ion	Systems approach
Fruit (many types)			CHM		PFA		
Vegetables, many types			CHM		PFA		
Apple	CT	CAT			PFA	INS	SYS
Apricot	CT				PFA	INS	
Avocado	CT				PFA, SA	INS	SYS
Blueberry	CT		CHM			INS	
Breadfruit			SWB				
Cape gooseberry	CT						
Carambola	CT			IRR			
Cherimoya			SWW				
Cherry	CT	CAT					SYS
Citrus	CT	HTF			PFA		
Clementine	CT	VHT					
Durian, other large fruits			SWB				
Eggplant		VHT		IRR			
Ethrog	CT						
Garlic					PFA		
Grape	CT		FUM				SYS
Grapefruit	CT	VHT			PFA	INS	
Guava				IRR			
Horseradish roots		HWT					
Kiwi fruit	CT						
Kumquat	CT	HTF					
Lemon	CT	HTF					
Lime		HWT, HTF	SWW				
Litchi (lychee)	CT	HTF, VHT		IRR			
Longan	CT	HWT		IRR		INS	
Loquat	CT						
Mandarin	CT						
Mango	CT	HWT, VHT		IRR	PFA		
Nectarine	CT	CAT					
Orange	CT	HTF, VHT					
Ortanique	CT						
Papaya		HTF, VHT					
Passion fruit			SWW				

[19] Some of these heat facilities are small and may not be suitable for perishable products. These 7 heat facilities are intended for imported products only. This number does not include the heat facilities approved for ISPM-15 treatments in the USA.

Perishable commodities	Examples of alternative quarantine treatments or procedures						
	Cold	Heat	Chemical	Irradia-tion	Pest free areas	Inspect-ion	Systems approach
Peach	CT	CAT			PFA	INS	SYS
Pear	CT					INS	SYS
Pepper (bell)		VHT			PFA	INS	
Persimmon	CT						
Pineapple		VHT		IRR			
Plum, Plumcot	CT						SYS
Pomegranate	CT				PFA	INS	
Rambutan		HTF, VHT		IRR			
Squash		VHT					
Tangerine	CT	HTF					
Tomato		VHT					
Zucchini		VHT					

Source: Extracted from Table 1 of Annex 2 in QPS Task Force Report (2009).

Key to table:

CAT Forced moist air or vapour warm air with controlled atmosphere treatment, e.g. 1% oxygen, 15% CO_2.
CHM Chemical dip or spray, e.g. specified fungicide, acaricide or nematicide, other than MB.
CT Cold treatment
FUM Fumigant other than MB, e.g. phosphine, sulfuryl fluoride.
HTF High temperature forced air treatment
HWT Hot or warm water treatment
INS Inspection
IRR Irradiation
PFA Approved pest-free production area
SA Systems Approach comprising measures such as pest free areas, trapping, field sanitation, registered packhouses, screened storage etc.
SWB Soapy water + brushing
SWW Soapy water + wax
VHT Vapour heat treatment

TABLE 37: EXAMPLES OF ALTERNATIVE NON-MB QUARANTINE TREATMENTS USED ALONE OR IN COMBINATION APPROVED BY NATIONAL QUARANTINE AUTHORITIES FOR FRESH FRUIT AND VEGETABLES (LISTED BY PEST GROUP) FOR SPECIFIC QUARANTINE SITUATIONS INVOLVING PARTICULAR EXPORTING AND IMPORTING COUNTRIES

Categories of pests controlled by approved treatments	*Examples of alternative quarantine treatments or procedures*						
	Cold	Heat	Chemical	Irradiation	Pest free area	Inspection	Systems approach
External feeders, surface pests		HWT	SWB			INS	
Fruit borers	CT					INS	
Fruit flies	CT	CAT, HTF, HWT, VHT		IRR	PFA	INS	SYS
Fruit moths (a)	CT	CAT			PFA	INS	SYS
Fungi (b)			CHM		PFA	INS	
Insects			FUM	IRR		INS	
Mealybug	CT	HWT			PFA	INS	
Mites (c)			SWW, CHM			INS	SYS
Nematodes		HWT			PFA	INS	
Spiders			CHM			INS	
Weevils	CT	VHT			PFA	INS	
Unspecified quarantine pests	CT	VHT, HTF	CHM		PFA	INS	

Source: Compiled from Table 1 of Annex 2 in the QPS Task Force Report (2009). (a) Including codling moth, false codling moth, light brown apple moth. (b) Including citrus black spot, fruit rusts. (c) Including spider mites, false spider mite.

6.15. Scope for replacement of methyl bromide used for QPS applications

6.15.1. Sources of information

Decision XX/6 asked the QPSTF to estimate consumption of MB per category of use and then evaluate amounts that could be replaced with alternatives presently available and feasible (TEAP, 2009). For this, several sources of information were used, including direct responses from 24 Parties, surveys conducted previously (including the UNEP/ROAP survey of QPS uses in Asia and the Pacific and the 2004 QPS survey) and others. MBTOC further conducted a new survey of MB uses in 2010, for both controlled and exempted uses among larger MB consumers (50 tonnes and more).

It was apparent that the breakdown of categories was different in Article 5 and non-Article 5 Parties and that it is necessary to account for specific circumstances in the different regions involved when considering possible replacements of methyl bromide with alternatives (TEAP, 2009; 2010). Logistical issues, and availability of technologies or infrastructure were important considerations when estimating replaceable amounts, and different scenarios were thus proposed for Article 5 and non-Article 5 Parties.

Decision XXI/10 requested MBTOC to assess- for Article 5 and non-Article 5 parties separately- the availability and market penetration of technically and economically feasible alternatives for the four largest consuming categories of methyl bromide for QPS: sawn timber and wood packaging material (ISPM-15); grains and similar foodstuffs; pre-plant soils use; and logs. Estimation was based on information previously available from the QPSTF report (TEAP 2009; 2010)

6.15.2. Scope for replacing MB used for QPS in non-Article 5 Parties

The main categories of use in non A5 Parties were soils in situ (30%), logs (17%), grain (7%), and wood packaging material for compliance with ISPM 15 (5%). A suggested best-case scenario for the replacement of methyl bromide for these uses in non-Article 5 Parties was presented by MBTOC (TEAP, 2010).

MBTOC estimated that in Non-Article 5 Parties that more than 60-80% of the methyl bromide used in sawn timber and wood packaging material could be replaced by heat or non-wooden pallets; less than 10% of the methyl bromide used as a quarantine treatment in grains and similar foodstuffs could be replaced by alternative fumigants and controlled atmospheres, and more than 80% for pre-shipment treatments in grains and similar foodstuffs could be replaced by fumigants, protectants, controlled atmospheres and integrated systems; about 50% of the methyl bromide used in soil could be replaced by alternative fumigants, provided the alternatives meet certification standards (a higher proportion may be feasible as new alternatives have become registered); and 10-20% of the methyl bromide used in logs could be replaced by alternative fumigants, conversion to sawn timber (lumber), immersion, debarking, heat and drying.

6.15.3. Scope for replacing MB used for QPS in Article 5 Parties

The principal categories of use of methyl bromide for QPS purposes in Article 5 countries were logs (38%), wood packaging material for compliance with ISPM 15 (14%) and grains (22%), of which a large amount is estimated to be used for pre-shipment (Figure 19). No pre-plant soils uses were classified as QPS in A5 Parties. As stated previously in this Chapter, Asia is the major consuming region.

MBTOC estimated that in Article 5 Parties more than 60% of the methyl bromide used for treating sawn timber and wood packaging material could be replaced by heat or alternative fumigants; less than 10% of the methyl bromide used as a quarantine treatment in grains and similar foodstuffs could be replaced by alternative fumigants and controlled atmospheres, and 30-70% for pre-shipment treatments in grains and similar foodstuffs could be replaced by fumigants, protectants, controlled atmospheres and integrated systems; and 10-20% of the methyl bromide used in logs could be replaced by alternative fumigants, conversion to sawn timber (lumber), immersion, debarking, heat and drying.

6.15.4. Feasibility of global replacement of methyl bromide for QPS

The technical and economic feasibility of alternatives to methyl bromide used for QPS in all countries depended mainly on the infrastructural capacity of the country, end-use customer requirements, phytosanitary agreements where relevant, and logistical requirements for the use of the alternative.

MBTOC TEAP estimated that currently available alternatives and substitutes could replace about 31% to 47% (1,937 to 2,942 tonnes) of QPS consumed in the four largest categories of QPS use determined Since these four categories account for about 70% of total 2008 QPS methyl bromide use, it was estimated that the available technologies can immediately replace approximately 22% to 33% of global QPS consumption (TEAP, 2010).

6.16. Opportunities for emission reduction and recovery of methyl bromide used for QPS purposes

Detailed information on emissions and possibilities for their reduction including recapture can be found in Chapter 9 of this Assessment Report. Some general comments pertaining to QPS are included in this Chapter.

6.16.1. Reducing volumes of methyl bromide use as a phytosanitary measure

The IPPC recommendation "Replacement or reduction of the use of methyl bromide as a phytosanitary measure" (IPPC 2008) states the reduction of methyl bromide emissions can be achieved through the use of reduced dosages of methyl bromide as a phytosanitary measure or decreased treatment frequency. In addition, existing methyl bromide use should be analysed carefully to determine if the treatment is appropriate and necessary.

The following approaches may, where appropriate, be pursued to reduce the use of methyl bromide as a phytosanitary measure (IPPC 2008):

- inspection-based fumigation instead of mandatory fumigation (i.e. to detect and identify the quarantine pest of concern)
- avoidance of unjustified re-fumigation with methyl bromide (i.e. re-fumigation should be used only when a quarantine pest situation is evident)
- improvement of treatment facilities as appropriate to maximize efficiency of fumigation, thus reducing replenishment or re-fumigation requirements
- increasing exposure time with a view to reducing dosage, where technically feasible
- compliance with phytosanitary requirements for exporting commodities
- avoidance of application in situations where efficacy is doubtful or marginal
- reassessment of doses and exposure times in order to reduce them
- use of optimal temperatures when fumigating
- use of appropriately sized treatment facilities
- evaluation of pest risk and treatment efficacy (through a pest risk analysis) to determine if a more appropriate dose or alternative treatment is possible.

6.16.2. Application of best practice

Several quarantine authorities (NPPOs) have codes of practice or similar documents that detail best practice in use of methyl bromide for QPS treatment of commodities. These include sections in the USDA PPQ manual (USDA 2009, USA), AQIS Methyl Bromide Fumigation Standard (AQIS 2009a, Australia) and Theory and Practice of Plant Quarantine Treatments (JFTA 2002, Japan). The FAO web-based document 'Guide to Fumigation under Gas-Proof Sheets' (FAO 2009) also provides instruction on use of methyl bromide for QPS treatments. Use of best practice for QPS treatment of commodities minimises emission losses (leakage) prior to venting at the end of treatment, while maximising effectiveness of a particular dosage of methyl bromide.

Treatment of commodities for QPS purposes under best practice is typically carried out in well sealed enclosures designed to retain the fumigant gas at effective levels throughout the exposure time of the treatment. The level of sealing should be such as to minimise unintentional fumigant loss, caused by atmospheric forces such as wind and temperature changes (e.g. van Someren Graver and Banks, 2008). There are a range of standards set for sealing of enclosures (freight containers, fumigation chambers, sheeted stacks, silo bins, sheds etc.) for fumigation with methyl bromide. These standards vary with circumstances and country regulations or codes of practice. They are typically based either on a pressure test or a gas retention test, with pressure half life of 10 seconds to 5 minutes and gas retentions exceeding 70% of initial dosage at the end of a 24h exposure in an empty fumigation enclosure, with circulation fans running, if applicable.

A fumigation enclosure used with methyl bromide must be well sealed in order to minimise gas loss for both industrial safety and efficacy reasons. In practice, methyl bromide treatments of commodities, for both QPS and other purposes, are often carried out in poorly sealed enclosures with substantial rates of gas loss. To compensate for this loss, some NPPOs and other authorities (e.g. AQIS 2009, USDA 2009) allow ‘top up’, a process of adding additional methyl bromide during the course of a fumigation to maintain effective gas concentrations. This top up process may give a good treatment from the QPS point of view, but leads to increased methyl bromide use and emissions compared with adoption of better sealing. This is under conditions where gas loss occurs from leakage, not reaction and sorption on the commodity and packaging.

Application of audited best practice for QPS fumigations in several countries that trade with Australia under the AFAS scheme has saved (avoided use of) substantial quantities of methyl bromide. It is estimated that AFAS countries (India, Indonesia, Malaysia and Thailand) have collectively reduced methyl bromide usage by 153 tonnes from 2004 to 2008 (Fox 2008, Cox 2008) This saving was achieved largely through avoiding repeated methyl fumigations after failures in the initial treatments were detected.

6.17. Constraints to adoption of alternatives for QPS uses

6.17.1. Economic

Methyl bromide for QPS purposes continues to be in plentiful and unrestricted supply, as expected under the exemption from phaseout under Article 2H para 6. The cost of methyl bromide gas to end users is a relatively small component of the total cost of a QPS treatment. Compliance costs associated with the handling and use of a highly toxic gas to exacting occupational, environmental and effectiveness standards, increases the overall cost of conducting QPS methyl bromide treatments. Nevertheless the methyl bromide treatment costs present a competitive barrier to the development and adoption of any new alternative processes.

Cost of methyl bromide to the end user and the fumigator, has remained relatively stable over the last 5 years, with price approximately in the range $US 4-16 per kilo in many developed and developing countries. In some countries, the price of methyl bromide has fallen recently, possibly as a result of new suppliers entering the market. For instance, in Australia, methyl bromide for QPS purposes is now approximately $US 6.50 per kilo, down from about $US 8.00 in 2002. Price for 'Q-gas' in the US is about $US 15.00 per kilo at this time, with substantial discount available to large volume users.

The advantage that methyl bromide enjoys arises in part because methyl bromide based systems do not include the costs of the damage to the ozone layer and ultimately to human health. The extent of such costs is however not known. In addition, other QPS systems also have unaccounted costs to the environment and human health. Sulfuryl fluoride and heat for example, also carry environmental impacts. Again, the extent of these costs is not known.
In the absence of regulatory or economic incentives to adopt alternatives and assuming methyl bromide is in most cases the lowest cost effective system at present, an alternative would not be voluntarily adopted unless it performed as well or better at the same market cost. Technically feasible alternatives will have limited market acceptance if they are more costly – and in the world of bulk commodities, it is difficult to entice end buyers to pay a higher price for goods treated with alternatives.

If however the goal is to replace methyl bromide with alternatives while maintaining protection against high risk pests as a primary goal and market forces have not resulted complete adoption of alternatives, then alternative actions such as the following may be considered to encourage further steps. The following list shows some diverse examples of activities that different Parties have chosen to undertake, leading to reductions or expected reductions of methyl bromide use for QPS:

- Publically (government) subsidized or direct research into alternatives e.g. Argentina, Australia, China EC, Japan, and the USA.

- Subsidies to encourage use of non-MB systems, e.g. the first alternative treatment facility at a major port in the Netherlands, initially received a government subsidy as seed funding (this led to further commercial adoption without subsidies).

- Taxes on the use of MB systems. e.g. Czech Republic and several other countries have applied taxes on the imports of MB (and other ODS) for many years; this encouraged the uptake of alternatives.

- Voluntary levy to fund research. e.g. New Zealand Stakeholders in Methyl Bromide Reduction

- Prior approval for each MB fumigation taking account of the availability of an alternative treatment, e.g. in the 1980s the Netherlands introduced a prior approval system for each MB fumigation – the use of MB was not authorised in situations where alternatives could be used.

- Obligatory use of recapture/destruction equipment, e.g. in 2007 Belgium required the capture of 80% of available gas from MB fumigations. This requirement increased the cost of methyl bromide treatments while reducing the environmental impact of MB use.

- Reassessment of MB conditions of use increases compliance costs or restricts use.

- Cap or freeze on the quantity of MB permitted for QPS, e.g. the EC placed a freeze on QPS consumption from the year 2001 onwards (Regulation (EC) no 2037/2000).

- National prohibitions or bans on QPS uses of MB, e.g. Denmark (Statutory Order 974, 1995), Sweden (Pesticides Ordinance 1998:947), Finland (CSD 262/98, 1999); the EC has recently de-registered MB as a pesticide because MB failed to meet the safety/health criteria, and enacted a ban on MB use effective 18 March 2010.

- Prohibitions or voluntary restrictions on specific QPS uses, e.g. Canada and Taiwan have discontinued the use of MB for ISPM 15, using alternatives only (TEAP 2008 p.113).

- Unilaterally or multilaterally banning all or specific uses of MB for QPS.

Some parties already implement variations of the first option. A ban on MB use for QPS has now been adopted in some Parties (e.g. Denmark (Statutory Order 974, 1995), Sweden (Pesticides Ordinance 1998:947), Finland (CSD 262/98, 1999)) and has been adopted at the regional level e.g. in 2010 in the EC, and has been announced for 2015 in Brazil. The Russian Federation no longer allows use of methyl bromide, including for QPS, though there are pressures to reverse this ban (communication to MBTOC, 29th OEWG).

A large number of Parties (e.g. 97 A5 Parties) have reported no use of MB for QPS altogether as discussed previously in this Chapter.

In some cases methyl bromide alternatives are in use, even though their market prices are higher. This has occurred for diverse reasons – such as health or safety concerns about methyl bromide, idiosyncratic circumstances or because the users anticipate that methyl bromide will be banned or taxed and they expect their early adoption will soon result in higher profits.

In many cases, MB is an established and traditional practice, not subjected to the rigorous and expensive efficacy testing that might be required of a new entrant in the market. It is also often the case that MB alternatives are more practical when applied at the point of origin, thus relocating the quarantine barrier offshore. More options may be available at that location including strategies to ensure product health during the production process. Factors of scale may also be relevant in this respect: large quantities of products at the point of origin may allow for more cost efficient treatment, for example by justifying installation of irradiation facilities, cold or heat treatment facilities, and others, which would not be feasible at points of entry.

However, treatment with MB often affects product quality negatively, which mainly translates into a reduced shelf life. This makes some exporters reluctant to apply treatments before export. Finally, most alternatives are more expensive than fumigation with MB at the port of entry, which further deters from their development and adoption.

6.17.2. Regulatory (including health issues)

Countries have regulations that list requirements allowing for a commodity to be imported into their boundaries, including quarantine treatment requirements. In some cases, the only treatment that is listed as acceptable is MB, indicating that there are no available data to prove the efficacy of alternatives at a level which is consistent with the country's quarantine security requirements.

Regulations prescribing MB treatment alone are a major barrier to adoption of alternatives as often there is little incentive for the regulation to be changed. Also, often the data have not been generated to prove effective control of all pests with an alternative to a standard similar to MB and Parties are unwilling to approve the alternative in the absence of this information.

Constraints to adoption of alternatives for treating soil where crops will be grown with MB are mainly regulatory – that is, alternatives not being registered at the location where treatment occurs or being highly restricted[20] by regulations. Certification regulations sometimes do not recognise other treatments different to MB to achieve the high plant health status required, although developments in this respect are beginning to occur (for example, NIPM Item #7 "Approved treatment and handling procedures to ensure against nematode pest infestation" lists 1,3-D and methyl iodide aside from MB, as alternative treatments to achieve certification requirements related to nematode control (CDFA, 2009)).

The registration of a new chemical or extension of the label are often a very onerous and expensive tasks, which can take years to resolve and require considerable data on safety and efficacy. For many countries the potential volume of use is too small or cannot guarantee the intellectual property rights to justify registration.

6.17.3. Post-entry quarantine measures

Given that activity normally taken place at ports, it is frequently considered impractical to establish treatment facilities such as for irradiation or other similar measures for treating goods infested with quarantine pests due to space or environment restrictions. Further, treatments are generally performed by private contractors not government authorities, which means there has to be sufficient through-put on a continuing basis to justify the costs of facilities as well as the training and maintaining of staff to operate them. Even if treatments are available in the area, quarantine officers will often not allow the product to be moved from the port for treatment due to risks of pest dissemination. In view of this, if pests are discovered at the port of entry, it is important to have access to a wide spectrum treatment which is fast and portable, generally fumigation. Presently, four fumigants are widely available for use: methyl bromide, phosphine and, to a lesser extent, sulfuryl fluoride and HCN. For a variety of reasons including tradition, efficacy, registration, occupational health and safety issues and speed of action, methyl bromide frequently is the leading available fumigant for use at many ports at present.

Decision on the actual treatment to be applied is made by the importing country. According to the particular case, it may even be decided that no treatment is necessary.

[20] These observations should not be taken as criticisms of the validity of the registration process.

6.16.5. Research priorities for alternatives to MB for QPS

Research should be focused on the highest volume use categories as stated in this assessment (logs, wood packaging materials, grain and fruit) and in those countries reporting an upward trend in MB use.

6.18. References

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7

7. Factors that have assisted with methyl bromide phaseout in Article 5 countries

7.1. Introduction

This chapter updates the progress made in phasing out controlled uses of methyl bromide in Article 5 countries. It identifies major technologies implemented and factors that have assisted MB phase-out in MLF projects. As the 2015 deadline for complete phase-out of controlled uses approaches, progress made, lessons learned and remaining challenges become more important in A5 countries.

Since phase-out in Article 5 countries has been achieved mainly through MLF-funded projects implemented by the agencies of the Montreal Protocol, a list of the main types and objectives of MLF projects is included, together with the main alternatives adopted in different counries and regions. Detailed information on consumption trends in Article 5 countries including the major consuming sectors can be found in Chapter 3 of this Assessment Report.

The following information sources were used in compiling this chapter: the Data Access Centre of the Ozone Secretariat (accessed December 2010), the project database of the MLF Secretariat (accessed December 2010), MLF project reports submitted by governments, information provided by national specialists and implementing agencies, and published papers listed in section 7.3.

7.2. MLF projects in Article 5 Countries

Established under Article 10 of the Montreal Protocol, the Multilateral Fund (MLF) has provided financial assistance to Article 5 countries for phasing out MB. The MLF projects, together with the voluntary efforts of growers and users, have made a major contribution to the MB reductions described in Chapter 3. In this section the main types of MLF projects are described and an overview of the main alternatives that Article 5 countries have selected and adopted on a wide scale in phaseout projects is provided. Technical descriptions and other background information about alternative technologies are not covered in this chapter but are provided in Chapters 4 (alternatives for soil treatments) and 5 (alternatives for commodity and structural treatments).

7.2.1. Types of MB users

MB users in Article 5 countries are diverse, ranging from small farmers (0.5 ha and less) to very large enterprises. There is also much variation with respect to the level of technical expertise, which is not necessarily correlated to the size of the operation, but possibly more to the destination of the crop - local market or export. Importing markets generally impose stringent quality demands (and increased compliance with social and environmental standards) and consequently are technically more demanding.

Consumption of MB is not restricted to technically advanced enterprises. Simple, low technology methods of MB fumigation using disposable MB canisters of about one pound are still available in a number of Article 5 countries, although they are now banned in others (for example Chile, Costa Rica, Kenya, Argentina and Morocco). Disposable canisters have undoubtedly stimulated use of MB because they avoid the need for large and expensive injection rigs and professional applicators for soil treatments with MB. The transfer of disposable-canister technology to China, for example, in the mid-1990s (resulting from an Israel-Sino agreement) led to large increases in MB use in China at that time. The ban on canisters is considered to be one of the key factors that helped Chile, for example, return to compliance with Montreal Protocol commitments regarding MB.

7.2.2. Overview of MLF projects

Many Article 5 countries have implemented, or are in the process of implementing, MLF-funded projects to complete MB phase out. Projects have undoubtedly contributed significantly to the MB reductions achieved to date. By December 2010 the MLF had approved a total of 373 projects in more than 80 Article 5 countries, with an approved expenditure of approximately $130 million (MLF, 2010). This included all types of MB-related activities: demonstration projects, technical assistance, training, project preparation, workshops, awareness raising and MB phaseout projects. The latter are also called investment projects, multi-year projects or national phaseout plans and involve agreement to completely phase-out MB before the 2015 deadline.

MLF projects can be classified into the following broad categories, which are explained in more detail in the following sections. The figures below provide data on MLF projects approved between 1992 and December 2010 (MLF, 2010):

- **Demonstration projects** – 44 were approved since 1992 (2 were cancelled).
- **Technical assistance** - 90 projects concerning information and awareness-raising activities such as workshops, technical assistance, information exchange on MB phaseout and alternatives, policy development and various other activities (one cancelled).
- **Project preparation** - 126 initiatives for the preparation of new projects, including the collection of data on MB uses (11 cancelled); and
- **Investment or MB phaseout projects** – 113 projects. This category is the one showing the largest increase since 2006. At present, 41 of these projects are on-going, 3 have been newly approved and 71 have been completed. One was cancelled.

MLF data indicates that 291 (78%) of the total 373 MB projects were completed by December 2010, while 67 (18%) of MB projects are due to be completed within the next few years. Four per cent of the projects (15 projects) have been cancelled

In addition to the MLF work, a number of MB projects have been funded from other sources, by Article 5 countries themselves - for example China – or by the Global

Environment Facility (GEF), or bilateral assistance for example from the governments of Australia, Germany (GTZ), Italy, Canada and Spain. In some countries farmers or exporters associations or private enterprises have also financed experiments to identify or adapt alternatives to MB; examples include those in Morocco, Egypt, Jordan, Lebanon and Kenya. In all projects, costs are shared with a local counterpart institution and key stakeholders (for example growers or their trade organizations).

MLF projects approved by December 2010 are scheduled to eliminate a total of 12,794 metric tonnes of MB in Article 5 countries (MLF, 2010). The total phaseout achieved by MLF projects by December 2010 was 10,320 tonnes (Table 38), which is 81% of the total due to be phased out by the projects. Many Article 5 countries have achieved the MB reductions and phase-out that were scheduled in MLF projects. In some cases there were delays, in other cases projects achieved the MB reductions faster than scheduled.

TABLE 38: IMPACT OF MLF MB PROJECTS APPROVED TO DECEMBER 2010

Project type	MB phaseout planned in projects (tonnes)	Phase-out achieved by December 2010 (tonnes)
Investment	12,271.6	9,631.2
Demonstration	38.6	38.6
Technical assistance	473	640
Training	10.5	10.5
Total	**12,793.7**	**10,320.3**

Source: MLF Secretariat, December 2010

7.2.3. Demonstration projects

In 1997, Decision IX/5 relating to conditions for control measures on MB in Article 5 countries stated, inter alia, that the MLF should meet, on a grant basis, all agreed incremental costs of Article 5 countries to enable their compliance with the control measures on methyl bromide. The MOP agreed that the Executive Committee of the MLF should develop and apply specific criteria for MB projects in order to decide which projects to fund first and to ensure that all Article 5 countries are able to meet their obligations regarding MB.

At that time, Parties agreed to give immediate priority to MLF activities for the purpose of identifying, evaluating, adapting and demonstrating alternatives. As a result the MLF approved a series of demonstration projects, which formed the basis for investment and phaseout projects undertaken later.

Demonstration projects were not intended to reduce or phase-out MB consumption, but rather at transferring technologies to Article 5 regions from countries that already used alternatives, evaluating and comparing performance and efficacy of alternatives (including yields, costs, etc.) under the specific circumstances found in Article 5 countries, as compared to MB. The projects considered differences in agricultural practices, resource availability, climatic conditions and other relevant factors. Table 39 provides a summary of demonstration projects approved in the past. Detailed information on these projects can be found in the MBTOC 2002 and 2006 Assessment Reports.

Demonstration projects evaluated a wide range of chemical and non-chemical alternatives, in diverse situations, climates, soil types and cropping systems. They involved many different types of MB users, ranging from small producers with less than 0.5 ha, to medium and large producers, who produced under low, medium and higher levels of technical sophistication (which does not necessarily correlate with size of operation).

With very few exceptions, demonstration projects enabled the identification of suitable alternatives for all sectors using MB in Article 5 regions. They also helped highlight possible barriers and constraints to commercial adoption of alternatives which were taken into account when implementing investment projects.

TABLE 39. DEMONSTRATION PROJECTS IMPLEMENTED UNDER THE MLF AND BILATERAL AGREEMENTS

Region	Country	Crops covered in demonstration projects (soil fumigation)	Postharvest sectors covered
Latin America and Caribbean	Argentina	Tobacco, Protected vegetables, tomato, flowers, strawberry	Cotton and citrus
	Brazil	Tobacco	
	Chile	Tomato, pepper	Commodities
	Colombia	Banana	
	Costa Rica	Melon, cut flowers,	
	Dominican Republic	Tomato, melon, tobacco, flowers	
	Ecuador	Flowers	
	Guatemala	Broccoli, melon, tobacco, tomato, flowers	
	Jamaica		Tobacco
	Mexico	Tomato, strawberry, melon, flowers, tobacco	Structures
	Uruguay	Cucumber, pepper, tomato seedbeds, tobacco, nurseries	
Africa	Botswana	Tomatoes and cucurbits	
	Cameroon	Tobacco	
	Egypt	Strawberry, tomato, cucurbits	Stored grain
	Kenya	Flowers	Stored grain
	Morocco	Tomato, cucurbits, strawberry	
	Senegal		Peanut seed
	Tunisia		Dates
	Zimbabwe	Tobacco	Stored grain
Asia	China	Tobacco, tomatoes, cucumber, strawberries, ginseng	Stored grain
	Indonesia		Stored products: milled rice, wood products
	Jordan	Cucumber, tomato, other soil uses	
	Lebanon	Tomato, cucurbits, eggplant, strawberry	
	Malaysia		Stored timber
	Philippines	Banana, other soil uses	
	Sri Lanka	Tea plantations	
	Syria	Post-harvest and horticulture	
	Thailand	Stored grain: rice, maize, tapioca, feed	

Region	Country	Crops covered in demonstration projects (soil fumigation)	Postharvest sectors covered
		grains, pulses	
	Vietnam	Stored grain, rice, silos, timber	
Europe / CEIT	Croatia	Tobacco	
	Macedonia	Tobacco, horticultural seedlings, vegetables	
	CEIT region	Tomato, cabbage, pepper, celeriac, strawberry	
	Turkey	Tomato, cucumber, flowers	

7.2.4. Phaseout projects

MLF phaseout projects (also called investment projects, multi-year agreements, national phaseout plans or sector plans) aimed to eliminate MB use by assisting the commercial adoption of alternatives that have been identified as technically and economically feasible for a particular country and crop situation, either as a result of demonstration projects carried out previously or from experience derived from similar regions and circumstances.

These projects have normally provided assistance to growers and other MB users in the adoption of MB alternatives; such assistance was often in the form of equipment and materials needed to implement the selected alternatives; by training large numbers of MB users and extension staff on the effective application of alternative methods; and/or providing technical expertise. The projects also helped to overcome barriers or constraints to the widespread adoption of alternatives, including the development and implementation of policy measures, and facilitating registration of alternatives when necessary.

The project guidelines of the Executive Committee to the MLF define MB phaseout (investment) projects as follows:

"Projects whose primary objective is the reduction, and eventual elimination of methyl bromide consumption in sectors or for uses where there are clearly demonstrated efficacious alternative technologies. They should be accompanied by a package of policy measures that the country has committed to ensure that the use being phased out will not merely be replaced by an increase from other users shortly after the projects are completed (i.e. bans and import restrictions)…" (Decision 32/80. UNEP/OzL.Pro/ExCom/32/44. MLF 2000).

The development of policy measures in particular was emphasised in the Executive Committee's guidelines. Although a number of countries have complied with this requirement, the need to reinforce regulations and specifically tracking systems to ensure that MB imported for QPS (exempted) uses does not end up being used in controlled applications is being emphasised.

Investment projects are normally executed by the interested country with assistance from the implementing agencies of the Montreal Protocol - UNDP, UNIDO and the World Bank. Bilateral cooperation with individual countries (e.g. Germany/GTZ, Italy, Spain, Canada, Israel, Australia and France) has also occurred in some projects.

Only those countries that have ratified the 1992 Copenhagen Amendment of the Montreal Protocol - adding MB to the list of controlled ozone-depleting substances – are eligible for MB investment projects funded by the MLF (MLF, 2000).

Investment projects have normally included schedules or timetables for national MB reductions that lead to phase-out earlier than the Protocol schedule of 2015. This has greatly contributed to the global reduction of MB use in A5 countries described in Chapter 3. In addition, early phaseout has brought other benefits for example by improving production practices in Article 5 countries, making productive sectors more competitive, and allowing efficient exports in many cases.

Table 40 illustrates progress in the MLF phase-out projects achieved by December 2010 in Article 5 regions. The greatest progress has occurred in CEITs and Asia, where 98% and 88% (respectively) of the regional tonnage covered by projects was phased out by the end of 2010.

TABLE 40. MLF MB PHASEOUT PROJECTS BY REGION (AT DECEMBER 2010)

Region	MB phaseout planned (tonnes)	Phase-out achieved by December 2010 (t)
Africa	3,043.5	2,205.5 (73%)
Asia and the Pacific	3,435.3	3,006 (88%)
CEIT	919.1	902.5 (98%)
Latin America/ Caribbean	5,394.8	4,301.8 (80%)
Total	**12.793**	**10,320.2 (81%)**

Source: MLF data, December 2010

Phaseout projects have specifically addressed those sectors where MB use was relevant in Article 5 regions, especially strawberries (fruit and runners), cucurbits, flowers, tobacco seedlings, tomato, pepper and eggplant, and others, such as green beans, ginger, bananas and fruit tree production.The majority of projects in the postharvest sector have been for stored grain and dried foodstuffs.

The projects have shown that very large MB reductions are feasible over periods of 4 – 5 years, especially in cases where governments and MB users make constructive efforts to transfer and adopt existing alternatives. This period has in many cases included registration of chemical alternatives not previously available to users, as well as the adoption of non-chemical technologies.

7.2.5. Alternatives chosen in phaseout projects

The fact that MB uses cannot generally be replaced by one in-kind alternative was highlighted in past MBTOC reports (1994, 1998, 2002, 2007) and was confirmed in MLF projects. This often meant that growers and other stakeholders had to change their approach to production and even had to make important changes in process management. Such changes mostly relate to the implementation of IPM practices but also time management as some alternatives require longer exposure times than MB. Reluctance to change has often been cited as one of the major reasons delaying adoption of alternatives, even above economic concerns.

Projects conducted in Article 5 countries have demonstrated that a similar range of alternatives as those of non-Article 5 countries can be successfully adopted. Differences in costs, logistics and resource availability can lead to a preference for different alternatives in Article 5 compared to non-Article 5 countries. Table 41 lists the main alternatives adopted by some Article 5 countries by region and the degree to which they have currently displaced MB use (many have phased out MB completely). For a detailed description of alternatives please refer to Chapters 5 and 6 of this Assessment Report.

TABLE 41. TECHNOLOGIES ADOPTED IN MB PHASEOUT PROJECTS, BY REGION

Region	Country	Soil technologies selected	Postharvest technologies selected	MB displacement status (2009)
Latin America and Caribbean	Argentina	Chemicals (1,3-D/Pic, MI, MS, DMDS), steam, floating trays		64% of baseline
	Bolivia	Steam, substrates		Phased out
	Brazil	Floating trays, substrates, metham sodium, steam, solarisation (solar collector)		Phased out
	Chile	1,3-D/pic, steam, steam + Trichoderma, metham (rotary-spading injection), methyl iodide		70% of baseline
	Costa Rica	1,3-D/pic, metham, solarisation, biocontrols, steam		55% of baseline
	Cuba	Floating trays. Steam, grafting, biocontrols	Phosphine + CO_2 and heating , sulphuryl fluoride	Phased out
	Dominican Rep.	Floating trays, solarisation, metham sodium, steam, substrates		Phased out
	Ecuador	Substrates, chemicals		77% of bseline
	Guatemala	Chemicals, grafting,biocontrols		60% of baseline
	Honduras	Chemicals, floating trays, grafting, biocontrols		52% of baseline
	Mexico	Grafting, chemicals, IPM, steam, solarisation	Phosphine + CO_2	66% of baseline
	Peru	Steam, floating trays, solarisation, biocontrols, biofumigation		Phased out
	Uruguay	Solarisation + chemicals (1,3-D/Pic, MI, MS, DMDS), biofumigation, steam		75% of baseline
Africa	Congo	Metham, IPM		Phased out
	Egypt	Substrates, steam, biofumigation, grafting	Phosphine, sulfuryl fluoride	80% of baseline
	Kenya	Metham (rotary-spading injection), substrates, steam, grafting, IPM		2% of baseline
	Malawi	Floating trays, chemicals (metham sodium, dazomet)		Phased out
	Morocco	1,3-D/pic, metham, grafting, solarisation + chemicals, steam, substrates		15% of baseline
	Senegal		Phosphine, (tablets of metallic phosphide) IPM,	Phased out

Region	Country	Soil technologies selected	Postharvest technologies selected	MB displacement status (2009)
	Sudan		Phosphine, IPM	60% of baseline
	Uganda	Metham (rotary-spading injection), steam, substrates		Phased out
	Zimbabwe	Steam, IPM, floating trays		Phased out
Asia	China	Metham sodium, grafting, chloropicrin, 1,3-D, limited biocontrol	Phosphine	22% of baseline
	Indonesia		Phosphine, IPM	Phased out
	Iran	Steam, solarisation, with IPM	Phosphine, IPM, Metallic phosphides	9% of baseline
	Jordan	Solarisation, grafted plants, chemicals, biocontrols, others		15% of baseline
	Lebanon	1,3-D,, 1,3-D/ Pic, metham sodium, solarisation, solarisation + reduced doses of chemicals, grafting, crop rotation, biofumigation, floating trays		Phased out
	Libya	Solarisation + chemicals (low doses), substrates, grafting.		32% of baseline
	Syria		Phosphine + CO_2 IPM	9% of baseline
	Thailand		Phosphine, CO_2, aluminium phosphide, IPM, sulfuryl fluoride	24% of baseline
	Tunisia		Phosphine + CO_2	79% of baseline
	Turkey	Grafting, metham sodium, 1,3-D, 1,3-D/Pic, solarisation, substrates, grafting, resistant varieties, steam (limited)	CO_2 and magnesium phosphide	Phased out
	Vietnam		IPM, phosphine, CO_2, sulfuryl fluoride	54% of baseline
Europe / CEIT	Bosnia & Herzegovina	Floating trays, solarisation, biofumigation		Phased out
	Bulgaria [a]	Metham (rotary-spading injection), dazomet		Phased out
	Croatia	Floating trays		Phased out
	Hungary	Metham (rotary-spading injection), dazomet		Phased out
	Macedonia	Floating trays, solarisation+biofumigation		Phased out
	Poland [a]	Metham (rotary-spading injection), dazomet, steam		Phased out
	Romania	Chemicals, grafting, solarisation + 1,3-D/ Pic, metham sodium		Phased out

Sources: UNIDO, UNDP, World Bank, national experts and Desk Studies on Methyl Bromide Projects, MLF, 2005c, MLF, 2007, MLF. 2005 Evaluation of Methyl Bromide Phase-out projects. Sub-sector reports and country case studies. Consumption data from Data Access Centre of Ozone Secretariat, December 2010.

[a] GEF regional project in CEIT countries

7.2.6. Crop specific technology choices in A5 countries

The main alternatives selected for the different sectors where MB is still being used in A5 countries are briefly described below. For a more detailed descrption of these alternatives please refer to Chapters 4 and 5.

7.2.6.1. Ornamental crops

Floriculture is a complex industry with hundreds of flower types, production cycles and cropping systems involved. Increasingly, flowers and ornamental plants are produced in tropical and subtropical countries (mostly Article 5 countries) and then exported to industrialised countries. Quality and production standards for ornamentals are stringent, and play an important role in the industry. Several certified eco-labels and quality assurance programs restricted or prohibited the use of methyl bromide, as one of the conditions of certification. ASOCOLFLORES, MPS and Global-GAP, for example, prohibited the use of MB as a soil fumigant in ornamentals from 1998, 2001 and 2004, respectively (ASOCOLFLORES, 2010; MPS, 2005; Eurep-GAP 2003, Global-GAP 2009). Thousands of cut flower and ornamental producers have complied with these certified standards, in many countries around the world.

Progress has been made since 2006 with the registration of various chemical alternatives not previously available to growers in developing countries. Adoption of alternatives that do not need registration such as steam and substrates has increased particularly for flowers grown in protected environments. Roses, carnations and gerberas are the flowers most commonly grown in substrates in countries like Uganda, Kenya, Ecuador, Colombia and Brazil among others, and this production system is now expanding to other flower types, for example many kinds of bulbs and lisianthus. Although the initial set-up cost of a soil-less production system is comparatively expensive, growers are generally able to compensate the extra cost through significantly better yields and quality, higher planting density, optimum plant nutrition and improved pest and disease control. The identification of cheap substrates which are often locally sourced, significantly contributes to the economic feasibility of substrate systems.

Steaming methods and equipment have improved, with mobile and quicker devices now available (e.g. Movilvap machine developed in Argentina). Although still expensive, steam is a very effective alternative for protected flower production in soil and for sterilizing re-utilised substrates. Experience has demonstrated that the costs associated with steaming can often be reduced through implementation of IPM strategies and by considering different types of fuels, boiler types and steaming systems. Steaming is used by flower growers in Brazil, Costa Rica, Kenya, Mexico, Uganda and Colombia and has been found to be particularly successful when combined with organic amendments like compost and biocontrol agents such as *Trichoderma* spp.

Chemical alternatives which are used increasingly in ornamental production include dazomet, metham sodium and 1,3-dichloropropene, the latter often combined with chloropicrin (Pic). Methyl iodide has been registered in several Article 5 countries and is in the process of registration in others.

Solarisation, once considered unsuitable for ornamental crops, is proving effective in particular instances. For example, pot plant growers in Brazil, Mexico and Cuba are finding the “solar collector” (Ghini, 1993; 2004; Ghini *et al.,* 2007) to be very useful for quickly and easily cleaning small amounts of substrate at a very low cost. The solar collector was developed by Ghini (1993) to disinfest substrate using solar radiation, which heats the substrate and inactivates plant pathogenic microorganisms. The equipment comprises six aluminum tubes (15-cm diameter) placed in parallel rows in a wooden box (1.5 m × 1.0 m × 0.3 m), covered with transparent plastic film. Soil or substrates are placed inside the tubes through the upper hatch, during the early morning, and recovered through the lower hatch, after 24 hours of treatment of a sunny day. After treatment, the substrate can be immediately used in potting mixes or stored. A case study to illustrate MB phase-out in the flower sector of Brazil can be found at the end of this Chapter.

7.2.6.2. Strawberry fruit

Strawberry fruit and other berries accounted for about 23% of the remaining MB consumption for controlled uses in A5 countries in 2009 (section 3.7.8). The most effective chemical alternatives for strawberry fruit production in MB projects include 1,3-D + Pic and drip-applied formulations of either Pic alone or 1,3-D/Pic with or without a follow-up treatment of metham sodium.

Chloropicrin alone has proven successful for example in China where its use has gained popularity since its registration as a soil fumigant in 2002. Results obtained are equivalent to those achieved with MB and at lower cost (Cao, 2006).
Metham potassium, Pic alone (drip-applied), 1,3 D-Pc, and metham sodium all gave equivalent results to MB 50:50 in Baja California, Mexico and are being transferred to high tech level growers (Cotero et al.; 2009).

Metham ammonium and iodomethane are giving good results on controlling weeds and pests in northwest (Borquez et al.; 2009) and southeast (Adlercreutz, et al.; 2009) Argentina´s strawberry fruit production (Maero et al, 2008).

Treatments with metham or metham + VIF showed no significant difference from MB in yield, vigour and quality of strawberry in China (China-Italy Project, 2003).

Drip fumigation with metham sodium has increased sharply as of 2002 in Morocco, replacing large amounts of MB used in the past (Chtaina, 2006). Yields and fruit quality obtained with metham sodium were equivalent to those achieved with MB. Adoption of other chemical alternatives is also taking place, like metham potassium, 1,3D/ Pic and metham sodium +1,3-D.

Steam and substrates have been adopted in specific circumstances where these alternatives are economically feasible, such as some specific areas of Argentina and China among others.

7.2.6.3 Strawberry nurseries sector

MB is used for the production of strawberry runners in some cases to meet the stringent certification standards for virtually pest-free strawberry runner stock, which is often grown in high altitudes under cold and wet conditions. Presently, the combination of 1,3-D + Pic continues to be the leading alternative to MB for runner production in Article 5 countries. Trials with methyl iodide and metam sodium applied with a spading machine have also given encouraging results (Maero *et al*., 2008).

Simple, economically feasible substrate systems have proven particularly useful for the production of strawberry runners. Various materials are used as substrates (e.g. rock wool, peat moss, rice hulls, coconuts husk and pine bark) and can be reused after sterilising with steam, solarisation or hot water. Bunker steaming has been found to be a feasible alternative for example in Argentina. In Lebanon, soil solarisation combined with a crop rotation cycle of 3 years is used as an alternative to MB in strawberry nurseries.

7.2.6.4 Nurseries and propagation material for other crops

Propagation material of many types (bulbs, cuttings, seedlings, young plants and trees) is also subject to high health standards. Substrates, in trays or larger containers according to the plant type and size, have proven to be suitable and effective MB alternatives in countries, such as Costa Rica, Chile, Colombia, Kenya, Ecuador and Argentina.'

In Chile the combination of steam + Trichoderma was successfully adopted as a MB alternative for nursery trees grown in substrates. In Brazil, very large forest nursery companies produce millions of tree seedlings every year wholly on substrates with excellent results.

7.2.6.5. Tomato, pepper, eggplant and other vegetables

Tomato, pepper, eggplant and other vegetables (excluding cucurbits) accounted for about 24% of the remaining MB consumption for controlled uses in Article 5 countries in 2009 (Section 3.7.8). The most effective alternatives for these vegetable crops are combinations of chemicals such as 1,3-D, chloropicrin, metham sodium and dazomet and non-chemical methods such as substrates, grafting, resistant varieties, biofumigation and solarisation. These combinations have been widely adopted in A5 countries that have used MB for vegetable production.

Grafting has expanded very significantly in A5 countries (Besri, 2004, 2007; Miguel, 2004a). Turkey for example, replaced the substantial quantities of MB previously used on its tomato, pepper and eggplant sectors by growing grafted plants on solarised soil (Yilmaz *et al,* 2006; 2007). One hundred percent of tomatoes in Morocco are now produced on grafted plants. Mexico is reducing MB consumption in its vegetable sectors by using grafted plants.

7.2.6.6. Tobacco seedbeds

The substrate float system (also called floating tray system) is an effective MB alternative, applicable to most regions where tobacco is grown. Most Article 5 countries that implemented MB phaseout projects in tobacco chose the floating tray system as their preferred option, with excellent results. In some cases additional features were adopted, such as water aeration to prevent disease, or mechanisms to moderate water temperature. The use of substrate systems has become widespread for tobacco seedlings in countries like Brazil, Cuba, Peru, Zimbabwe, Argentina, Malawi, Macedonia and Croatia, and has shown very good potential in China.

In some countries, effective results in tobacco seedbeds were also achieved with metham, steam, dazomet and dazomet + solarisation, e.g. Malawi, Macedonia and Argentina. Tobacco seedlings, once accounting for a significant proportion of the MB used in Article 5 countries, now accounts for only about 2% of total use (see section 3.7.8 for additional information).

7.2.6.7. Cucurbits

Cucurbits accounted for about 32% of MB consumption for controlled uses in A5 countries in 2009 (section 3.7.8). Improved grafting techniques that facilitated using resistant plants at lower costs, are increasingly available and now widely used in cucurbit production in many countries (Miguel, 2004ab; Besri 2008). Many different cucurbits have been grafted, including cucumber, cantaloupe, watermelon, pumpkin, squash, and gourd . Grafting is intensive in hand labour and requires appropriate training and investment, however its applicability is widespread due to the international availability of seeds of resistant rootstocks.

Production of grafted cucurbits continues to expand in Mediterranean countries (Besri, 2008) as well as in Central America (Díaz-Pérez *et al*.; 2008), and adoption is increasing in Mexico (Ricárdez- Salinas *et al*.; 2010). China produces more than half the world's watermelons and cucumbers, and approximately 20% of these are grafted.

Other alternatives selected for investment projects involving cucurbits included solarisation, which is presently used on several hundred hectares grown with melons in Costa Rica (Abarca, 2006) and chemical fumigants, mainly 1,3-D/Pic and metham sodium, combined with crop rotation and IPM practices.

7.2.6.8 Flour mills and food processing premises

The main alternatives to the disinfestation of flour mills and food processing premises include sulfuryl fluoride, heat and IPM programmes that involve careful sanitation and cleaning and pest monitoring. Sulfuryl fluoride has proven effective for example in projects in Egypt, Mauritius, Thailand and Vietnam. It has been approved or registered in Mauritius and Trinidad and Tobago (A. Kawal, *pers. comm*., December 2004; A. Schreyer, *pers. comm.,* March 2009).

7.2.6.9. Stored grains, dried fruit and nuts

In the case of stored grain and dried foodstuffs (which account for the larger postharvest use in Article 5 countries), phosphine, particularly in fast generating gas forms has also become an important alternative in some applications, primarily commodities. Combinations of phosphine (often as magnesium phosphide) + CO_2 are also reported to be efficient, especially when used within an IPM framework. A good example of results obtained with this combination is the control of dried fig pests in Turkey (Meyvacõ *et al*., 2003; Aksoy, 2006). Other treatments such as controlled atmosphere (low-oxygen) + raised temperature, and controlled atmosphere alone, have also been found effective for high-value stored products, such as dried fruit in Turkey (Emekci et al. 2004). Controlled atmosphere/heat treatment facilities have been established in countries such as China, India, Indonesia, Singapore, Turkey and Vietnam (J. Van Golen, *pers. comm*. December 2010).

7.2.7 Lessons learned from projects

The phase-out of MB for controlled uses in Article 5 countries is well advanced, with only 28% of the aggregate baseline consumption remaining 5 years before the established phaseout deadline of 2015. The implementation of MLF projects has provided many useful experiences that can be summarised as follows:

- As controlled uses are phased out it has become increasingly important to document and characterise QPS uses more closely, to prevent 'leakage' to other uses, and to strengthen policy measures relating to MB use.
- Technically effective alternatives to MB have been found for virtually all pests and diseases, however a small number of sectors and situations still pose challenges, for example high moisture dates in Tunisia, Algeria and others, ginger in China and strawberry nurseries in Argentina and Chile.
- The cost and profitability of alternatives was found to be acceptable or comparable to MB in many projects. However it is desirable to make further efforts to reduce the costs of alternatives in some specific situations, to prevent users reverting to MB.
- While a number of projects have promoted alternatives that will be environmentally sustainable in the longer term (such as IPM and non-chemical approaches), some projects focussed primarily on chemical alternatives. Chemical treatments, particularly fumigants, are likely to face increasing regulatory restrictions worldwide in future. .
- The capability to adapt to site-specific conditions is essential to the success of any alternative.
- Projects demonstrated that successfully evaluated alternatives can be adopted by large numbers of growers in developing countries in periods of 2-4 years within proactive projects. Also, activities related to demonstration projects led larger or more technically prepared growers to adopt alternatives at their own initiative.
- Involvement of an ample range of key stakeholders is essential to the success of a project or the phase out achieved.

7.2.8. Cases of non-compliance and revision of phase out schedules

The number of countries in non-compliance with the freeze of 2002 or the 20% reduction of 2005 was small (5.5% failed to meet the 20% reduction step on time). A study conducted by the MLF found that common reasons to explain non-compliance at the time included late ratification of the Montreal Protocol, a weak National Ozone Unit (or lack of continuity due to frequent staff changes), delayed approval of ODS-related legislation, expansion of key MB-using sectors after the baseline years and reluctance to change on the part of key stakeholders (MLF, 2005a; 2006; 2007).

Presently, all Article 5 countries are in compliance with Montreal Protocol obligations relating to MB consumption. The exception is Kazakhstan with a baseline of 26 tonnes and a reported consumption of 112 tonnes in 2009. This country however has not ratified the Copenhagen Amendment, and therefore is not bound by the control measures for MB.

Whilst remaining in compliance, several countries requested an amendment to the phase out schedules agreed upon the initiation of their in multi-year projects with the MLF, for MB phaseout ahead of the 2015 deadline. The main reasons were scepticism towards alternatives on the part of growers, active campaigns in favour of MB and the CUEs granted to non-article 5 countries in similar sectors (cucurbits, strawberries, flowers). Revised schedules have nevertheless helped such countries to return to compliance when necessary and to get back on track with efforts to phase out MB.

One example is Argentina, which initially made strong progress in phasing our MB; at its 46th meeting the ExCom reported that Argentina had phased out 51 tonnes more than the amount committed to in its MLF project agreement (Report of 46th ExCom meeting. UNEP/PzL.Pro/ExCom/46/47 page 34, paragraph 118). However, the project later encountered reticence from MB users in the strawberry sector and adoption of alternatives stalled, making it difficult to meet the original project schedule. At present, Argentina is implementing a regional technical assistance project to introduce modern alternatives (including newer formulations of 1,3-D/Pic and the registration of methyl iodide) and this has contributed to renewed progress in achieving MB phase-out, which will be complete by 2015 (UNIDO, 2008). Uruguay, although a smaller user, is also part of this project with equally positive results (UNIDO, 2008).

Another case is Chile, which came into non-compliance with the MB freeze obligations of 2002. Through an Action Plan approved by the 16th Meeting of the Parties, it returned to compliance both with the freeze and the 20% reduction of 2005. Two investment projects were approved for the phaseout of MB in Chile: one executed by UNDP as the implementing agency and aimed at phasing out 127 tonnes of MB in the replant and nursery sectors, which was succesful, and a second project, approved in April of 2005 aimed at phasing out all remaining uses of MB with the World Bank as the implementing agency. However, strong reticence towards the adoption of alternatives – mainly among new MB users in strawberry fruit and runners - led to the cancellation of this project at the request of the Government of Chile (UNEP/PzL.Pro/ExCom/48). Chile remained, nevertheless, committed to reduce MB consumption to 283.3 tonnes in 2005, in line with the 20% reduction required and also to limit consumption to this level until 2015 using import restrictions and other policies as necessary. Presently, Chile is implementing a technical assistance project to support efforts in achieving total phase out of remaining MB uses (mainly tomatoes, strawberry fruit and runners) by 2015.

Costa Rica also revised its schedule in 2008, which had called for total phaseout by that date. This country revised its consumption and import figures in 2005/ 2006 after finding that the initial breakdown for MB consumption and use was incorrect and consumption in the melon sector was higher than originally estimated (although total consumption figures were accurate). Phase-out is now scheduled for 2013, which is also in line with other large cucurbit producers in the region like Guatemala and Honduras.

Guatemala increased MB use after the baseline years, and later experienced difficulties in achieving compliance with Protocol requirements. Reasons cited by the country at the time included expansion of melon production areas leading to greater use of MB; resistance to phaseout by MB users due to the approval of CUEs for the country's primary export market; higher costs of alternatives; and insufficient involvement of key stakeholders (UNEP, 2006). At present, Guatemala has returned to compliance and is successfully working under a revised phase out schedule which will be completed in 2014.

Honduras was also in non-compliance with Protocol requirements. There too, the melon sector had expanded after the baseline years with an associated increase in MB consumption. Honduras submitted a revised plan of action to ensure its prompt return to compliance with the Protocol's control measures to the MOP (Decision XVII/34) which has been working successfully (UNIDO, pers comm., 2010). This country is back in compliance and is expected to complete the MB phase out by 2012.

7.2.9. Constraints on adoption

One constraint noted in Article 5 countries is the lack of registration of the more modern chemical alternatives (MLF 2005, bc). This pertains mainly to iodomethane, DMDS , 1,3-dichloropropene and its different formulations with chloropicrin for soil uses, and sulfuryl fluoride in the postharvest sector. However, contrary to expectations, lack of registration has not turned out to be a substantial barrier to making progress in MB phaseout. Several Article 5 countries have now registered 1,3-D and chloropicrin formulations, methyl iodide and sulfuryl fluoride, while others have been able to achieve substantial MB reductions and phase-out using other types of alternatives that do not require registration. (Iodomethane, for example, is presently registered and used in Turkey for tomatoes, and approvals are anticipated in 2011 and 2012 in Mexico, Guatemala, Morocco, Egypt and South Africa (Arysta, *pers.comm*, 2010.).

Since 2003/4 the unexpectedly large CUEs requested by some non-Article 5 countries have slowed the progress of MLF projects and other phase-out initiatives in a number of Article 5 countries because their CUEs reduced the confidence in alternatives and the feasibility of achieving MB reductions. This was illustrated by the reaction of growers in some countries in Central America, for example (UNEP 2006). Recent large reductions in CUNs are expected to provide encouragement to Article 5 countries to complete their phase-out by the scheduled date.

7.3. Case studies

The projects have provided useful experiences on the substitution of MB and the adoption of alternatives at the commercial level. Following are two examples of successful phase out of MB in economically important sectors for Article 5 countries – floriculture in Brazil and strawberries, bananas and cut flowers in Morocco.

Solar collectors and steam as alternatives to MB in the Brazilian flower sector

Cut flowers and ornamental plants (for export and domestic use) comprise a dynamic sector valued at US$ 2 billion/year. Diverse environmental conditions allow for year-round production of many species, in both open and protected systems, but pests and diseases led growers to use MB for many years. In 2002, the Government of Brazil issued an administrative rule establishing a phase-out schedule of controlled uses of MB by type of crop with a complete ban of all such uses for 2007. A project was implemented jointly by UNIDO and the Ministries of the Agriculture and Environment of Brazil to phase-out MB in the flower sector.

Two alternatives were selected to replace MB: the solar collector (Ghini, 1993) - used to treat substrate to be used in potting mixes - and steam for soil treatment. Solar collectors can be used all year in Brazil; treated substrates easily reach temperatures above 70°C on sunny days, and this results in adequate control of soil-borne plant pathogens, including *Fusarium*, *Pythium*, *Rhizoctonia*, *Sclerotium*, *Sclerotinia*, *Phytophthora*, *Meloidogyne* and *Ralstonia* (Ghini, 2004; Ghini *et al.,* 2007). The solar collector proved as efficacious as MB, and avoided any problems from the viewpoints of occupational health and environmental contamination. Crops grown in solarised soil showed increased growth and improved flower quality. Since the treatment does not sterilize the substrate, beneficial microorganisms survive and help keep reinfestation in check. The solar collector is economically feasible and cost effective.Steam is expensive, but can be kept within a cost-effective frame when used with wood instead of other fuels and whilst using IPM measures to maintain disease incidence at low levels.

For steam treatment of soil, steam pasteurization was implemented, using a mobile steam injector to guarantee homogeneous application of the steam. Growers received a kit comprising a boiler (600 kg steam / h) powered by eucalyptus wood, which is a secondary product of timber exploits and a mobile steam injector in the soil. Twenty-eight boilers, 27 mobile steam injectors, and 823 solar collectors were donated to fower growers farmers associations in accordance to their reported MB consumption between 2002 and 2006. Training on alternative technologies was provided. Sterilization with steam does not provide long-term protection, and additional IPM measures were essential to keep diseases controlled during the growing period.

At present, 165 growers are using the selected alternativesand diffusing them to other farmers who did not use MB, but nevertheless need to treat soil or substrate. The MB phase-out project not contributed to the protection of the ozone layer, but also provided an opportunity for growers to adopt non-chemical technologies, making them more competitive in the international market. *Provided by Raquel Ghini, Embrapa, Brazil, MBTOC Member*

Alternatives to MB in the Moroccan strawberry, banana and cut flower sectors

In accordance with Montreal Protocol decisions, the government of Morocco agreed to phase out by 2008, 259 tonnes of MB in the strawberry sector, 60 tonnes in the banana sector and 42 tonnes in the cut flower sector. Two MLF investment projects were implemented by UNIDO. The Department of Plant Pathology of the Hassan II Institute of Agronomy and Veterinary Medicine, Rabat, Morocco was the counterpart institution.

In the strawberry sector, drip applied soil fumigation with metham sodium (MS) was used successfully to control fungi (*Rhizoctonia solani , Verticillium dahliae , Phytophthora cactorum)* and weeds (more than 40 species e.g. C*ynodon dactylon, Chenopodium sp , Amaranthus sp*.) MS is injected at a dosage of 200 to 250 g /m^2. MS proved highly effective and economically feasible, and did not require modifications in the cropping system. Yields and fruit quality obtained with metham sodium were equivalent to those achieved with MB (Chtaina and Besri, 2006; Chtaina, 2008a).

In the protected (greenhouse) banana sector, an alternative combining soil solarisation and drip fumigation with 1,3-D EC at a dosage of 20 ml/m^2as a broadcast or row treatment was developed in 2002 – 2004 to control nematodes (*Meloidogyne javanica, Helicotylenchus multicincthus*). This method however requires installation of drip tapes which are connected to the main pipeline independently of the existing sprinkler irrigation system and plastic mulch before treatment, and is time consuming so proved difficult to adopt (Chtaina, 2005). Presently other chemical alternatives such as fenamiphos, cadusafos, oxamyl and fosthiazate are more widely used (Chtaina, 2008b).

In the cut flower sector, solarisation combined with drip application of 1,3-D/Pic drip proved to be efficient for controlling F*usarium spp, Rhizoctonia sp* and nematodes (*Heterodera sachtii and meloidogyne spp.)*. This alternative does not require modifications to the cropping system as the fumigant can be applied through the existing drip irrigation system (Chtaina, 2008b).

All chemical alternatives are registered in Morocco including various formulations of MS and 3 additional formulations of 1,3 D. However, chemical fumigant use in Morocco is in conflict with the European pesticide regulatory controls (***Directive*** 91/***414***/CEE, Annex 1).

Costs of these alternatives compared to MB appear below

		US$/ 1000 m^2
MB	All	640 (1)
Metam sodium (127, 5 g /m^2 of active ingredient) or 250 ml /m^2 of commercial product of 510g/litre ai.)	Strawberries	225 (2)
Solarisation +1,3-D (200 l/ha) (93% ai)	Banana	270 (1) 135 (2)
Solarisation + 1,3-D 65%+ Pic 35% 450 kg /ha	Cut flowers	332 (1)

(1) Broad acre application
(2) Row acre application

Information provided by Mohamed Besri

7.4. References

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8

8. Economic issues relating to methyl bromide phase-out

8.1. Introduction

The purpose of this Chapter is to provide the framework within which decisions on the economic feasibility of Critical Use Nominations (CUNs) are made, and to survey the existing literature as a guide to what is known about the economic impact of the Methyl Bromide phase-out for non QPS use.

Economic appraisal of CUNs remains difficult despite advice from the Parties regarding the nature of the economic information to be provided in the nominations. This difficulty arises because of the absence of practical criteria for determining the financial and economic feasibility of alternatives.

The relevant articles of the formal decisions on which these are based (Decision Ex. I/4 Sections 6 and 9 and Annex 1 Section B4; and Annex I of the Report of the 16th MOP, Section C1, C19 and C20) were replicated in the Assessment Report of 2006 (pages 273 *et seq.*).

8.2. Progress in the assessment of economic feasibility

8.2.1. Background

The experience that MBTOC has gained in the economic assessment of CUNs shows that the following points should be considered in deciding on the information required for the assessment of the economic feasibility of alternatives to the use of methyl bromide:

- The economic assessment starts with a financial analysis of the impact of the relevant activity with methyl bromide and with the alternatives on the 'bottom line' of individual firms.
- Such an analysis is generally conducted on working farms and factories, etc., but may also form part of field trials. In this regard, there is a need to recognise that short term trials can be more expensive than improved procedures eventually used commercially and after experience has been gained over time with alternatives.
- All nominations for a CUE should include a full financial argument for at least the most likely technically feasible alternatives whether or not the nomination is based on technical feasibility. This is to provide for situations where MBTOC may differ on the issue of technical feasibility.
- Accounting systems to measure financial performance differ across jurisdictions. However, the basic components for assessing financial feasibility described below,

i.e. revenue and costs are universal. Accounting systems can also be ignored as they are unlikely to change between the use of methyl bromide and the next best alternative.

- A financial analysis typically provides a snapshot of circumstances given existing prices of inputs and outputs. However, in some cases especially if the adoption of alternatives is expected to change the supply and/or demand for inputs and outputs., it will be necessary to supplement the financial analysis with a more comprehensive economic analysis. In this case, input and/or output prices will change, leading to different budget outcomes. Such partial equilibrium analyses (i.e. analyses of the changes in the input and output markets most directly affected) could be necessary for commodities and structures, soils, or QPS uses.
- Furthermore, it may become necessary to extend the scope of the analysis to take account of the general equilibrium effects of such changes (i.e. the indirect effects of changes in these markets on other markets). General equilibrium analyses typically require considerable resources and will not be used often, but may become necessary in, for example, assessing the impact of the phase-out of QPS uses, which could impact on multiple markets.
- As a final step, economic tools can also be used to assist in answering questions about the economic impact of environmental implications of the changes proposed in a CUN.
- Nevertheless, it is MBTOC's considered opinion that a partial budget analysis will suffice in most economic assessments of CUNs.

8.2.2. Components of an assessment of financial feasibility

In assessing financial feasibility, the calculation of each of the following key components is done for: (i) the firm operating with methyl bromide and (ii) the firm operating with each of the next best technically feasible alternatives for each use:

- **Gross revenue** measures the earnings of the firm; broadly the quantity of the product sold times the average selling price per unit. Where gross revenue is not expected to change as a result of the adoption of an alternative (e.g. use of SF in place of MB in the fumigation of a mill or 1,3 D/chloropicrin use to replace MB for preplant soil fumigation), it is not necessary to consider gross revenue.
- **Variable costs** are those costs of production that vary with the amount produced, e.g. fumigation costs; broadly the quantity of the input used times the cost per unit of input. Borrowing costs for capital equipment (see capital costs below) and the remuneration to the owner are conventionally excluded from variable costs.
- **Fixed costs** are those costs of production that do not vary with the amount produced, i.e. they are incurred whether or not there is any production, e.g. property taxes and insurance premiums. Fixed costs may be difficult to deal with in situations where firms produce more than one product, as they then have to be allocated to different products produced by the firm.
- **Capital costs** are classified as fixed costs; e.g. investment in new machinery. Capital includes a time element as it generates revenues over more than one production cycle and its costs are spread over time through interest on borrowing. Where transition to an alternative involves investment in capital equipment, the costs of such equipment should be spread over the economic life of the asset.

- The **gross margin** is what remains from gross revenue after subtracting certain variable costs. The process of calculating the gross margin is conventionally referred to as **partial budgeting** because it does not include fixed and capital costs.
- It is sometimes necessary to measure a **margin above specified costs**[21], for example where certain capital costs or even fixed costs change as the result of the adoption of an alternative. In this event it is important to specify which costs are included, and how they are measured.
- **Net Revenue (or Net Returns)** is what remains from gross revenue after subtracting variable, fixed and capital costs.

8.2.3. Estimating the components for assessing financial feasibility

- A responsible financial assessment requires sufficient data to construct a partial budget for the current use (in this case production with methyl bromide) as well as for the next best technically feasible alternative.
- However, enterprise budgets in agriculture are difficult to construct because of:

  ⇒ The diversity of firms in terms of size, age and geographic location, etc.;
  ⇒ The diversity of conditions that can affect input use as well as gross revenue;
  ⇒ Changes introduced as a result of the adoption of the next best alternative, such as increased risk of loss in production, increased variability in yields or efficacy, missed market windows, the creation of new markets (e.g. organics), etc.

- Because of this diversity, it is important that the presentation of the budgets be accompanied by explicit statements of the way in which each figure was calculated. Examples of well constructed enterprise budgets can be found at the UC-Davis Department of Agricultural and Resource Economics[22].
- In all these cases, it is not always possible to provide proprietary information on individual firms. Hence, data should be provided for either a ‘typical’ or an average enterprise, i.e. one that shares similar physical, economic, etc. characteristics as the firm(s) in question.
- The information regarding financial feasibility must be assessed for internal consistency, completeness, and reasonableness. Because there are virtually no published sources on the financial feasibility of the adoption of methyl bromide alternatives, MBTOC is largely dependent on the Parties to provide objective sources. **To this end, the work of MBTOC will be made easier if the data that is provided has been verified by a third party**, e.g. via banks that serve the clients in question, government agencies such as extension services, and farmer study groups, etc.
- In terms of financial feasibility, the following considerations apply:
  ⇒ Alternatives that result in significant negative gross margins are not financially feasible.
  ⇒ In the event that the gross revenues are higher and costs are lower (a situation which is unlikely as initial profit gains are generally short term and likely to be offset by increased supply over time), the alternative **is** financially feasible.

[21] In the rest of this Chapter, references to gross margin should be construed as including the option of measuring a margin above specified costs where the use of the latter is warranted.
[22] http://coststudies.ucdavis.edu/current.php

⇒ In the unlikely event that changes in costs and revenues are absolutely equal, the alternative **is** financially feasible because of the environmental benefits accruing.
⇒ When costs and revenues increase or decrease simultaneously, the result is ambiguous, and there is a need to define default values.
⇒ All other effects on the economics of the business are assumed to remain unchanged (e.g. high fuel prices, changes in the commodity price), unless explicitly stated otherwise in the analysis.

- Default values:

⇒ Financial feasibility criteria are needed for those cases where gross margin declines but remains positive. **Thus, Parties asserting that methyl bromide alternatives are not financially feasible should explain why projected impacts are of sufficient magnitude to support their claim.**
⇒ **MBTOC has adopted the default assumption that alternatives leading to decreases in gross margins (or in a margin above specified costs where appropriate) of more than around 15 to 20 percent or more are not financially feasible.**

8.3. A review of the literature

The existing peer-reviewed literature on the economics of the Methyl Bromide phase-out is small, with some 49 publications appearing over the past decade. These follow on some peer-reviewed (US-based) publications from the early-1990s (e.g. Sharpe *et al*, 1993) and other articles such as Forsythe and Evangelou (1994); and Yarkin *et al* (1994a; 1994b).

The literature of the past decade can be divided into three groups:

- Articles that report only the changed (increased) costs of using methyl bromide alternatives;
- Articles that use some form of partial budgeting technique to assess the impact of the use of methyl bromide alternatives on the revenues and costs of a particular application, i.e. on the net financial position of firms (mostly farmers in pre-harvest applications). In these cases, the current use of methyl bromide (in terms of application methods and application rates, etc.) is used as the norm from which deviations are measured;
- Articles that report the impact of the use of methyl bromide alternatives on the sector (e.g. California strawberries, cut flowers in Spain) as a whole.

8.3.1. Cost analysis

There are a number of studies that report the impact of the use of methyl bromide alternatives on the cost structure of the firm. In some cases this impact is extrapolated to the whole industry. Examples include the impact in postharvest applications of methyl bromide alternatives in food facilities (Aegerter and Folwell 2000; Aegerter and Folwell 2001; Odeh *et al* 2004; Tilley, *et al.,* 2007; Adam 2007; Muhareb 2010); in soils use (Caballero and Miguel, 2002; Sorribas *et al* 2002); and in the cost of heating glasshouses (KWIN, 2003).

While these studies are useful in their own right, they do not contribute to an understanding of how to measure the economic impact of the methyl bromide phase-out.

8.3.2 Partial budgeting

A partial budget consists of a full financial analysis of an existing activity (in this case an activity using methyl bromide), and then a repetition of that financial analysis for the activity using an alternative to methyl bromide, where all costs (variable, fixed and capital) and revenues that have changed as a result of the alternative are adapted. The profitability (some measure of total revenue minus total costs) of the two activities is then compared.

At least 27 publications over the last decade have used this approach to assess the impact of the methyl bromide phase-out. Some two thirds of this research was conducted in the USA (Byrd *et al.*, 2006a; Byrd *et al.*, 2006b; Byrd *et al.*, 2006c; Byrd, *et al.,* 2007; Carpenter *et al.*, 2000; Fennimore *et al.,* 2008a; Fennimore *et al.,* 2008b; Fennimore and Goodhue, 2009; Ferrer, *et al.,* 2010; Hueth *et al.*, 1997; Klonsky, *et al.,* 2009; Nelson, 1996; Sydorovych *et al.,* 2004; Sydorovych, *et al.*, 2006; Sydorovych, *et al.*, 2008; Subbarao, 2007; Taylor, *et al.,* 2006; and Taylor, *et al.,* 2008), and the rest in Europe (Akkaya *et al* 2004; Engindeniz 2004; Engindeniz, 2007; Engindeniz, 2008; Engindeniz and Gül, 2009; Grafiadellis 2000; Slusarski and Pietr, 2009; and Yucel *et al.,* 2007).

Furthermore, the Global Horticultural Markets initiative at Michigan State University[23] has a program on the economics of methyl bromide alternatives which aims to evaluate alternatives to methyl bromide in the production of herbaceous perennials and conifer seedlings, using partial budgeting techniques.

8.3.3. Sector-wide analyses

Partial budgeting is used to assess the economic (financial) impact of the methyl bromide phase-out at the level of the individual firm, although the results can be extrapolated to an entire industry in the event that the analysis is conducted for 'typical' firms in that industry. The problem, however, is that such analyses are based on the assumption that **an individual firm** cannot affect the market. In the case of most industries where methyl bromide is currently used this assumption probably holds; however, when extrapolating to the industry as a whole, this is not true in most cases. When a whole industry is affected, demand, supply and hence prices of the product and of the inputs to its production change, affecting the eventual outcome in terms of impact on the individual firm. As a result, economists have devised a wide range of techniques to model the sector and economy-wide impacts of a change such as the methyl bromide phase-out. There have been few such studies published in the past decade, most of them addressing soils use in the USA, and most focusing on the California strawberry industry.

Carter *et al* (2005) point out that, while the benefits of the methyl bromide phase-out accrue globally, the costs are borne by farmers using methyl bromide. However, these costs are not distributed equally amongst all users. High-cost producers and those with access to inferior substitutes will bear the cost disproportionately, as will producers who face competition from producers who are not subject to the phase-out (such as Mexican farmers, who can use methyl bromide until 1 January 2015). To measure this differential impact, the authors use different estimates of the price elasticity of demand for strawberries to assess the impact of the phase-out on different regions in California where strawberries are grown, and test the sensitivity of their results. These show that strawberry revenues will fall due to

[23] http://www.globalhort.msu.edu/

the elastic nature of demand, especially in the peak production period, and that regional differences in impact exist. However, they fail to consider the impact of increased demand on prices, and hence on revenue.

De Canio and Norman (2005) take a completely different approach in an article based on work that was originally done for the Agricultural Economics Task Force of TEAP. They argue that the environmental benefits of regulation (in this case the Methyl Bromide phase-out) must also be taken into account. This, they argue, can be accomplished by considering what non-Article 5(1) countries have paid to the Multilateral Fund, whose task it is to assist with phase-out projects in Article 5(1) countries. By their estimate, this amounted to roughly $24,000 per ton of methyl bromide abated (or $24 per kg), i.e. if a firm (e.g. a strawberry farmer) could show that the use of an alternative would lead to a profit reduction of more than $24 per kg of methyl bromide used, that alternative was not economically feasible. The authors stress that a reduction in the use of an ozone depleting substance benefits the entire globe, regardless of where the reduction took place. However, their approach has been criticized on the grounds that projects have all been implemented in Article 5(1) countries where the costs of implementation are not the same as in non-Article 5(1) countries. The authors also recognize that the cost of the phase-out need not be borne only by the producers, as governments can implement programs (e.g. tax incentives, subsidies) that shift part of that cost on to society as a whole.

Deepak *et al* (1996) used a quadratic programming model to evaluate the economic impact of the methyl bromide phase-out on the US winter fresh vegetable market for tomatoes, green peppers, cucumbers, squash, aubergines (eggplant), and watermelons. Their model accounts for "equilibrium prices and quantity consumed by month and crop in … New York, Chicago, Atlanta, Los Angeles … shipments by month and crop from … Florida, Mexico, Texas … to each market, and the acres planted to each cropping system in each supply region." Their results are based on increased production costs and reduced yields, hence a ban on methyl bromide has a severe negative impact on US producers and positive impact on Mexican producers, while consumers pay higher prices for fresh vegetables.

This study was repeated for a broader set of markets by **VanSickle *et al* (2000).** They note that the results are critically dependent on the assumptions around the impacts of the methyl bromide phase-out on production costs and yields (showing that these classes of model are also dependent on typical farm budgets). They also note the important influence that a change in production practices (e.g. as a result of the methyl bromide phase-out) can have on producers' access to the market, i.e. on market windows. **Deepak *et al* (1999)** also model the impact of alternative policy instruments (i.e. as alternatives to a ban on methyl bromide) such as marketable quotas and a tax, while the study of **Spreen *et al* (1995)** focuses on the impact of a ban on the state of Florida.

Ferguson and Lee (1997) take as their point of departure the observation that a ban on the use of a pesticide such as methyl bromide has predictable results: less efficient production and higher consumer prices, the latter providing a windfall gain to producers who a) did not use the banned product, and/or b) could find substitutes faster. Hence, they argue in favor of a phase-out as opposed to an outright ban, in order to provide all producers with the opportunity to adjust. The methyl bromide phase-out is used as an example of the benefits of the latter approach.

Goodhue *et al* (2005) discuss the pitfalls of relatively simple budgeting procedures (e.g. what prices to use, what factors will affect prices temporally), then use detailed budgets from an experimental trial plot in the California strawberry industry as well as an assumption about the price elasticity of demand for strawberries to ascertain the industry-wide effects of the methyl bromide phase-out on producers and consumers, measuring the producer and consumer surplus respectively. Their analysis is based on an assumed yield loss of 10-15% for strawberries.

Ninghui (2003) has conducted one of the only analyses of this type outside of the USA: in this event, the market for vegetables, strawberries and ginseng in China. He developed a two-stage linear programming-type model that maximizes the production of each of the crops given the prices of methyl bromide and its substitutes as well as a budget constraint in the first stage. In the second stage total production is optimized, and the results tested under three scenarios that reflect different methyl bromide phase-out rates.

Norman (2005) has provided probably the most satisfactory analysis of the impact of the methyl bromide phase-out to date – in this case again using the California strawberry industry to illustrate the argument. While there may be dissent about her results, the virtue of the article lies in the fact that she continues to ask the question behind every question. For example, other authors have noted the possibility that Mexican producers will benefit from the methyl bromide phase-out largely because they can use it until 2015: Norman investigates the factors that will affect the supply and demand of Mexican strawberries on the US market.

Her main argument runs along the following lines:

- The US is a net exporter of fresh strawberries, with exports (mostly to Canada) at 10.5% of production and imports (mostly from Mexico) 6.3% of consumption; with the exception of a few overseas markets, trade is only feasible within North America, and in all cases will take place only when prices in the export market are significantly higher[24]. Furthermore, while an increase in imports from Mexico can be expected, Mexican production capacity would have to grow at historically unprecedented rates if such imports were to have a material influence on the US market. The possibility of such investment is ameliorated by the fact that Mexico has to phase out the use of methyl bromide by 2015, that new Mexican production will come from more marginal resources, and that the Mexican domestic market is growing rapidly.
- US demand for strawberries is increasing rapidly because of a) the price of strawberries relative to other fruit (which also means that if strawberry producers are adversely affected by the methyl bromide phase-out, they will switch to other strawberry substitutes that do not require methyl bromide where this is technically feasible), b) the longer availability of strawberries on the market, and mostly c) because of increasing per capita incomes in the US domestic market, i.e. the income elasticity of demand for strawberries is high;
- Even accepting that the reduction in net income to a 'typical' California strawberry

[24] MBTOC notes that US trade data for fresh strawberries shows 9% to 12 % of exports are to places outside North America (notably Japan, EU, Hong Kong, UAE, and Saudi Arabia) (see the GATS trade data system at http://www.fas.usda.gov/gats/default.aspx

farmer can be as high as the 20-57% as was reported in the 2003 US Critical Use Nomination, she shows that the upward movement in the farmers' long-term cost curve has to be read in conjunction with the shift in demand for strawberries. In this regard, economic theory tells us how to estimate what share of the increase in costs is borne by producers, and what share by consumers, as long as the share of fumigation costs in production and the own-price elasticity of demand for strawberries are known. Hence, a more accurate estimate of the impact on farmers' net revenue is possible. Furthermore, as fumigation becomes more expensive, producers will substitute towards other, cheaper inputs. The extent to which substitutability is technically possible will determine the lower bound of the final share of the cost increase borne by producers.

- Finally, the impact on consumers depends on factors such as the spread of the burden of the increased costs over a large number of consumers; exactly when in the season Mexican imports are expected to be highest; the rate at which demand for strawberries is increasing; and the rate at which the cost of methyl bromide alternatives are becoming cheaper.

Finally, **Tullio *et al.* (2006)** evaluate the long-term macroeconomic impact of replacing methyl bromide with other soil disinfestation technologies in three scenarios. The first scenario (the 'status quo maintenance' scenario) assumes that all soil fumigants except methyl bromide can be used – the results show a negative impact on the margin of relevant crops equivalent to 24 million Euros. The second scenario ('no fumigants at all') generates a loss in income of 140 million Euros. The third scenario ('limited availability of fumigants') shows a reduction in income of 91 million Euros.

All of these sector-wide studies attempt to measure the wider impact of using an alternative to methyl bromide, whether only the economic impact or the wider social and environmental impacts. Yet they are all dependent on the usual assumptions about the functioning of competitive markets that economic modeling requires, and on the proper identification of technically feasible alternatives to the use of methyl bromide. In this regard, it is clear that there has been insufficient research in this field.

Recently evidence has arisen of at least one incidence of CUN rationing of methyl bromide creating an incentive for trade in, and a higher selling price for, illegally sourced methyl bromide[25]. Illegal trade has been known to occur with other ODSs, e.g. for CFC's this was estimated to be 7,000 to 14,000 tonnes a year in 2005 (Clark 2007; Ivanova 2007). These estimates of the illegal trade of ozone depleting substances, based on quantities of seizures of ODS, market surveys, and discrepancies in ODS trade data, suggest the illegal trade was 10 to 20 percent of the legal trade in 2005 (Clark 2007).

8.4. Conclusion

This chapter has shown that provision of partial budgets for the key alternatives within a sector is essential (and the bare minimum of information) if proper evaluation of the economic feasibility of alternatives to use of method bromide is to be determined. In particular this information is required by Parties reporting economic infeasibility of an

[25] http://www.jpost.com/HealthAndSci-Tech/Health/Article.aspx?id=180911

alternative when applying for CUNs. The review of economic impacts of the bans on methyl bromide shows that much work needs to be done if we are to have a better understanding of the true impacts of the methyl bromide phase-out. While this literature provides a useful starting point to the types of analyses that are required, future studies need to be extended to countries outside of the USA (especially in Article 5(1) countries) and to a wider range of methyl bromide uses.

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9

9. Methyl bromide emissions

9.1. Introduction

The phase out of MB under the Montreal Protocol has emphasised protecting the ozone layer from the destructive effects of MB through a schedule of progressive reductions in production and consumption of MB. The Parties have taken several explicit decisions calling for steps to minimise emissions of MB where it is still used under Decisions which allow exemption from phaseout. These include the Critical Use Exemptions (Decision IX/6) and exemptions for QPS use (Article 2H, Decisions VII/5(c) and XI/13(7)). There is opportunity for Article 5 countries to adopt emission control technologies during progress towards full phase-out of MB in 2015, where such technologies also reduce the quantity of MB needed for a particular use or treatment.

This chapter makes a best estimate of the level of emissions for the uses of MB as at 2009, the most recent year for which there is a good data set of consumption and use available. It also provides a summary of the impact of regulation of these emissions, updates on developments in reducing emissions of MB, particularly the use of barrier films and reduced MB dosages for soils, and the potential for recapture, recycling and destruction for commodity and structural treatments.

Methyl bromide is a gas at normal ambient temperatures (boiling point at normal atmospheric pressure: 4°C). During fumigation some of the gas becomes sorbed on the treated materials and components thereof. Some of the sorbed MB remains unchanged and will air off at the end of the treatment, but a portion of the sorbed MB is converted into nonvolatile residues. Except for this portion, all the MB applied during fumigation will eventually be emitted to the atmosphere. During any fumigation operation there are three distinct sources or opportunities for MB to be emitted to the atmosphere:

i. By leakage during the set up and actual fumigation treatment.
ii. During intentional discharge of the remaining unreacted MB after completion of the set exposure period.
iii. Following treatment when the treated soil, commodity or structure emits any sorbed, unreacted MB.

The first and to some extent the third situation can be controlled or reduced by better containment (sealing and film permeability) of the fumigation site (Section 9.3 (soil treatments) and fumigation enclosure (Section 9.6 (commodities)). Leakage and uncontrolled emissions in these instances are undesirable. They reduce effectiveness of the treatment as well as having worker safety and local air quality implications.

The second situation can be controlled by a reduction in MB dosage applied or by recapture of the MB followed by recycling, reclamation or destruction (Sections 9.8 and 9.9). For most fumigation operations, intentional venting following fumigation results in the largest discharge (emission) to the atmosphere. Theoretically, this methyl bromide is available for recapture and reuse or destruction, though there are several problems that lead to reduced recapture efficiencies.

Only a small fraction of added gas may be present after termination of a fumigation and subsequent airing. It can, however, lead to sufficient air concentrations in some situations to present possible health hazards to workers and bystanders.

9.2. Summary of impact of regulation of MB emissions

The MB phaseout has led to a 20% fall in total bromine (60% of anthropogenic bromine)from MB in the troposphere as measured at Cape Grim, Tasmania, Australia (Figure 9.1) from the late 1990s to 2010. A greater fall of 25% has been measured globally due to higher reductions in the atmorphere in the northern hemisphere (Montzka *et al.* 2011) This has led to a 30% fall in effective chlorine load in the stratosphere as at 2009 (Porter *et al.*, 2010). Owing to the short atmospheric half life of MB (0.7 years) in the stratosphere, changes in emission of MB at ground level are rapidly reflected in changes in tropospheric and stratospheric MB concentrations. This is in contrast to almost all other ODS's regulated under the Protocol as these usually have much longer atmospheric half lives. The Scientific Assessment Panel (WMO, 2007) rated the importance of MB in contributing to ozone layer recovery as higher than previously calculated, because MB atmospheric reductions were greater than previously anticipated.

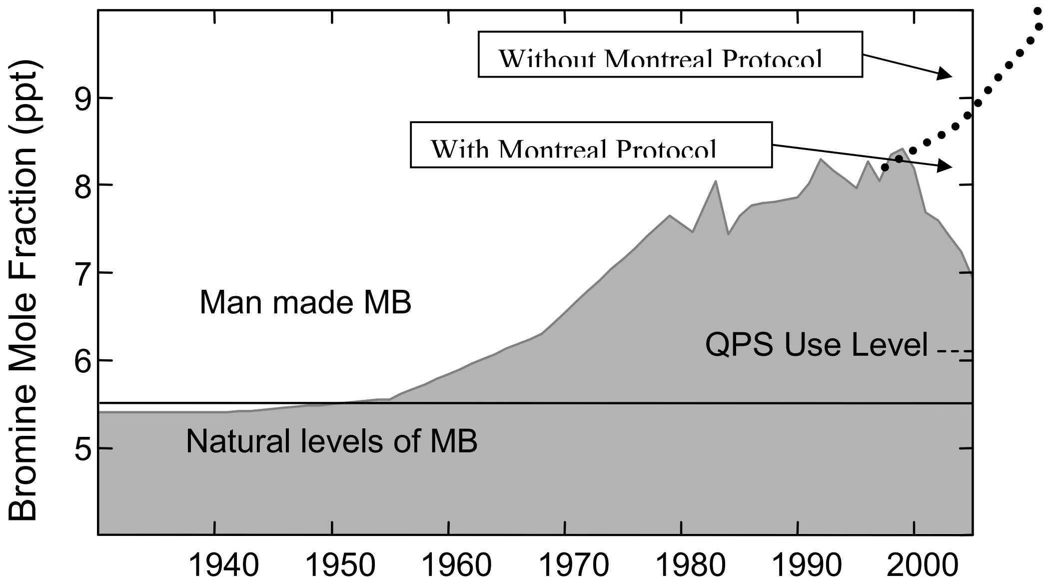
The 2010 Science Assessment of Ozone Depletion: 2010 report (Montzka *et al.* 2011) reported that by 2008 'Total tropospheric bromine had decreased from its peak values in 1998, and ' total bromine in the stratosphere is no longer increasing and showing signs of decreasing slightly'**.** These recent changes have largely been a consequence of regulation and phase out of MB.

In 2010, it was reported (Porter *et al*. 2010) that prior to the onset of the widespread use of MB as a soil and structural fumigant in the 1960s, the historical background or baseline concentration of MB in the atmosphere was 5-6 ppt (Figure 39 and Figure 40). The concentration then grew rapidly through the 1970s to the late 1990s due to large anthropogenic (man-made) use of MB (up to 72,000 tonnes annually). In the mid 1990's the concentration reached 8-9 ppt (more than 50% above the 1950s natural baseline concentrations).

In 2003, it was predicted that MB levels in the southern hemisphere would fall to about 7 ppt before levelling off (Figure 40, A1 WMO, 2003). However, by 2007 the levels had continued to fall to 6.5 ppt and show signs of falling further. It is clear is that the Montreal Protocol restrictions on the use of MB are having greater impact on atmospheric MB than thought possible 5 years previously.

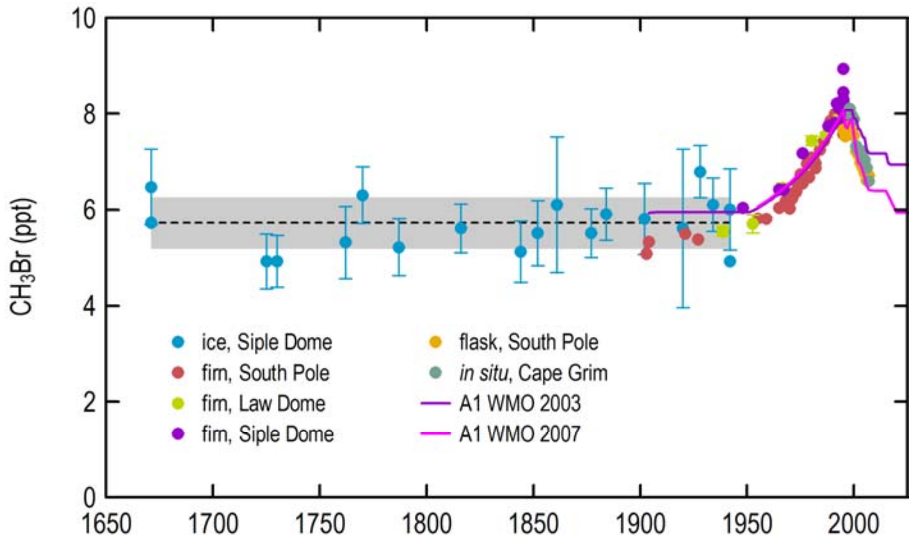
The latest WMO scenarios (Figure 40, A1 WMO, 2007) suggest that further small reductions in atmospheric concentrations are possible over the next few years, but will occur only if the remaining uses in developing countries (A5 Parties) and non A5 critical uses are phased out, and if emissions or use of MB for QPS are reduced significantly.

FIGURE 39. THE IMPACT OF THE MB RESTRICTIONS ON NON-QPS USE ON REDUCTION IN BROMINE CONCENTRATIONS IN THE TROPOSPHERE SINCE THE LATE 1990'S.



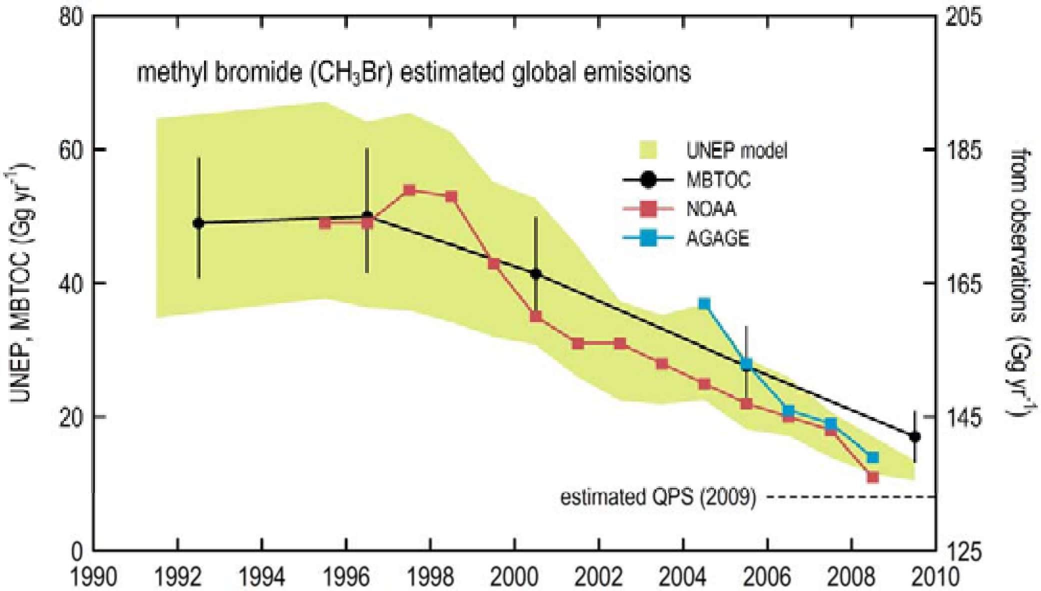
The *solid line* indicates the bromide from natural sources (i.e. the historic baseline). The *dashed line* indicates the approximate level that bromide concentration would presently fall if all non QPS MB was phased out. The possible scenario without the regulations of the Montreal Protocol is estimated from past trends (Montzka and Fraser, 2003; Clerbaux and Cunnold, 2007; Daniel and Velders, 2007.)

FIGURE 40. HISTORIC METHYL BROMIDE MEASUREMENTS (PPT = 10 12 MOLAR) IN THE SOUTHERN HEMISPHERE OVER THE PAST 350 YEARS



The dashed line represents the natural MB equilibrium). Data are from Cape Grim, Tasmania, and various atmospheric and ice/firn sampling sites in Antarctica compared to modelled CH 3 Br levels in 2003 (WMO, 2003) and 2007 (WMO, 2007), as summarised in Porter *et al.,* 2010).

FIGURE 41. MAN-MADE (QPS + NON-QPS) AND TOTAL (FROM ATMOSPHERIC DATA) GLOBAL EMISSIONS OF METHYL BROMIDE.



(i) Man-made: (a) for 1992, 1996, 2000, 2005 and 2009 from MBTOC Assessment Reports (1994, 1998, 2002, 2006, 2011), black dots and uncertainty bars, left axis; (b) from a simple emissions model, based on reported UNEP global QPS and non-QPS consumption data, green shaded area = range of emissions calculated from high and low emission factors (Figure 1-8 in Montzka *et al.*, 2011; R. Rhew, U. Berkley, personal communication), left axis;

(ii) Total (man-made + natural) from atmospheric observations (NOAA: red, AGAGE: blue), using a 1-D model (NOAA), right axis (Montzka, Reimann *et al.*, 2011). The estimated methyl bromide emissions from QPS in 2009 are 8 Gg (Table 9.1). Weighted mean estimated emissions of methyl bromide from fumigations, including QPS. Data for 1992, 1996, 2000 and 2005 from MBTOC Assessment Reports of 1994, 1998, 2002 and 2006.

As shown above (Figure 39 and Figure 40) the tropospheric MB concentration has fallen from a peak of 8.4 ppt in 1999 to 6.5 ppt in 2007. This equates to a reduction in MB emissions of 38,000 metric tonnes of MB (Figure 41. Correcting for the MB loss rate, this is equivalent to an annual reduction in MB entering the troposphere of about 3,200 tonnes between 1999 and 2007. Since MB has an atmospheric half life of about 0.7 years, the % annual change in concentration approximately equates to the % change in global emissions. In the absence of known changes in natural sources and sinks for MB, low emissions from feedstock uses, it can be assumed that the change in atmospheric MB concentrations reflects changes in emissions from MB fumigations.

Emissions reductions from 1996 to 2008 estimated from atmospheric data ('top down' method: 38,000 tonnes) are about 25% greater than that obtained from the bottom up analysis, given below (30,300 tonnes from 1996 to 2008 (interpolated)).

9.3. MB emissions from current uses for soil, commodities and structures

All the MB applied during fumigation will be released to the atmosphere excepting that which reacts irreversibly with treated materials (e.g. soil components, commodities or structural materials) or which is recaptured and destroyed. Since there is insignificant use of recapture and destruction at this time to influence significantly global emissions, the only 'sink' within the MB fumigation process is a reaction to give inorganic, non volatile bromide ion. From the capacities of currently installed recapture equipment known to MBTOC, is estimated that the MB recaptured and destroyed in 2009 was not greater than 200 tonnes.

There continues to be remarkably little firm quantitative field data available on this production of bromide ion or other measures of loss of MB from particular systems. For the purposes of this report, as in the 2006 MBTOC Assessment, MBTOC has relied on some particular data for specific situations and estimates provided by MBTOC members that were first used in the 1994 MBTOC Assessment Report. Ranges of estimates are given. These are used to encompass both the true variability to be expected with different sites, techniques and situations and also the range of opinions expressed by experts within MBTOC. An approximation of the quantity of MB emitted to the atmosphere has been made by integrating this information over the total usage of MB (Table 42). Supporting calculations for some of the emission levels used in these calculations are given or referenced in previous MBTOC Assessments (MBTOC 1995, 1998, 2002, 2006).

Table 42 includes estimates for emissions from four types of application to soils. The variation given in two of these is wide and reflects the range of data available to MBTOC experts. It is not possible to provide a weighting of figures within these ranges to give a precise average emission as the distribution of emissions over the global range of practices cannot be estimated because of lack of data. However, it is likely that the true value lies within the range quoted.

The overall usage figures given in Table 42 are derived from a combination of reported 2009 global production for QPS, usage in 2009 in Article 5 countries estimated by MBTOC survey (Chapter 3, Section 3.7.6) and 2009 use in non-Article 5 countries as authorised for CUE purposes (Chapter 3, Section 3.7.5) and use of stockpiles as reported annually by Parties under Decision XVI/6. The usage figures for the individual sectors are based on tonnages estimated from these data sources. Under current usage patterns, the proportions of applied MB eventually emitted to the atmosphere are estimated by MBTOC to be 41 – 91%, 85 - 98%, 76 – 88% and 90 - 98% of applied dosage for soil, perishable commodities, durable commodities and structural treatments respectively. These figures, weighted for proportion of use and particular treatments, correspond to a range of 58 - 91% overall emission from agricultural and related uses, with a mean estimate of overall emissions of 75%, or 17,041 tonnes based on estimated use of 22,860 tonnes in 2009.

Best estimates of annual MB emissions from fumigations in 2009 were 38% lower than in 2005 in total (Figure 39). There have been substantial reductions in usage for soil fumigations for controlled uses, counterbalanced to some extent by increases in fumigation of timber and wood packaging materials treated to meet Quarantine and Preshipment requirements and the recategorisation of some soils uses to QPS. It appears that the usage on perishables was overestimated in the 1994 and 1998 MBTOC Assessments.

Estimated usage was based on QPS consumption data (this Assessment), authorised CUE use (TEAP Oct 2009) and MBTOC survey of Article 5(1) consumption and use conducted in 2010, excluding feedstock. Reported use of stocks is included, but no allowance for unreported use was made.

TABLE 42. ESTIMATED GLOBAL USAGE OF MB AND EMISSIONS TO ATMOSPHERE IN 2009 FOR DIFFERENT CATEGORIES OF FUMIGATION BY MAJOR USE CATEGORY, INCLUDING QPS USE.

Type of fumigation and commodity/use	**Estimated usage**		**Estimated emissions**	
	tonnes	%	Tonnes	% (*a*)
Enclosed space – durables				
Grains, dried fruit, other dry foodstuffs.	1,546	7	789 – 1,376	51 - 89
Timber and wooden packaging	3,365	15	2,961	88
Subtotal - durables	***4,911***	***21***	***3,750 – 4,337***	***76 – 88***
Enclosed space – structures	**447**	**4**	**402 – 438**	**90 – 98**
Enclosed space – perishables	**765**	**3**	**650 – 750**	**85 – 98**
Soil fumigation				
Soil injection, shallow with PE tarp or ‘hot gas’	9,955	44	3,982–9,159	40 – 92
Soil injection – deep without tarp	200	1	160	80
Small cans – with PE tarp	600	3	480– 552	80 – 92
Soil treatment, with LPBF(*b*)	1500	6	525 – 1,305	35 – 87
Pre 2005 stocks used for soil fumigation	1,200	*5*	*420 – 1104*	
Subtotal - soil fumigation	***13,455***	***59***	***5,567 – 12,280***	***46 – 91***
Uncategorised QPS use	**3,282**	**14**	**2954**	**90**
Total estimated fumigant use	**22,860**	**100**	**13,323 – 20,759**	**58 – 91**
Best estimate over all categories			17,041	75 (*c*)

a For original sources of estimates, see MBTOC 1995) with minor subsequent adjustments

b Fluxes of MB through LPBF tarps are very low, but loss can occur after lifting the tarp. This is very dependent on the duration of tarping and the soil type and conditions (Yates, 2005; Fraser *et al.*, 2006). Experimentally, very low emissions can be obtained (e.g. 6%, Yates, 2005; <4% Yates et al, 2009). Regulations prevent use of barrier films in specific places (e.g. California) and price and availability mean they are not used in some soil sectors in many countries.

c MBTOC recognises that the true value of emissions may differ from this best estimate.

9.4. Methyl bromide reaction and measurement

During fumigation a proportion of any applied dosage of MB reacts with the treated material (e.g. soil, grain, fruit or the associated structures and packing materials). The end product of this reaction is typically non-volatile bromide ion and various non-volatile methylated products. Some methyl chloride may also be produced. The proportion of non-volatile bromide residue formed as a result of a treatment is a direct measure of the proportion of the applied MB *not* emitted to atmosphere. The proportion emitted is found by difference. This 'mass balance' approach is typically used to estimate quantities of MB released to atmosphere from a treatment. It gives a conservative estimate and is simple to use as bromide ion tends to be easily detected and quantified. An allowance must be made for natural bromide ion already present prior to treatment.

An alternative approach is to observe the quantities emitted directly. This is experimentally difficult as it relies on quantification of a number of fluxes of gas and may miss some important ones. The approach tends to underestimate the emissions, but is often used in soil fumigation studies.

The proportion of applied MB converted to fixed residues and thus not released to the atmosphere, varies widely with the particular treatment situation. It is influenced by the degree of gas tightness (sealing, permeability of the enclosure) and the temperature, moisture content and reactivity of the treated material (e.g. soil, commodity). With soil fumigation, the mode of application is also a major factor since it influences the contact time between the MB and substrate and thus the opportunity for varying degrees of reaction and dispersion within the soil before loss from the system.

9.5. Emission reduction through better containment

Improving the gas tightness of a fumigation treatment can provide four potential pathways for reducing the emission of MB. These are:

i) by limiting the release to the atmosphere of any MB leaking during the treatment,
ii) by improving the proportion of added MB retained for recapture or destruction,
iii) by allowing lower initial MB dosages or MB top-ups to be applied, with improved ct-products obtained with reduced leakage and
iv) by prolonging the effective fumigation period, allowing increased opportunity for breakdown of MB on the commodity, structure or substrate.

9.5.1. Soil fumigation

It is generally understood, that MB emissions to the atmosphere from soil fumigation can come from any of three major sources:

i) permeation through plastic sheets and leakage through joins and holes during fumigation;
ii) leakage from edges during fumigation; and
iii) desorption and venting from soil after lifting the sheets after fumigation.

Degradation is due to reaction with soil organic matter and some mineral constituents as well as other reaction pathways such as hydrolysis (De Heer *et al.,* 1983; Dungan and Yates, 2003).

9.5.2. Use of barrier films and other plastic covers to reduce emissions

Studies under field conditions in a number of regions (Table 43), together with the large scale adoption of barrier films in Europe support the use of these films as a means to reduce MB dosage rates and emissions. Research validated by commercial use has shown that barrier films can reduce effective use rates by up to 50% and consequently reduce emissions due to the lower use rates (Table 43).

Controlled studies have also shown substantial reductions in MB emissions (Yates, 2005; Fraser *et al.,* 2006). It is estimated in commercial practice, that emission ranges from 40-92% occur from the use of standard polyethylene (PE) and 35 - 87% for the wide range of barrier films that have been used (Table 42). The relatively high emission rates quoted are because figures include the emission after the tarp is removed. Recent studies with TIF Totally Impermeable Films) (Chow *et al.*, 2009) have been shown to reduce emissions to 22- 45% of the applied MB (Ntow *et al.* 2009) and these films may offer further opportunity for dose rate reduction providing offgassing can be minimised. Under experimental conditions with full tarping, not strip treatment, and extended exposure periods, emissions can be reduced to even lower levels during tarping, ie. < 6% of applied MB (Yates, 2005, Papiernik *et al.,* 2004; Ntow *et al.*, 2009;Yates *et al.,* 2009). Ntow et al., 2009 showed that when compared to standard PE films, TIF films can reduce peak emissions during the first 24 hours by up to 85% when MB was applied below 45cm; 80.5% when potassium thiosulphate was applied and 67% when the TIF film was used with shallow shank injection of MB at 30cm. TIF films may be so effective that offgassing becomes a greater issue when the tarp is lifted and this may pose concerns to worker safety. Fraser *et al.,*. (2006) stated that a Virtually Impermeable Film (VIF), a semipermeable barrier film (metallised with aluminium) and more recently \TIF were 6 to 9 times more effective in blocking MB flux to the atmosphere.

Table 43 shows that typically equivalent effectiveness is achieved with 25 –50% less MB dosage applied under the LPBF films (VIF, SIF (semi-impermeable films), TIF) compared with normal polyethylene fumigation films. Recent advances in the cost and technical performance of barrier films, especially metallised polyethylene films have reduced cost and extended their suitability for use with MB and also several of the fumigant alternatives, e.g. Pic chlor 60 (60% chlorpicrin/40% 1,3-D); methyl iodide, 1,3-D (Fennimore *et al.,* 2009; Gao *et al.*, 2009) alternatives. Barrier films are a requirement for use of methyl iodide, a key MB alternative, in the SE of the US (Mike Allen, Arvesta, pers com.) Previous difficulties with sealing and gluing barrier films are no longer seen as a technical barrier to their implementation as new application technologies (i.e. glues, polyethylene edges and perforated films) have solved earlier problems, such as encountered by Fennimore *et al.* (2006) at least for some products.

The use of low permeability barrier films (VIF or equivalent) became compulsory in the member states of the European Union (EC Regulation 2037/2000) in 2000 and are in increasing use in the US with MB and MB-containing mixtures. In most other regions of the world, LPBF films are considered technically feasible, but may not be practical for MB fumigation because of small areas leading to lack of availability or high cost. The State of California in the US, however, has a regulation which prevents implementation of barrier films with MB but not the key alternatives (California Code of Regulations Title 3 Section 6450(e)). It was implemented because of concerns over possible worker exposure due to offgassing of MB when the film is removed or when seedlings are planted.

There is some use of barrier films in A5 countries, but generally the remaining uses for preplant soil use is with standard permeable PE films due to low cost. Changeover to barrier films and similar films that reduce emissions and allow lower MB dosage rates does not typically attract funding support from the MLF as it is regarded as a 'transitional' strategy only, and not adoption of an alternative technology.

MBTOC considers that an optimum film for soil fumigation is a barrier film which maintains integrity when stretched, is able to be glued, allows for maximum dosage reduction of MB and allows for some permeability of gasses whilst the film is in place to prevent offgassing when the film is lifted. It is important to consider film type and permeability with climatic conditions, crop and soil type.

9.5.3. Barrier film permeability

A rapid, reliable, and sensitive method to measure the permeability of various films has been developed (Yates *et al.,* 2009), which allows estimating the mass transfer coefficient (*h*), a standardised measure of permeability. The mass transfer coefficient is a measure of the resistance to fumigant diffusion, is a function of the films composition and the fumigant chemical, but is independent of the concentration gradient across the film. In general, each chemical-fumigant-temperature combination produces a unique *h* value. For some films, other factors may also affect *h*, (e.g., presence of water vapour).

TABLE 43. RELATIVE EFFECTIVENESS OF MB/PIC FORMULATIONS APPLIED IN COMBINATION WITH LOW PERMEABILITY BARRIER FILMS COMPARED TO THE COMMERCIAL STANDARD MB/PIC FORMULATION APPLIED UNDER STANDARD LOW DENSITY POLYETHYLENE FILMS

Country	Region	Commodity	Brand or Type of Barrier Film	Untreated – Std film Yield	Methyl Bromide/Chloropicrin Mixtures (Product rate per treated area) – Std film MB/Pic Formuln.	Product Rate kg/ha	Barrier Film – Relative yield compared to standard polyethylene: Not Spec 300	98:2 400	98:2 300	67:33 98	67:33 196	67:33 200	67:33 294	67:33 336	67:33 392	50:50 200	33:67 200	Notes	Reference
MB Dosage rate (g/m2)								**392**	**294**	**66**	**131**	**134**	**197**	**225**	**263**	**100**	**66**		
Spain	Vinderos	Strawb. Runner	VIF - NotSpec	74	50:50	400											93	Fusarium, Phytophthora, Pythium, Rhizoctonia and Verticillium	De Cal et al 2004 a,b
	Navalmanzano			78	50:50	400											80		
Spain	Vinderos	Strawb. Runner	VIF - Not Spec	68	50:50	400										114	102	Fusarium, Cladosporium, Rhizoctonia	Melgarejo et al 2003
	Navalmanzano			34	50:50	400										76	75		
Spain	Avitorejo	Strawb. Fruit	VIF - Not Spec		50:50	400											97	2003 results	Lopez-Aranda et al 2003
	Malvinas				50:50	400											99		
Spain	Valencia	Strawb. Fruit	VIF - Not Spec	59	Not Spec	600	94											1998 Fusarium At 10cm & 30cm	Bartual et al 2002
				53	Not Spec	600	93											1999 results	
Spain	Avitorejo	Strawb. Fruit	VIF - Not Spec	80	67:33	400										112		Meloidogyne and weeds (unspec.)	Lopez-Aranda et al 2001a
	Tariquejo			54	67:33	400										106			
Spain	Moguer/Cartaya	Strawb. Runner	VIF - Not Spec		50:50	392										99		Inoculum not specified	Lopez-Aranda et al 2001b
Spain	Cabeza, Nav.	Strawb. Runner	VIF - Not Spec	74	67:33	400						105, 92						1998 Two sites	Melgarejo et al 2001
	Arevalo, Nav.			84	50:50	400										104, 104		1999 results, nurseries	
	Vinaderos, Nav.			49	50:50	400										95, 123		2000 results, nurseries	
Spain	Huelva	Strawb. Fruit	VIF - Not Spec	82	67:33	400						101						1997-1998 Inoc.unspecified	Lopez-Aranda et al 2000
				72	67:33	400						102						1998-1999 Inoc. Unspecified	
				68	67:33	400						109						1999-2000 Inoc. Unspecified	
Spain	Moncada	Strawb. Fruit	VIF - Not Spec	60	98:2	600			95									1998 No major pathogens but Fusarium buried 10cm&30cm.	Cebolla et al 1999
				54	98:2	600			91										

Country	Region	Commodity	Brand or Type of Barrier Film	Untreated	Methyl Bromide/Chloropicrin Mixtures (Product rate per treated area)													Notes	Reference
				Std film			Barrier Film – Relative yield compared to standard polyethylene												
				Yield	MB/Pic Formuln.	Product Rate	Not Spec	98:2	98:2	67:33	67:33	67:33	67:33	67:33	67:33	50:50	33:67		
						kg/ha	300	400	300	98	196	200	294	336	392	200	200		
MB Dosage rate (g/m2)								**392**	**294**	**66**	**131**	**134**	**197**	**225**	**263**	**100**	**66**		
France	Douville	Strawb. Fruit	VIF - Not Spec	65	Not Spec	800		99										Inoculum not specified	Fritsch 1998
NZ	Havelock North	Strawb. Fruit	VIF - Not Spec	83	67:33	500								98				Phytophthora present	Horner 1999
USA	Florida	Pepper	VIF Plastopil	69	67:33	392					78							Nutgrass	Gilreath et al.s 2005
			VIF Plastopil	69	67:33	392				99								Present	
			VIF Vikase	69	67:33	392					83								
			VIF Vikase	69	67:33	392				86									
USA	Florida	Strawb Fruit, Cantaloupe	Barrier - Pliant, Metallised		98:2 67:33	Trials on 18 Commercial Farms between 2000-2004; no increase in disease or weeds when rates reduced up to 50% under VIF wrt. polyethylene												Nutgrass and pathogens present	Noling and Gilreath 2004
USA	California	Strawb. Fruit	VIF - Not Spec	72	67:33	336								108				Inoculum not specified	Ajwa et al 2004
				80	67:33	392									96				
USA	Florida	Tomato	VIF - Not Spec	31	67:33	392					111		93		114			Nutgrass and rootknot nematodes	Hamill et al 2004
USA	California	Strawb. Fruit	VIF - Not Spec	75	67:33	392									106				Ajwa et al 2003
				83	67:33	392									111			Watsonville, high pathogen pressure	
				65	67:33	392									102				
USA	Florida	Tomato	VIF - Not Spec		67:33	392	"No significant reduction in yield"												Noling et al 2001
USA	California	Strawb. Fruit	VIF - Not Spec	45	67:33	364									116				Duniway et al 1998
USA	Georgia	Nurseries	VIF – not spec		67:33	389	See reference												Carey and Godbehere, 2004
USA	California	Roses			67:33 98¨2	392 392	See reference												Hanson et al, 2006; 2009
USA	Florida	Pepper	VIF – not spec		67:33	392	See reference												Santos and Gilreath, 2004
USA	Florida	Pepper	VIF – not spec		67:33	392	See reference												Santos et al, 2005
USA	California	Ornamentals	VIF – not spec		67:33	392	See reference												Klose 2007, 2008
Unweighted averages (relative % yield)				66			94	99	93	93		102		103	108	104	91		

For references above Final Report on 2009 CUNs, September 2009, UNON, Nairobi (http://www.unep.org/ozone/teap/Reports/TEAP_Reports/

9.5.4. Correct application of barrier films to reduce emissions

Barrier films consists of either 1) multi-layer laminates with outer layers of low density polyethylene and a barrier layer of polyamide or ethylene vinyl alcohol, or 2) a mixture of these materials, often called an "alloy" or 3) multilayer, metallised polyethylene films.

Barrier films reduce MB emissions from soil fumigation by retaining the introduced MB in the soil for extended periods to allow the gas to degrade by reaction with soil components. Maximal degradation and thus reduction in emissions is obtained (Yates *et al.* 1998) when:

- the entire field is covered with barrier film;
- all film strip over-laps are well glued and sealed;
- the barrier film edges are sealed (buried under soil);
- the MB is injected deeply in the soil;
- the film is kept on the field, completely sealed, for more than 10 days; and
- the soil temperature, moisture and organic matter content are optimal - medium temperatures, moist soil, and high organic matter.

Barrier films are less effective at reducing MB emissions from soil fumigation (Rice *et al.,* 1996; Thomas, 1998; Wang *et al.,* 1999, Yates *et al.,* 2009) when:

- only part of the field is covered with barrier film (i. e. with strip or bed fumigation);
- any of the film strip over-laps become unglued or are otherwise unsealed;
- any of the film edges anywhere around the field become unsealed;
- the film seal is broken before 10 days have passed; and
- soil temperature, moisture, organic matter are in any way sub-optimal (hot, dry soil or very wet soil with little organic matter).

Studies have shown that, with traditionally laid LDPE or HDPE films, most unreacted MB either passed through the films or was emitted from the edges of the film (Yates, 2005). In general, fumigation films remain in place for 5 to 7 days and with standard films this ensures maximum effectiveness of the applied dosage. With barrier films, even though lower dosages of MB are used, longer periods of tarping may be required to ensure complete degradation of the applied MB, to effectively reduce MB emissions and to avoid off gassing of unreacted MB when the tarps are removed.

9.5.5. Adjustments of dosage rates in MB/Pic formulations to reduce emissions

One key strategy to reduce MB dosage and therefore relative emissions has been the adoption of MB:Pic formulations with lower concentrations of MB (e.g. MB:Pic 50:50, 30:70 or less). These formulations are considered to be equally as effective in controlling soilborne pathogens as formulations containing higher quantities of MB (e.g. 98:2, 67:33) (e. g. Porter *et al.,* 1997; Melgarejo *et al.,* 2001; Lopez-Aranda *et al.,* 2003). Formulations containing high proportions of chloropicrin in mixtures with MB have been adopted widely by non-Article 5 countries to meet Montreal Protocol restrictions where such formulations are registered or otherwise permitted. Their use can be achieved with similar application machinery which allows co-injection of MB and chloropicrin or by use of premixed formulations. Consistent performance has been demonstrated with both barrier (Table 43) and non barrier films.

Figure 40 demonstrates the reduction in dosage rates achievable with barrier films compared to standard fumigation films.

9.5.6. Other cultural management methods to reduce emissions

Irrespective of what surface barrier is used to contain MB during soil fumigation, there are a number of key factors which affect emissions of MB during soil fumigation. Recent reports (Yates, 2005, 2006, Yates *et al.*, 2009) have shown that manipulation of many other factors can reduce emissions of applied MB, but the extent to which these factors are practiced by industry is unreported.

They concluded that emissions can be reduced by improving containment of the MB gas and by increasing degradation time, however natural soil degradation is insufficient to reduce fumigant emissions to the atmosphere. Methods to improve containment included barrier films as discussed above, but also improvements in cultural factors of the cropping system including soil management, e.g. strip verses broadacre treatment, increased containment time, addition of sulphur containing fertilizers, increasing organic matter, soil water content, soil compaction and surface sealing with water.

9.5.6.1. Soil characteristics

Studies of MB degradation in various soil types have shown that soil type greatly affects degradation, depending upon the time the MB is held in the soil. High organic matter and soil water content and increasing bulk densities are major factors which assist reduction in emissions (Gan *et al.,* 1997; Thomas, 1998; Yates, 2005).

9.5.6.2. Fumigation period

Tarps left on soil for longer periods increase the residence time of the MB in the soil, thereby decreasing emissions. Wang *et al.* (1997a) demonstrated that emissions were reduced from 64% with PE tarps to 37.5% with VIF over a 5 day exposure, and from 56.4% to less than 3% respectively for a 10 day exposure with a sandy loam soil.

9.5.6.3. Irrigation, organic amendments and fertilisers

MB emissions can be reduced if the air filled porosity of the soil is reduced by increasing the water content. The presence of water increases the hydrolysis of MB to bromine ions. Irrigation reduces the variability in the distribution of MB in the soil, thus achieving a more reliable fumigation result (Wang *et al.,* 1997a).

In laboratory and field studies, Yates (2005, 2006) reported that the use of ammonium thiosulphate fertilizer added to the surface of soil could reduce emissions from 60 to less than 10%, and irrigation and surface sealing with water were an inexpensive way to reduce emissions.

The above results supported earlier work that addition of nitrogen fertilisers and organic amendments enhance degradation of MB. Lime, ammonia fertiliser and ammonia oxidation bacteria also increased the degradation rate of MB in soil (Ou *et al.,* 1997; Gan *et al.*, 1997). These products have been shown to enhance degradation of MB. However, further research is required to identify their use for emission reduction.

9.5.6.4. Soil surface structure

A light rolling (pressing) of soil immediately after shank application closes furrows and seals the soil surface. This decreases direct emission from the injection points (channelling) within the first 24 hours after application and may assist reduction of total emissions (Anon 1997). Yates (2005) showed that surface compaction could reduce emissions from 90 to 64% of the applied MB.

9.5.6.5.Depth of injection

Emissions of MB can be reduced by injecting the material deep into the soil. The extent of the reduction depends upon soil conditions. For example, in field and laboratory studies, increasing the depth of injection from roughly 25 to 60 cm resulted in a 40% decrease in emissions under tarped conditions (Yates *et al.,* 1996). In laboratory studies, it was shown that increasing injection depth delays the occurrence of maximum volatilisation flux and also decreases cumulative emissions (Gan *et al.,* 1997; Yates, 2005). The deeper the MB is injected the lower the emissions. Deeper shank injections increased the path distance, thus increasing the residence time for degradation (Wang *et al.,* 1997ab) and minimising emissions.

9.5.6.6. Broadacre vs. strip

Strip fumigation (bed fumigation) can reduce the amount of MB applied by 20-40% as only the crop rows are treated rather than the entire field. This technique is common in many vegetable crops and most strawberry crops outside California. However, the 'edge effect' predominates and losses of MB from the edge of the bed tends to offset some of the advantages of strip fumigation with regard to emission reduction.

9.5.7. Regulatory practices to reduce MB emissions from soil

There are a number of practices in use in various parts of the world that result in reduced MB emissions from soil treatments, including:

- limiting the frequency of MB fumigation by requiring intervals of 12–60 months between treatments. Alternative treatment methods could be implemented in the intervening period such as IPM, steam, solarisation, alternative fumigants and predatory fungi treatments. Reductions of 17–50% are feasible by implementing a reduction in fumigation frequency (refer to Table 8.1 in Anon. 1997). Reductions of >75% are feasible when other methods of pest control are used in combination.
- imposing permit systems which could ensure that only technically necessary fumigation would be carried out (e.g. The Netherlands in 1981, Belgium 2005). The criteria for permits could be proof of: (a) disease present and (b) that other pest control options have been examined. An organisational structure is needed to support this.
- adjusting pesticide controls. For instance, MBTOC has suggested maximum dosage rates for specific uses which suggest the likely maximum dosage rate required to achieve effectiveness (TEAP 2006). In 1998 Spain introduced a maximum rate of 40 g m^{-2} and 20 g m^{-2} when used in combination with LPBFs.
- regulating the users of MB to contractors only and licencing and training operators responsible for fumigation.
- where possible, shifting practices from 'hot gas' methods using high concentrations of MB to soil injection that uses mixtures of MB/chloropicrin at lower MB concentrations, or substitute other chemical and non chemical treatments.

9.6. Structural and commodity fumigation

9.6.1. Sealing and dosage rate minimisation

Post-harvest disinfestation of commodities and structures using MB is performed under well sealed conditions that limit loss of the fumigant to atmosphere during the exposure period. Commodity fumigations may be carried out either in fixed-wall structures such as fumigation chambers, in transport vehicles including containers and ships or under gastight tarpaulins.

Controlled conditions allow manipulation of the key fumigation parameters: dosage, temperature and time. Greater control of emissions is potentially more easily achieved in an enclosed structure than in relatively uncontrolled field situations. Providing the fumigation enclosure is relatively gastight, the dosage of MB can be reduced by increasing either the temperature or the exposure time, or both, providing the commodity is able to tolerate the conditions. Forced air circulation reduces the range of concentration - time (*ct*) products experienced within the enclosure, thus reducing the need for high dosage rates to compensate for areas that may otherwise receive insufficient concentrations of fumigant.

Developing high temperature schedules, with or without longer fumigation durations, could also reduce MB use providing the marketability, including food safety of the produce is acceptable. Improving the gastightness of fumigation facilities will minimise leakage of MB into the atmosphere. Simple test criteria have long been available to the industry for determining the gastightness of chambers (Bond, 1984) and these may be part of the mandatory fumigation requirements for trade (Quarantine treatments) of many perishable commodities e.g. as in APHIS PPQ manual
http://www.aphis.usda.gov/import_export/plants/manuals/index.shtml .

In a paper that modelled gas loss of MB from structures under fumigation with MB and with sulphuryl fluoride, Cryer (2008) emphasised the effect of good sealing on the half-loss time of buildings and effective use of particular dosage rates.

A combination of gases, e.g. MB with carbon dioxide and phosphine, allows a reduction in MB. The mixture is less phytotoxic to cut flowers and ornamentals than MB or phosphine alone and has the same insecticidal activity. Reduced emissions can also be achieved by using reduced MB dosages in combination with carbon dioxide and/or heat. The MAKR™ system (Sansone, 1994) is an alternative treatment that combines MB and carbon dioxide to reduce MB dosage from 24–36 g m^{-3} to 8 g m^{-3}. By adding 10% carbon dioxide, the amount of MB required is reduced by 50–66%. The carbon dioxide is heated, expanded and introduced into a structure with MB. The effects of carbon dioxide are twofold: it provides more efficient dispersion of MB into all parts of the structure; and increases the toxicity of the MB, perhaps by increasing the respiration rate of insects, reducing the amount of MB needed to eradicate the infestation.

Mixing MB with other gases such as pure phosphine may also allow a significant reduction in MB concentration. For example, effects of MB, phosphine and a mixture of MB and phosphine were tested on satsuma mandarins (Citrus reticulate). No injury was observed on fruit at 48 g m-3 of MB for 2 hours at 15, 20 and 25oC and mixtures of 14 g m-3 of MB and 3 g m-3 of phosphine for 3 hours at 20oC (Akagawa et al., 1997). However, waxed fruit were damaged when fumigated with the mixture. This research demonstrates that half the dosage of MB could be feasible compared to the use of MB alone.

9.7. *Fumigant recapture and destruction*

9.7.1. Scope for emission reduction by recapture

Parties have been urged to minimise emissions of MB in situations where they still use MB and are unable to adopt non-ozone depleting alternatives. This includes both QPS treatments and fumigations carried out under CUEs (Decisions VII/7(c), IX/6). One approach to minimising emissions is to adopt recapture technology, with subsequent destruction or reuse of the MB.

The discussion, below, concentrates mainly on availability and operation of recapture technologies for well-contained commodity and structural fumigations, including QPS applications. Some attempts have been made to apply recapture to soil fumigations, but the geometry and situation of soil fumigations render this problematic, and no systems, to knowledge of MBTOC, are in current use.

At this time, there are no processes for MB approved as a destruction process under Decision XV/9 and listed in any updates to annex II of the report of 15 MOP that listed approved destruction processes by source and destruction method. However, the situation is currently under review (Decision XXII/10). Parties have previously submitted information on recapture processes for MB in use, following Decision XVII/11. This information and a review thereof is given in TEAP Report (TEAP 2006.)

9.7.2. Efficiencies and potential quantities of MB available for recapture

For maximum 'recapturable' MB from a fumigation, losses within and from the system must be minimised. During any fumigation operation there four distinct opportunities for MB to be lost or emitted to the atmosphere:

i. by leakage during the actual fumigation treatment.
ii. during venting of the fumigation space immediately after fumigation or removal of the cover sheets where a deliberate discharge to the atmosphere takes place.
iii. following treatment when the treated commodity, packaging or structure slowly emits any sorbed MB.
iv. by reaction when sorbed MB is converted irreversibly to nonvolatile products

Situation (i) and, to some extent, (iii) can be controlled or reduced by better containment of the fumigation site. Leakage in these instances is undesirable from the fumigation perspective as it reduces the effectiveness of the treatment, as well as having worker safety implications (e.g. Baur *et al.* 2009).

The proportion of added non-volatile bromide residue formed as a result of a treatment is a direct measure of the proportion of the applied MB *not* emitted to atmosphere, provided an allowance is made for natural or added bromide ion already present prior to treatment. Only the remaining MB is available for recapture and/or destruction.

The proportion of applied MB converted to fixed residues, and thus not released to the atmosphere, varies widely with the particular treatment situation and treated material. It is influenced, *inter alia*, by the mass of material within the enclosure (the filling ratio) and its temperature and moisture content, and the exposure time. Longer exposure periods, higher temperatures, higher moisture contents and greater mass of material all lead to lower potential recapturable MB.

Methyl bromide may be temporarily and reversibly lost from the gas space within the fumigation enclosure through physical sorption on or in materials in the enclosure. This includes dissolving in fats and oils, surface adsorption and capillary condensation. In a fumigation it typically takes a few hours to approach equilibrium for this reversible sorption. Subsequent to the intentional exposure to the fumigant, the sorbed MB may volatilise from the treated commodity quite slowly, sometimes taking several days to reach low levels of emission. The rate of sorption and desorption is strongly dependent on the materials treated, their state and their dimensions.

There remains remarkably little firm quantitative field data published on the production of bromide ion or other measures of loss of MB from particular systems that could be used to estimate the maximum total quantity of MB available from fumigations. The general overall potential for recovery from enclosed space fumigation, such as almost all QPS treatments, can be estimated from the total emissions expected. Table 44 gives such emissions for some QPS situations. These figures include sorbed unchanged MB, present at the end of the fumigation.

TABLE 44. ESTIMATED EMISSIONS OF MB TO ATMOSPHERE FOR DIFFERENT CATEGORIES OF ENCLOSED SPACE QPS FUMIGATION.

Type of fumigation and commodity/use	Estimated emissions %
Enclosed space – durables	
Grains, nuts, dried fruit etc.	51 - 89
Timber, pallets, wooden packaging	88
Enclosed space – structures	90 – 98
Enclosed space – perishables	85 – 98

Extracted from Table 9.1. of TEAP 2010

As an approximation, most postharvest and structural fumigations have at least 85% of the applied dosage present at the end of the fumigation as MB in some form, *including* that lost by leakage. Fumigations of oily and high protein materials, such as nuts or oilseeds, may have 50% or even less available. The proportion of this theoretical limit that can actually be recaptured depends mainly on how much is lost by from the enclosure during the fumigation.

TEAP (2002) estimated that about 86% of the applied MB used in commodity and structural (space) fumigations remained as unreacted MB in some form at the end of the fumigation exposure period. This figure of 86% implies an average loss by reaction of 14% of applied dosage. In practice some leakage is inevitable and the time required for total desorption may be excessive. On the basis that 15% (8% loss from leakage, 6% residual material and other inefficiencies) of the originally applied material is lost from the system under best practice, TEAP (2002) estimated that 70% of applied material could be recovered from structure, commodity and QPS fumigations. The actual figure achievable in practice will vary substantially from this average figure according to the particular situation.

Since the material that reacts irreversibly with the commodity or structures does not contribute to emissions, and the reversibly sorbed material will eventually be released and is thus potentially recapturable, the only losses from the system relate to leakage and ventilation losses. With these less than 10% per day from well sealed systems (see below), there is theoretical potential for reduction of MB emissions of more than 90% of the quantity applied through adoption of recapture and efficient containment. Almost all QPS treatments are carried out under conditions that could potentially lead to a reduction in over 90% of applied dosage being emitted to atmosphere, though this would need adoption of substantially improved containment compared with much current practice.

On the basis of 70% recapturable MB, about 9,000 metric tonnes of MB emissions from the 2005 worldwide production of about 13,000 tonnes of MB for QPS purposes could have been prevented from entering the atmosphere by the fitting of recapture and destruction equipment (TEAP 2002). For the 6,123 tonnes used for commodity and structural treatments (from Table 9.1), including QPS, at 70% recapturable, the equivalent value is 4,286 tonnes.

In current practice, many fumigations are conducted in a way where there are losses from the system that prevent this theoretical 70% recaptureable value being attained routinely.

Worldwide many fumigations are conducted in poorly sealed enclosures, leading to high rates of leakage and gas loss. It is not uncommon to find <10% of applied MB present after a 24 h exposure, particularly with structural fumigations. For maximum potential for recapture, many fumigation enclosures would need substantially improved sealing to restrict leakage to a low level. Banks and Annis (1984) estimated loss rates of as low as 5 to 10% per day were achievable in most structures with appropriate sealing.

In good fumigation practice, such as specified by AQIS (2006), there is a residual gas level present after a fumigation. Table 45 gives the residual gas levels expected at various times.

TABLE 45. MINIMUM CONCENTRATIONS OF MB REMAINING AT VARIOUS TIMES FOR QUARANTINE FUMIGATIONS (AQIS 2006).

Time after dosing (h)	Minimum % concentration remaining
0.5	75
1	70
2	60
4	50
12	35
24	30

These values are aimed at achieving effective kill under practical quarantine conditions. They are not specifically targeted at achieving minimum emissions (losses by leakage) during fumigation. They provide a guide to what is typically achieved in good current commercial practice. With better sealing levels, relative MB concentrations remaining, even at long exposures, can be substantially improved. The figures underlie the need to minimise exposure periods if it is desirable to achieve maximum potential for recapture.

These minima represent minimum recapturable MB. They do not take into account desorbable MB. This may be as much as 50% of applied dosage with sorptive materials. Treatments of perishables are typically for less than 4 hours, but timber and durables may be exposed for 24 h or longer, to allow for full distribution and penetration of the fumigant.

The current version (IPPC 2006) of the ISPM 15 standard for treatment of solid wooden packaging materials in export trade have set a retention of 50 % of the initial standard dosage at the end of the 24h fumigation period (Table 46) This high level of retention is difficult to achieve in practice, requiring very good fumigation practice, including very good sealing levels and low filling ratios. Consequently, some fumigators are adding extra MB at the start of the ISPM15 fumigations to compensate for high leakage so that specified minimum concentrations at the end of the exposure are met. This process uses additional MB and reduces the proportion of MB added that is in practice available for recapture. The level of retention of 50% of initial dosage may not be possible practically for some log fumigations carried out under gasproof sheets.

TABLE 46. ISPM 15 STANDARD FOR TREATMENT OF SOLID WOOD PACKAGING MATERIAL. DOSAGE RATES AND FINAL CONCENTRATIONS SPECIFIED IN THE MODIFICATION OF THE STANDARD ENDORSED IN APRIL 2006 (IPPC 2006).

Temperature	Dosage (g m^{-3})	Minimum concentration (g m^{-3}) at 24h:	% retention at 24 h
21°C or above	48	24	50
16°C or above	56	28	50
10°C or above	64	32	50

9.8. Efficiency of recapture

The efficiency of recapture/destruction can be described in several ways. For dilute MB sources, the same general concepts may be applied as for dilute CFC sources. These are the overall Destruction Efficiency (DE), the Recovery and Destruction Efficiency (RDE) and the Destruction and Removal Efficiency (DRE). These various measures of efficiency of destruction, and thus ozone protection, are defined (TEAP 2002, a, b; 2006) thus:

- Destruction Efficiency (DE) is determined by subtracting from the mass of a chemical fed into a destruction system during a specific period of time the mass of that chemical that is released in stack gases, fly ash, scrubber water, bottom ash, and any other system residues and expressing that difference as a percentage of the mass of the chemical fed into the system.
- Destruction and Removal Efficiency (DRE) has traditionally been determined by subtracting from the mass of a chemical fed into a destruction system during a specific period of time the mass of that chemical alone that is released in stack gases, and expressing that difference as a percentage of the mass of that chemical fed into the system.
- Recovery and Destruction Efficiency (RDE) is given by the quantity of the chemical destroyed in the destruction system as a percentage of that present in situ prior to the start of the destruction system. This measure includes losses in segregation, decommissioning, mechanical recovery and incineration or other destruction process.

With specific regard to MB from fumigation, the DRE is a measure of the recapture/destruction process itself, while the DE is a measure of the complete process. It includes losses from leakage and reaction on the commodity, as well as inefficiencies in removing the substance (MB) from the fumigation enclosure for input to the recapture/destruction system.

Efficiency of destruction (DE) of MB from a fumigation can be expressed thus:

$$DE = R1 * 100 / M1 = (M1 – L – R2 – R3 - R4) * 100 / M1,$$

where M1 is the initial charge of MB introduced into the system, R1 is the gas quantity retained by the recapture or destruction system, L is the quantity lost during the fumigation by leakage or reaction, R2 is the residual free gas left in the enclosure after extraction of MB into the recapture system, R3 is the remaining sorbed gas, and R4 the quantity of MB transiting the recapture/destruction system or lost by leaks in the system.

In practice, it may be better to measure efficiency of recapture on the basis of recapture of the gas present at the end of the fumigation, without allowance for leakage during the fumigation or loss by reaction. The latter is not recoverable and is, effectively, destroyed.

Thus the net efficiency of recapture (DRE) becomes:

$$DRE =R1 * 100 / M2 = (M2 –R2 – R3 – R4) * 100 / M2,$$

where M2 is the total gas left in the fumigated system at start of recapture.

Parties have submitted DRE information for some recapture systems in use in 2006, summarised in TEAP (2006).

Well designed, sized and operated recapture systems based on activated carbon as recapture medium have almost complete recovery of MB. Fumigant concentrations are typically 10-100 g m^{-3} entering the recapture system and much less than the low, tolerable workspace concentrations (about 0.004 g m^{-3}) on exit, giving DREs of >99.9%.

In order for a carbon-based recapturing unit to be considered for use by USDA APHIS, it must meet the following specifications (USA 2009):

A system should:

- accommodate a variety of enclosure types (portable chamber and fixed chamber)
- accommodate MB monitoring sensors in the air flow (number and placement of sensors will depend on the size of the equipment)
- accommodate the fumigant concentrations and temperature conditions listed in this (Treatment) manual
- ensure that all untreated ventilation air is under negative pressure (in the event of a leak, ambient air will leak into the system instead of contaminated air escaping from the system)
- leak-tight (includes valves, ducts, canisters)
- provide a minimum adsorptive capacity of 1 pound of MB per 10 pounds of carbon (The quality of the carbon will determine the adsorptive capacity. A lower quality carbon could cause a ration of 1 pound of MB per 20-25 pounds of carbon.)
- provide between 4 and 15 complete gas exchanges per hour
- provide flow and pressure system monitoring

- provide onsite installation, training, and continual technical support
- reduce emissions of MB by at least 80%
- retain approved fumigation and aeration times as mandated by the PPQ Treatment Manual
- not exceed 500 ppm (2 oz/1000 ft3) MB gas released to the atmosphere and provide the ability to document MB concentration levels

9.9. Commercial and developmental processes for MB recapture, with destruction or recovery

A number of techniques have been proposed or investigated for their potential to recapture MB after fumigation operations. In some cases the recaptured MB is recovered in liquid or gaseous form, but usually the MB is subsequently destroyed or released by further processing after recapture. While versions of many of the approaches given below have been in some commercial application, recapture on activated carbon is currently the main system in use.

9.9.1. Sorption on activated carbon

Activated carbon can adsorb relatively large amounts of MB. MB capacities vary with carbon type, conditions and tolerance for quantities of fumigant transiting through the system. Capacities of up to 30% by weight are said to be achievable at low temperatures (10°C) (Snyder and Leesch, 2001), but in practice maximum loadings are likely to be around 5 – 10%. Sorption is temperature dependent, with less MB sorbed at higher temperatures (Snyder and Leesch 2001). The sorption is exothermic (Leesch *et al.,* 2000). At low loadings, almost complete and rapid removal of MB from an air stream is easily achievable. Publications on carbon for MB recapture do not typically specify the type of carbon used. It appears that carbon derived from coconut husk is typically used. This is a microporous carbon that is widely used for removal of organic contaminants from air streams. It had the highest capacity of the three types of carbon tested by Leesch *et al.* (2000). Leesch *et al.* (2000) and Snyder and Leesch (2001) give mathematical descriptions of MB loading as a function of temperature and moisture content of the carbon.

There is some commercial adoption of recapture units based on activated carbon absorption beds. Additionally, some installations, formerly in use have been decommissioned. This has been for a number of reasons. The decision by the EU to discontinue MB fumigations completely within the (EC (2008) Commission decision of 18 September 2008 concerning the non-inclusion of methyl bromide in Annex I to Council Directive 91/414/EEC and the withdrawal of authorisations for plant protection products containing that substance. Decision 2008/753/EC.) resulted in plants in Belgium ceasing operation. These had previously been installed under a local decision to permit MB fumigation only if equipped with recapture.

Systems in current operation include various forms of the Nordiko system (Nordiko, 2010; TEAP, 2006), TIGG- supplied systems (TIGG, 2010) and Desclean systems (Spruyt *et al.,* 2006; E. Williame pers. com.). These and other systems no longer in use are described more fully in MBTOC (2007).

Some recapture systems are specifically sized to absorb kilogram quantities, typically up to about 10kg, appropriate to fumigations of containers and small under-sheet fumigations.

Recently some suppliers have produced units, based on active carbon beds, capable of absorbing larger quantities, in excess of 100kg MB, appropriate to large scale fumigations.

9.9.2. Sorption on zeolites

Zeolites are a special type of silica-containing material, which has a porous structure that make them valuable as adsorbents and catalysts. They are found naturally and can also be manufactured to precise specifications, such as very narrow pore size distribution tolerances, for specific applications. They can have moderate sorptive capacity, a few % by weight, and are particularly suited to removal of low concentrations of MB.

Several full scale trials have been carried out to demonstrate the technical feasibility of the technique. These are described in the previous MBTOC report (2006).

To MBTOC's knowledge, there are no MB fumigant scrubbing systems working on zeolite currently in commercial operation.

9.9.3. Recondensation

Because of the low MB concentration in vented gases from fumigations, typically <25 g m^{-3} and its low boiling point/high vapour pressure, recondensation has generally been considered too complex and expensive for recovery of MB. However, it may be appropriate where high concentrations (>120 g m^{-3}) of MB are applied, such as for fumigation against Giant African Snail, some treatments against fungi and some timber fumigations.

Recondensation was in use at one facility at the port of Los Angeles, USA. This unusual facility has two vacuum chambers, retrofitted with a recovery/recycling plant. At the time of fitting the system, the facility was for fumigating export cotton. A very high rate of MB, 144 g m-3, was used in this treatment, making recondensation feasible using liquid nitrogen cooling. Residual traces of MB was removed on activated carbon.

9.9.4. Fumigant transfer

At sites where there are multiple vacuum chambers treating large quantities of commodities there is the opportunity to reduce the amount of MB being emitted to the atmosphere by direct transfer of the MB that would otherwise be vented at the end of a fumigation treatment to an adjacent chamber where a treatment is about to commence. There is no intermediate concentration or storage step. This process needs equipment for accurate and rapid measurement of MB concentrations to be available so that the 'topping up' dosage can be calculated to compensate for MB lost through sorption into the commodity and through reactive breakdown.

There is an installation in Shanghai, China that uses a version of this technique (Wagn Yuejin, per somm 2011.) The site has a high throughput of logs requiring MB fumigation. It is claimed that the fumigant use was reduced by 30% using the transfer plus top up technique.

9.8.5. Direct destruction systems

9.8.5.1. Combustion

A recovery plant was installed in late 1996 at a cotton fumigation facility at the port of Los Angeles, USA. It is now no longer operational. This facility carried out other fumigations including QPS ones at that time. It used ozone to destroy the MB in the discharge and air washes from the vacuum fumigation chambers. The air-fumigant-ozone mixture was passed through a large carbon bed prior to discharge to atmosphere to complete the reaction and scrubbing processes. The system appears to be unique. It was installed to meet strict local air quality requirements.

9.8.5.2. Reaction with ozone

MB reacts with nucleopliles to produce bromide ion and methylated products. Typical reactive nucleophiles include activated oxygen, sulphur and nitrogen. The reaction occurs when MB reacts with many constituents of foodstuffs and other natural products, giving rise to the bromide residues typically produced in MB fumigations.

Several different nucleophiles have been used on an experimental and pilot scale to recapture and decompose MB after fumigations. These include thiosulphate in aqueous solution and various amines, as reviewed in MBTOC (2006). In a US patent, Joyce *et al.,* (2004), propose a scrubber system based on reaction with aqueous thiosulphate, with or without an immiscible organic solvent present to assist trapping the MB.

Reaction with aqueous thiosulphate forms the basis of destruction of the MB recaptured on carbon in one form of the Nordiko system (2006a).

9.9.6. Microbial degradation

Use of bacteria that oxidise methyl halides, including MB, has been suggested for decomposition of MB (Miller *et al.* 1999, 2003; Patel-Predd, 2006). The system may be appropriate for destruction of residual gas from freight containers, including trace quantities, but is likely to be impractical for elimination of large quantities of MB (> a few kilos). The bacteria may also be useful for decomposing MB after recapture and possibly naturally present in landfills where MB-containing materials may be dumped.

9.9.7. Destruction following recapture

9.9.7.1. Combustion

MB has a history of use as a fire extinguisher, discontinued many years ago because of its toxicity. However within narrow limits, 11.5 – 12.5% v/v, it is combustible and explosive when mixed in air at room temperature, when ignited by a high energy spark. The Approved Destruction Technologies given in Annex II to the meeting report of 15MOP, for destruction of halons, such as combustion in cement kilns, can presumably also destroy MB, itself actually a halon, provided toxicity issues can be managed appropriately.

It is reported that MB, previously captured on activated carbon or zeolite, can be decomposed in a reactor at 400 – 500 °C with quicklime giving inorganic salts as products (Yahata *et al.,* 2001). A bench scale apparatus has been described that gave MB concentration reductions of 99.99%.

Combustion is used to destroy MB-loaded carbon subsequent to its use in recapture in several systems (see Section *9.7.5.1*)

9.9.7.2. Reaction with nucleophiles following recapture

In one form of the recovery and destruction systems are now being sold (Nordiko, 2010; Gan and Yates, 1998) the sorbed MB on the activated carbon is destroyed by washing with aqueous thiosulphate followed by hot air regeneration of the activated carbon.

MB is not very stable on fresh, activated coconut carbon. At 40°C./21% m.c., trace quantities have a half-life of 11h (Gan *et al.,* 1995). Gan *et al.* measured kinetics of this hydrolysis under various conditions and attributed the instability to basic impurities in the charcoal. The Desclean recapture (Desclean, 2005) system includes a cooling step that allows the hydrolysis of the recaptured MB sorbed on carbon to be minimised, thus maximising the available material for recycling.

9.9.7.3.Landfill

Landfill sites provide highly active decomposition environments. They are capable of slowly decomposing even relatively inert materials, chemically similar to MB, such as CFCs (Altamar *et al.,* 2004). Loaded carbon from some systems is disposed of in landfill sites. Presumably the MB in these carbons will decompose slowly through direct hydrolysis (Gan *et al.,* 1995), reaction with organic materials containing active nucleophiles and possibly through bacterial action such as of the type described by Hancock *et al.* (1998).

9.9.8. Removal of methyl bromide for reuse or disposal.

Recycling processes have the potential to provide a means of reducing total emissions from a range of fumigation operations, and making MB available for uses where MB alternatives are more difficult to implement. Despite the attractiveness of the concept, practical and economicconsiderations, such as the need to remove contaminants picked up from the commodities treated, have resulted in destruction systems coupled with use of newly manufactured MB being favoured over recycling.

There are several technical options available for the removal of MB from loaded carbon that yield MB in a form for reuse or condensation for reclamation or recycling. Hot air, steam heating and pressure swing systems have been used. It is technically possible to recycle MB adsorbed on activated carbon by heating the carbon, by passing hot air or steam over it, or by altering the pressure (temperature and pressure swing adsorption). In the hot air system, circulating air strips the MB from the activated carbon. Potentially, the mixture can then be reintroduced into the fumigation chamber. The MB is reclaimed as a high concentration mixture in air, but some topping up will be necessary to compensate for system losses so as to achieve a satisfactory fumigation concentration. Pilot scale studies have demonstrated the technical feasibility of such a process (Smith, 1992) with up to 95% of the recoverable MB being available for direct reuse. Fire risk needs to be managed with hot air systems as the carbon is quite combustible. Use of nitrogen for purging has been suggested.

Electrothermal processes look particularly attractive technically as a means of producing a concentrated MB stream from loaded carbon, but are not in use at present for MB recapture systems. A laboratory demonstration of this process is reported in Snyder and Leesch (2001). The newly developed activated carbon fibre cloth (Sullivan *et al.,* 2004) may be more suited (less hazardous) to MB sorption than normal granular carbon. The material can easily be regenerated electrothermally.

An issue with any process aimed at recycling MB is whether the recovered MB is sufficiently pure to be able to be reused as 'pure MB' to comply with the specifications for established quarantine and other fumigations and also whether it can meet the labelling requirements of individual countries to be used as a fumigant. There have been concerns about the purity of recycled MB and, in particular, whether there will be build-up of other gas phase impurities with multiple recovery cycles that may be of concern for the treated products. In the USA and Canada, the original suppliers of the MB have said that they do not regard recovered MB as their product. It is thus effectively 'unlabelled' and requires reregistration before use. In some other countries (e.g. Poland) the MB recovered from carbon absorbant was apparently acceptable for reuse.

Developers of recycling technology have also encountered technical difficulties in designing equipment to perform the recycling step within the time constraints placed on commercial fumigation operations. An alternative approach, adopted by TIGG in the US (TIGG, 2010) and the developers of the (now discontinued) zeolite technology, is to transport loaded sorbant to a central facility for reclamation and recycling. Critical aspects of this technique include regulatory implications associated with the transportation and storage of toxic materials and environmental impact (truck fuel, energy use) of transporting equipment containing the loaded beds saturated with MB over some distance to the reprocessing plant. Similar considerations apply to transport of loaded carbon beds to a central destruction point.

9.10. Economics of recycling and destruction.

There is very little published data on the economics of recapture and destruction/recycling, apart from general statements that the costs can be substantial. Also it is said that the cost of producing a kilo of recycled MB is likely to be much higher than the supply cost of a kilo of newly manufactured MB.

TEAP (2006) gives costs per kilo of MB recaptured and destroyed for some commercial systems. Costs are strongly situation-dependent and subject to economies of scale. With widespread use, costs of recapture and destruction given in TEAP (2006) were projected to be in the range $US 3.2 – 17.0 per kg MB recaptured and destroyed. 2006 prices of MB to typical end users exceeded $US 15.0 per kg.

Statements on costs of recapture and reuse need to be viewed against a background of rising MB costs with increasing scarcity and regulation, possible production of cheaper recapture systems with widespread and routine use, and regulatory requirements where emission control for MB from fumigations may be part of "the cost of doing business". These regulatory controls could be local air quality and OH&S requirements in addition to any measures required for ozone layer protection.

At present MB prices, reclamation of MB for reuse may be difficult to justify solely on economic grounds, though it may be in future with constrained MB availability and improvements in recapture technologies.

During the development of one carbon-based system it was proposed that users instead of purchasing recovery systems, would be able to buy MB at a higher price that would include the cost of MB recovery, transport and disposal.

Given that the cheapest option, if permitted, will be venting residual MB to atmosphere after a fumigation, and that there are inefficiencies and constraints on the quantity and quality of material that can be recaptured, it remains unlikely that recapture/recycling will be adopted, purely on economic grounds. A further consideration, favouring destruction and new supply, are the uncertainties regarding the suitability and additional cost of reclamation procedures to meet appropriate standards for the recycled material.

There may be a special case where recycled, 'used' MB can be made available for uncontrolled uses that otherwise would be forced to use non-ODS technologies and have a particular desire to use MB. An issue with any process aimed at recycling MB is the fact that the recovered MB may not be regarded as being sufficiently pure to be able to be reused as 'pure MB' to comply with the specifications for established quarantine schedules and whether it can meet the labelling requirements of individual countries to be sold as MB for any permitted use.

Economics will tend to favour destruction over recycling in situations while new MB continue to be easily obtained for QPS purposes and destruction technologies are relatively cheap, including allowance for disposal of products of the destruction system.

9.11. Drivers and constraints for adoption of recapture

Despite Decisions VII/5(c) and XI/13(7) that urge Parties to adopt MB recovery and to minimise emissions for QPS MB treatments, there are no installations known to MBTOC that have been commissioned prior to 2010 specifically for ozone-layer protection. However there are increasing numbers of installations, based on active carbon systems that are designed to recapture MB after well-contained commodity treatments.

These units are being attached to MB fumigations in port areas and other urban environments to scrub emissions from fumigations to comply with local regulations for toxic gas emissions, air and environmental quality and worker safety. At this time, there are no recapture installations for MB, known to MBTOC, that are currently operational and installed specifically to reduce emission of ozone-depleting gasses.

Most of the recovery technologies mentioned above are complex in nature. In many cases, they are likely to be a significant part of the total cost of a new fumigation facility or to contribute significant capital cost or hire costs to apparatus associated with mobile treatment units. Most have significant running costs compared with costs of treatments

Because of the extra costs associated with recapture, it is unlikely there will be substantial adoption without some incentives or regulatory intervention. Adoption in the absence of such measures or other requirements, such as local air quality specifications, will place early adopters at a competitive disadvantage compared with those that chose not to adopt recapture.

The technologies are unlikely to become widely used to assist ozone layer protection without further international and national economic and regulatory drivers.

Recapture and recycling processes have the potential to provide a means of reducing emissions from a range of fumigation operations, and making MB supplies available as a transitional measure for uses where MB alternatives are most difficult to implement.

9.12. Containment

The aim of containment in the use of MB for the fumigation of structures is to enable reduced dosages to be effective and to reduce emissions to the atmosphere. Containment alone would not normally be considered as a viable possibility to reduce emissions to the atmosphere without effective recovery technology. However, improved containment and monitoring may in fact be considered as a strategy for reducing emissions from structures while maintaining efficacy.

Containment and emission reduction strategies for structures involve: leakage control; extending the fumigation period, while ensuring adequate *ct*-products are achieved; and pressure testing. This aspect of fumigation can be enhanced by improved monitoring of fumigant concentrations and adjusting dosages where they are excessive.

9.13. Emission reduction through modification of treatment schedules

MBTOC has suggested previously that Parties encourage their regulatory authorities to review their current treatment schedule requirements and confirming that only the minimum amount of MB needed to control pests including QPS pests, are required. A dosage reduction may be appropriate where better containment can be achieved. As an example, cut flowers from Israel consist of many different species, each with differs in tolerance to MB and each with a range of pests of quarantine concern to overseas markets. The MB dosage could be reduced by 2-2.5 times compared to many previous quarantine schedules, while at the same time avoiding phytotoxicity and controlling the three main quarantine pests discussed by Kostyukovsky *et al.,* (1998).

However, efforts at dosage-reduction may be negated by other research that continues to increase the dependency on MB. For example, research is still being commissioned in a number of countries to develop MB-based treatments for export crops that will continue to add to the amount of MB consumed for quarantine and pre-shipment treatments.

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Annex 1

Annex 1. Methyl Bromide Technical Options Committee - Committee Structure

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MBTOC structure as at 31 December 2006

Co chairs

MBTOC – Soils subcommittee

Dr. Mohamed Besri — Institut Agronomique et Vétérinaire Hassan II, Morocco

Dr. Ian Porter — Department of Primary Industries, Australia

MBTOC – QPS subcommittee

Ms Marta Pizano — Consultant, Colombia

MBTOC – SC subcommittee

Ms Michelle Marcotte — Consultant, Canada

Subcommittee chairs, chapter lead authors for this Assessment

Chapter 1 - Executive summary
Chapter 2 - Introduction to the assessment - lead author, Ms. Marta Pizano.
Chapter 3 - Methyl Bromide production, consumption and limitations on use (controlled uses) - lead authors, Ms. Marta Pizano and Dr. Ian Porter.
Chapter 4 -Alternatives to Methyl Bromide for soil treatment – Co-hairs of 'soils' chapter subcommittee and lead authors, Dr. Mohamed Besri, Dr. Ian Porter.
Chapter 5 - Alternatives for Treatment of Post-Harvest Commodities, Food Processing Facilities and Other Structures, Wood Products and Other Durables – Co-chair of 'structures and commodities' subcommittee and lead authors – Ms. Michelle Marcotte.
Chapter 6 – Quarantine and Pre-shipment - chair of the 'QPS' subcommittee and lead authors, Ms. Marta Pizano. Dr. Tom Batchelor.
Chapter 7 – Progress in Methyl Bromide phase-out. Lead authors, Ms. Marta Pizano, Mr. Alejandro Valeiro.
Chapter 8 - Economic Issues Related to Methyl Bromide Phaseout. Lead authors Dr. Jim Schaub, Dr. Nick Vink, Dr. James Turner
Chapter 9 - Reducing Methyl Bromide emissions. Lead authors Dr. Jonathan Banks and Dr. Ian Porter

Committee contact details and Disclosure of Interest

To assure public confidence in the objectivity and competence of TEAP, TOC, and TSB members who guide the Montreal Protocol, Parties to the Protocol have asked that each member to disclose proprietary, financial, and other interests. TEAP members have published such information for several years in the TEAP annual report.

As a result, Decision XVIII/19 was issued during the 18th Meeting of Parties to the Montreal Protocol held in New Delhi, India from 28 October to 3 November 2006. All MBTOC members are presently required to complete a disclosure of interest form.

Table 47 below contains the lists of members of each MBTOC sub-committee. Full disclosure details can be found at the Ozone Secretariat website http://ozone.unep.org/Assessment_Panels/TEAP/mbtoc-all-disclosure.shtml

TABLE 47. MEMBERS OF THE MBTOC SUBCOMMITTEES AS AT DECEMBER, 2010

A- MBTOC Soils subcommittee				
Chairs		**Affiliation**	**Time**	**Country**
1. Mohamed Besri	M	Department of Plant Pathology, Institut Agronomique et Vétérinaire Hassan II	A	Morocco, A5
2. Ian Porter	M	Consultant and Principal Research Scientist, Department of Primary Industries, Victoria	A	Australia, Non-A5
Members				
3. Cao Aocheng	M	Institute for Plant Protection, Chinese Academy for Agricultural Sciences	A	China, A 5
4. Antonio Bello	M	Prof. Emeritus, Centro de Ciencias Medioambientales, Madrid	A	Spain non-A5
5. Peter Caulkins	M	Associate Director, Special Review & Reregistration Division US EPA	B	USA, non-A 5
6. Abraham Gamliel	M	Agricultural Research Organization, The Volcani Center	B	Israel, non-A5
7. Raquel Ghini	F	EMBRAPA Meio Ambiente – Jaguariúna Sao Paulo	C	Brasil, A5
8. George Lazarovits	M	A&L Biologicals Agroecology Research Services Centre	B	Canada, non-A5
9. Andrea Minuto	M	Centro Regionale di Sperimentazione ed Assistenza Agricola CERSAA, Albenga	A	Italy, non-A5
10. Marta Pizano	F	Consultant, Hortitecnia Ltda	A	Colombia, A5
11. Sally Schneider	F	National Program Leader – Horticulture, Pathogens & Germplasm, USDA	B	USA, non=A5
12. JL Staphorst	M	Consultant, Plant Protection Research Institute (PPRI), Agriculture Research Council (ARC)	A	South Africa, -A5
13. Akio Tateya	M	Technical Adviser, Syngenta Japan	A	Japan, non-A5
14. Jim Wells	M	Environmental Solutions Group, LLC, Sacramento, CA	A	USA, non-A5
15. Alejandro Valeiro	M	National Project Coordinator, National Institute for Agriculture and Technology,Tucumán	B	Argentina, A 5
16. Janny Vos	F	CABI- Netherlands	C	Netherlands, non-A 5
17. Suat Yilmaz	M	West Mediterranean Agricultural Research Institute – BATEM, Antalya	C	Turkey, A 5
TOTALS				F= 4 M + 13 A5= 7 non A5 = 10

A > 10 yrs; B 5- 10 yrs; C 1- 5 yrs

MBTOC Quarantine and pre-shipment (QPS) subcommittee				
Chair		**Affiliation**	**Time**	**Country**
1. Marta Pizano	F	Consultant	A	Colombia A5
Members				
2. Jonathan Banks*	M	Consultant	A	Australia Non-A5
3. Tom Batchelor	M	Touchdown Consulting	C**	Belgium Non-A5
4. Ken Glassey*	M	Senior Advisor Operational Standards Biosecurity New Zealand, Ministry of Agriculture and Forestry Wellington	B	New Zealand Non- A5
5. Takashi Misumi	M	Quarantine Disinfestation Technology Section, Ministry of Agriculture, Forestry and Fisheries MAFF		Japan Non A5
6. David Okioga	M	Kenya Ozone Office. Min. of Environment	A	Kenya A5
7. Ian Porter	M	Consultant and Principal Research Scientist, Department of Primary Industries, Victoria	A	Australia Non A5
7. Ken Vick*	M	Consultant, USDA	A	United States Non-A5
8.Eduardo Willink	M	Estación Experimental Agroindustrial Obispo Colombrés, Tucumán	B	Argentina A5
Totals				A5=3; Non-A5=5 M = 6; F – 1

**Dr Batchelor was a member of MBTOC between 1992 and 2002. He joined MBTOC again in 2009

A - >10 years; B – 5-10; C – 1-5

* Also acting as corresponding members for SC subcommitee

MBTOC Structures and commodities (SC) Subcommittee				
Chair		**Affiliation**	**Time**	**Country**
1. Michelle Marcotte	F	Consultant	A	Canada Non-A5
Members		**Affiliation**		
2. Chris Bell	M	Consultant, retired from Central Science Laboratory (Government research)	A	UK Non-A5
3. Fred Bergwerff	M	Eco2, Netherlands	B	Netherlands Non-A5
4. Ricardo Deang	M	Consultant	A	Philippines A5
5. Patrick Ducom	M	Consultant, retired from Ministère de l'Agriculture (Government research)	A	France Non-A5
6. Alfredo Gonzalez	M	Fumigator	B	Philippines A5
7. Darka Hamel	F	Croatian Institute for Agriculture, Food and Rural Affairs - Institute for Plant Protection (Government)	C	Croatia A 5
8. Christoph Reichmuth	M	In transition to Professor at Humboldt University Berlin. Retired from JKI Germany (Government research) (October 2010)	C	Germany Non-A5
9. Jordi Riudavets	M	IRTA-Department of Plant Protection. (Government Research)	C	Spain Non-A5
10. John Sansone	M	SCC Products (Fumigator)	A	US Non-A5
11. Robert Taylor	M	Consultant, retired from UK research institute	A	UK Non-A5
12. Chris Watson	M	Consultant, retired from IGROX Ltd (Fumigator)	A	UK Non-A5
Totals				A5=3 Non-A5=9 M= 19 F- 2

A - >10 years; B – 5-10; C – 2-5

MBTOC Economists				
Jim Schaub	M	Office of the Chief Economist U.S. Department of Agriculture	A	USA, non-A 5
James Turner*	M	Resource Economist, AgResearch, Ruakura Research Centre, Hamilton	C	New Zealand, non-A5
Nick Vink	M	University of Stellenbosch, Department of Agricultural Economics	B	South Africa, A 5

* Dr James Turner resigned to MBTOC in January, 2011

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