Methyl Bromide Technical Options Committee

2018 Assessment Report

Montreal Protocol on Substances that Deplete the Ozone Layer

UN environment
United Nations Environment Programme
Ozone Secretariat

MONTREAL PROTOCOL

ON SUBSTANCES THAT DEPLETE

THE OZONE LAYER

2018 REPORT OF THE METHYL BROMIDE TECHNICAL OPTIONS COMMITTEE

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United Nations Environment Programme (UNEP)
2018 Report of the Methyl Bromide Technical Options Committee

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In Memoriam
Raquel Ghini

The 2018 MBTOC Assessment Report is dedicated to our dear friend and colleague Raquel Ghini who passed away in 2018. We will always remember Raquel for her kind disposition, her willingness to help and her commitment to protecting our planet's environment, especially the ozone layer.

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Glossary of Acronyms

1,3-D	1,3-Dichloropropene
A5	Article 5
AITC	Allyl isothiocyanate
ASD	Anaerobic soil disinfestation
CUE	Critical Use Exemption
CUN	Critical Use Nomination
DOI	Disclosure of Interest
EDN	Ethanedinitrile
EU	European Union
EPA	Environmental Protection Agency
EPPO	European Plant Protection Organisation
IPM	Integrated Pest Management
IPPC	International Plant Protection Convention
ISPM	International Standard for Phytosanitary Measure
LPBF	Low Permeability Barrier Film (including VIF films)
MB	Methyl bromide
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
WMO	World Meteorological Organisation

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Executive Summary

1.1. Mandate and report structure

Under Decision XXVII/26 taken at the Twenty-Third Meeting of the Parties to the Protocol in 2015, the Parties requested the Assessment Panels to update their 2014 reports in 2018 and submit them to the Secretariat by 31 December 2018 for consideration by the Open-ended Working Group and by the Twenty Seventh Meeting of the Parties to the Montreal Protocol, in 2019.

As required under Decision XIII/13, the MBTOC 2018 Assessment reports on advances since 2014 to replace Methyl Bromide (MB) used under Critical Use by both A5 and non-Article 5 Parties. It also reports on QPS uses, which are presently exempt from controls under the Montreal Protocol. It further reports on technically and economically feasible alternatives for non-QPS and QPS uses of MB and gives actual examples of their successful commercial adoption around the world. It shows trends in methyl bromide production and consumption in both Article 5 and non-Article 5 Parties, estimated levels of emissions of MB to the atmosphere, and strategies to reduce those emissions.

1.2. The Methyl Bromide Technical Options Committee (MBTOC)

As at December 2018, MBTOC had 16 members: seven (44%) from Article 5 Parties and nine (56%) from non-Article 5 Parties. Members come from seven Article 5 and eight non-Article 5 Parties. MBTOC is seeking new members, especially from non-A5 Parties; several members from this group of Parties have stepped down due to lack of funding.

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 also led countries to impose severe restrictions on methyl bromide use including 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 of concern.

The control measures, agreed by the Parties at their ninth Meeting in Montreal in September 1997, were for phase out of methyl bromide by 1 January 2005 in non-Article 5 countries. For Parties operating under Article 5 of the Protocol (developing countries) the controlmeasures were for 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 submitted nearly 150 applications for 18,700 tonnes for‘critical uses’ after 2005 for non-QPS purposes under Article 2H of the Montreal Protocol. By 2018 the number had declined to two applications for approximately 33 tonnes for use in 2018 and 2019. Use of methyl bromide under the ‘Critical Use’ provisions became available to ‘Article 5 countries in 2015 and initially

four countries applied for 590 tonnes of MB after 2014. Presently, two Parties have requested 118.5 tonnes of MB under the CUE provisions for use in 2019.
Although QPS uses must be officially reported under Article 7 of the Protocol they continue to be exempt from controls under Article 2H.

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 2017. Although a few cases of data gaps remain from the early years, reported data has become much more complete. All tonnages are given in metric tonnes in this report.

In 2017, global *production* for the methyl bromide uses controlled under the Protocol was 245 tonnes, which represented 0.4% of the 1991 reported production of 66,430 tonnes.

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. By 2013, global consumption was estimated at about 2,953 tonnes in 2013 and fell to 245 tonnes in 2017. Historically, in non-Article 5 regions, about 91% of methyl bromide was used for pre-plant soil fumigation and about 9% for stored products and structures.

The official aggregate baseline for non-Article 5 countries was 56,083 tonnes in 1991. In 2005 (the first year of critical use provisions), non-Article 5 consumption had been reduced to 11,470 tonnes, representing 21% of the baseline. Many non-Article 5 countries achieved complete phase out for controlled uses before 2010 (New Zealand, Switzerland and countries of European Community). Israel and Japan phased out for controlled uses (preplant soil fumigation) in 2011 and 2012 respectively. The USA, which was the largest non QPS user of MB historically, submitted its last CUN in 2014 for 2016 use for its remaining preplant soil use in the strawberry fruit sector. Non-A5 Parties requested CUEs from 2003 and in 2018 only two – Australia and Canada - remain (99% of the controlled baseline has been replaced). Many Article 5 previously included among the largest users reported complete phase-out by 2015 (i.e. Brazil, Egypt, Turkey, Lebanon, Zimbabwe, Morocco) and did not submit CUNs. Only four Article 5 Parties requested CUNs since 2014, and two – Argentina and South Africa - remain in 2018. Almost all (97.5%) of the controlled use baseline (15,870 tonnes) for A5 Parties has been replaced.

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 very specific constraints or circumstances 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.

Since controls were implemented on MB use in 1992, Parties have been able to identify alternatives for over 99% uses of the baseline consumption. Only 141 tonnes of the original 72,000 tonnes of MB used by non-A5 and A5 Parties for controlled uses remain. The rest of the uses have taken up a wide range of non chemical and chemical alternatives or developed new production sytsems or technologies which do not require MB fumigation. Of the remaining uses, MBTOC considers alternatives are available, but these may require time for adaptation and adoption.

1.5.1. 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 for controlled uses with amounts used in 2017 falling 99.5% from about 57,400 tonnes in 1992 to about 33 tonnes, in non-A5 Parties and 119 tonnes in A5 Parties in 2019.

Methyl bromide is presently used in non-Article 5 countries for strawberry runner production only. Some uses previously considered under the CUN process have been partially reclassified as QPS in one country under national legislation outside of the Montreal Protocol (e.g. forest nurseries, strawberry runners). Since 2014, A5 Parties submitted CUNs for strawberry fruit and runners, raspberry runners, ginger and tomatoes. In 2018 only strawberry fruit and tomatoes remained.

Over the years, MBTOC has identified a range of key chemical and non chemical alternatives that perform consistently across most regions and sectors. Chemical fumigants (e.g. Metham sodium, dazomet, 1,3 D alone or combined with cholopicrin (Pic,) dimethyl disulfide (DMDS) and others) are widely used around the world and have successfully replaced MB. A wide range of non-chemical alternatives to MB continue to be trialled around the world including disease-resistant cultivars and grafting desirable varieties onto resistant rootstocks; soil-less culture; anaerobic soil disinfestation; biofumigation and organic amendments; solarisation and biosolarisation; trap cropping; hot water; biological control; and microwaves. A combination of treatments within an IPM program continues to be reported as the most effective approach.

Since 2003, quantities of MB requested for critical use (120 critical use nominations from 10 non-A5 Parties plus the European Union) have fallen from 18,700 t for use in 2005 to 150 t for 2019/2020 use (four CUNs from 3 Parties, two A5 and two non-A5) .

This chapter of the 2018 Assessment report focuses on leading economically and technically feasible chemical and non-chemical alternatives for pre-plant soil fumigation adopted in the past by sectors in countries which previously used MB, particularly under the CUE process. It also focuses on alternatives for the remaining MB uses in the soil sector: strawberry fruit and tomato in Argentina, strawberry runner production in Australia and Canada. In the past, many tomato, strawberry fruits and runner industries around the world relied on MB soil fumigation to produce fruits and disease-free strawberry transplants, but most of them have phased-out MB and successfully implemented alternatives. Research is currently underway to evaluate different alternatives and it is expected that MB will be very soon phased out from soil disinfestations in these 3 remaining countries still using MB: Argentina, Australia and Canada.

1.5.2. Alternatives for treatment structures and durable commodities (non-QPS)

Uses remaining in the Structures and Commodities sector (non-QPS) are anticipated to consume less than 41 tonnes in 2019. At the time of the Copenhagen Amendment (1992), this sector is estimated to have consumed an estimated 6,500 tonnes per year, with much of the reduction attributable directly to the application of the Montreal Protocol measures.

Methyl bromide CUEs in this sector totaled 27.27 tonnes for 2014, all from non-A5 countries, and all phased out by 1 January 2018. The first Article 5 CUEs, were granted for 2016 use of 74.062 tonnes for South Africa. Of these 41.00 tonnes have been granted for use in 2019. The main alternatives adopted were fumigants. In this sector and in those countries where MB has been phased out, mainly phosphine and sulfuryl fluoride have taken its place with phosphine has mainly been adopted for disinfestation of durable products and sulfuryl fluoride mostly for disinfestation of empty structures. In some countries, ethyl formate, hydrogen cyanide and propylene oxide have also been registered and are in use for certain fields of application. The MB phse-out was in general associated with changes in application technology, logistics and use of additional IPM measures. There has been some adoption of not-in-kind alternatives (e.g. heat, cold, controlled atmospheres, contact pesticides, biological control). Adoption of particular alternatives has been situation and commodity dependant.

There are continued efforts to improve and register existing alternatives, including fumigants falling into disuse and to develop and register new or rmore environmentally friendly non-MB approaches. These include systems to avoid pressures to return to MB-dependance.

Several alternatives are under threat and may require replacement or further adaptation within the next few years, at least on a local basis. There is increasing reliance on phosphine treatment for protection of many postharvest durable products in store (e.g. cereal grains, pulses, cocoa beans). However, resistance to phosphine in several pest species has developed, to levels where phosphine is uneconomic due to the very high dosages necessary to control resistant strains. Sulfuryl fluoride fumigation, a potential alternative for the control of insect pests in infested empty structures (warehouses, mills, food and feed factories, wooden strutures in houses), has a high GWP that may change its widespread acceptability for use as an alternative to both phosphine and methyl bromide. Sulfuryl fluoride is also used for disinfestation of some selected durable pruducts, but these applications are under revision due to the risk of exceeding the maximum residue limits for fluoride. The risk of loosing this fumigant for pest control in structures poses difficult challenges for the MB phase out program of the last decades, in particular the disinfestation of large mills and food factories which would remain without feasible pest control measures. Regulatory issues also impact treatment of foodstuffs. Chemical alternatives (and methyl bromide itself) are under increasing regulation with potential to making their use infeasible in particular situations.

1.6. Alternatives to methyl bromide for Quarantine and Pre-shipment (QPS) applications (exempted uses)

Article 2H exempts methyl bromide used for QPS treatments from phase-out for quarantine and pre-shipment purposes. Methyl bromide fumigation is often the preferred treatment for certain types of perishable and durable commodities in trade worldwide, as it has a well-established, successful reputation amongst regulatory authorities to prevent the spread of quarantine pests.

Parties to the Montreal Protocol are nevertheless encouraged to minimize and replace MB for QPS whenever possible, ensuring, among others, that their official lists of quarantine pests are regularly updated and that MB is applied in the most efficient way possible (e.e. observing appropriate dosages, avoiding duplicate treatments, ensuring gastightness of fumigation chambers). Considering that in the past MBTOC has identified opportunity for replacing between 30 and 45% of QPS uses with immediately available alternatives, Parties may wish to step up efforts to reduce and replace QPS uses, particularly those for pre-shipment uses.

Since the MBTOC 2014 Assessment Report (MBTOC, 2015), several Parties have made significant technical advances and taken strict policy decisions leading to reductions and even phase-out of MB for some QPS applications. Such policies may go further that agreed per Montreal Protocol control measures, and are mainly driven by concerns for worker safety and local air quality. In 2010, the European Union phased out all uses of MB, New Zealand has recently implemented a policy of requiring recapture for all QPS uses of MB and North Carolina in the US has also imposed recapture technologies.

Quarantine treatments for host plants of potentially damaging plant quarantine pests are generally approved on a pest and product specific basis following extensive bilateral or regional negotiations, which may require years to complete. This process helps ensure safety against the incursion of harmful pests. For this and other reasons, replacing MB for quarantine treatments can be a complex issue. Many non-methyl bromide treatments are, however, published in countries quarantine regulations, but they are often not the treatment of choice due to cost or availability.

Nevertheless, since the 2014 Assessment report there has been acceptance under domestic quarantine (biosecurity) protocols, bilateral arrangements and IPPC regulations that a number of technical alternatives are as effective as MB for specific commodities. These include irradiation, cold and heat treatments, modified atmospheres, cool temperature phosphine treatment, SF, EDN and ethyl formate.

Global production of methyl bromide reported for QPS purposes in 2017 was 10,217 tonnes, increasing by about 15% 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. Production occurs in five Parties, China, India, Israel, Japan and USA.

In 2009 the QPS consumption exceeded non-QPS for the first time, being 46% higher. By 2017, reported QPS consumption was 70 times larger than controlled consumption. From 2012- 2014 it appeared that there was a trend towards reduced QPS use, but over the last three years (since the global phase out for controlled uses) QPS consumption has increased substantially from 8,500 tonnes to over 10,000 tonnes.

Of the 50 countries still regularly using MB for QPS 14 show significant reductions in their methyl bromide consumption for QPS but others (13) have shown sharp increases. This is possibly due to increased pest risks and trade in commodities requiring treatment such as pulses and logs. Countries with significant increases include Australia, China, India and New Zealand. Owing to this increase in use for QPS by some countries, the major reductions obtained in others, some greater than 50% (EU, Japan, Thailand, USA and others) have been offset and there has been no overall sustained reduction in QPS use in the last twenty years.

Reported consumption shows that MB used for QPS now exceeds the baseline levels set for controlled uses in 16 countries, particularly for Australia, Pakistan, New Zealand and Vietnam. In addition some of these countries, five countries (El Salvador, Fiji, India, Korea and Nicaragua) never used any methyl bromide for controlled uses, but now have significant uses under QPS. Regulations have existed which prevent any new uses for preshipment applications, but MBTOC is unclear if this has occurred due to unreliable reporting.

In 2017, QPS consumption in A5 Parties (6,617 tonnes) represented 69% of global consumption; non-A5 Party consumption of 3,343 tonnes was 31%. Overall, MB consumption for QPS in Article-5 Parties has trended upward over the past 15 years, whereas consumption in non-A5 Parties has a downward trend. Global consumption averaged 9,617 tonnes over the period 2010 to 2017 and in 2017 has increased to about 10,000 metric tonnes.

On a regional basis, since 1999 consumption in the Latin America and the Caribbean, Africa and Eastern Europe regions has remained much lower since 1999 than in Asia and in North America. In 2017, Asian countries accounted for 55% of global QPS consumption.

In 2017, QPS use of MB contributed over 97% of the global emissions of methyl bromide (Chapter 4) which is approximately 34 times greater than the emissions from the consumption for critical uses controlled under the Montreal Protocol. Control of these emissions is the biggest immediate gain that can be made under the Montreal Protocol to the reduction of ODS substances in the stratosphere. Parties who have reduced emissions of MB for QPS have either regulations which speed up the uptake of alternatives or are adopting recapture technologies.

Improvements in recapture technologies and approval by the Parties of the first destruction technology for methyl bromide (TEAP 2018) mean that technologies are now available to reduce the level of MB emissions. As the implementation of these technologies imposes a cost on the user, their uptake will most likely only occur if Parties impose regulations mandating their use. To date, Parties who have reduced emissions of MB for QPS have either regulations which speed up the uptake of alternatives or are adopting recapture technologies

Accurate reporting (as noted, for example by the sudden jump in MB use by India) and classification of use is still a major problem. Some Parties continue to express concerns over difficulties in interpreting the categories of MB uses between controlled and exempted uses and some of the QPS reported use appears to be wrongly reported. MBTOC also still has difficulty in determining the actual pests and commodities for which MB is used in QPS and Parties may wish to consider improved means with which Parties can obtain and report this information more effectively.

While there remain some data gaps and uncertainties, information supplied by the Parties allowed MBTOC to estimate that five uses consumed more than 80% of the methyl bromide used for QPS in 2017: 1) Sawn timber and wood packaging material (ISPM-15); 2) Grains and similar foodstuffs; 3) Pre-plant soils use; 4) Logs; and 5) Fresh fruit and vegetables. On the basis of these estimates and currently available technologies to replace methyl bromide for QPS, MBTOC has estimated that between 30 and 45% of the MB used for QPS purposes could be replaced with immediately available alternatives.

The International Plant Protection Convention (IPPC) recently approved sulfuryl fluoride as a treatment for compliance with ISPM-15 (wood packaging materials). Heat (including dielectric heating) and non-wooden pallets provide additional options. Alternatives under consideration by IPPC for logs include phosphine, sulfuryl fluoride, ethanedinitrile (EDN, cyanogen); heat (including vacuum steam), and debarking provide further options. Ethanedinitrile has been registered or is close to registration in several countries and with a growing body of efficacy data has potential to replace a significant portion of QPS use for nonfood items, particularly if accepted by the IPPC.

In contrast to quarantine treatments, MBTOC considers that a range of alternatives are available and ready for use for preshipment fumigation. This is because preshipment use targets cosmopolitan pests, where alternatives have generally been shown by the country to be effective under the phase out of controlled uses or critical uses. Parties may wish to reconsider whether this part of the QPS exemption from controls could be reviewed. This category contains a high proportion of durable commodities for which MBTOC considers alternatives are more suitable and more effective. The preshipment exemption is often a confusing issue for Parties. MBTOC is aware of MB uses which do not fall within the preshipment category, nor the broader QPS exemption but are nevertheless reported as such

For pre-plant soil quarantine treatments, alternative fumigants are available, provided the alternatives meet certification standards; substrates also may be used at least partially in the propagation systems.

For perishables, there are various approved treatments, depending on product and situation, including heat (as dry heat, steam, vapour heat or hot water dipping), cold (sometimes combined with modified atmosphere), modified and controlled atmospheres, alternative fumigants (e.g. ethyl formate), physical removal, chemical dips and irradiation. Irradiation of fresh food continues to grow in trade between countries.

The technical and economic feasibility of alternatives to methyl bromide used for QPS in all countries mainly depend on achieving the high level of efficacy required against quarantine pests of concern.

In the absence of regulatory or economic incentives to adopt alternatives, methyl bromide is often the lowest cost effective option at present, an alternative would not be voluntarily adopted unless it performed as well or better at a similar market cost. However, increasing health and safety concerns are driving the market to alternatives and QPS consumption is in decline in many countries. Those concerns are also increasing the use of recapture equipment of QPS methyl bromide.

1.7. Emissions from methyl bromide use and their reduction

The large reduction in consumption of methyl bromide (MB) since 1999 has resulted in a significant decline in atmospheric emissions of MB, mostly in line with the reduction measures imposed on Parties) under the Montreal Protocol. Based on reported consumption data under Article 7 of the Protocol, MB emissions to the atmosphere from known current usage are expected to be around 8,500 tonnes in 2017 (see Table 4.2). Since 1998, MBTOC estimates that anthropogenic emissions of MB have declined by 80-85% from the peak emissions of around 48,000 tonnes in 1998. Owing to the reported phase-out of nearly all controlled uses of MB (i.e. for soil fumigation and domestic commodity and structural fumigation) the bulk (98%) of the present emissions should now only be from QPS (quarantine/pre-shipment) uses. These QPS uses are predominantly to support international trade of durable and perishable commodities and some structural fumigations, but also some pre-plant soil fumigation to produce high health nursery/turf products moving across jurisdictional boundaries in the US. MBTOC has estimated that most (i.e. nearly 80%) of the MB used for QPS is presently emitted after treatment directly to the atmosphere. Some countries (e.g. New Zealand) have imposed regulations to prevent emissions and instead ensure that MB is recaptured/destroyed as much as practical from fumigation operations.

As anticipated, the decline in the atmospheric concentration of MB due to restrictions on MB consumption has slowed since 2015 as 98% of the reported consumption for controlled uses occurred prior to 2015, the final phase-out date for A5 countries. The remaining emissions are now supposedly only from the small amounts used for critical uses (Critical Use Exemptions – CUEs), i.e. 290 tonnes of MB consumed in 2017 for CUEs and 10,100 tonnes from QPS use in 2017. The emissions from the 4,000 tonnes of MB used for feedstocks are considered insignificant (probably less than 100 tonnes). Fugitive emissions from industrial syntheses continue to be a cause of concern.

Recently (2013 to 2017) changes in global atmospheric MB concentrations do not appear to be ot explained by global production and consumption data (Figure 3.3). From 2013 to 2015 there appeared to have been a 5 ktonne rise in emissions of MB, followed by a similar magnitude fall in emissions (2015 to 2017). The reason for this are unclear and potentially indicates that there may be some consumption which is unreported or other sources of MB which are now more predominantly influencing emissions.

The Montreal Protocol has set several policy steps to minimise emissions of MB. (Article 2H, Decisions VII/5(c), and XI/13(7), where Parties are encouraged to adopt emission control technologies. As a consequence, emission reduction steps have been developed for all controlled uses. For preplant soil uses, barrier films were widely adopted by the Parties for controlled uses and for commodity uses recapture technologies have been available but not widely used. MBTOC considers that barrier films should be mandatory for any remaining pre-plant soil fumigation of MB globally and that recapture/destruction technologies should be considered for all remaining commodity uses where practically feasible.

Since the last assessment, MBTOC estimates that alternatives to MB are available for approximately 40% of the MB used for QPS uses. Even if alternatives are not adopted and MB continues to be used, MBTOC considers that recapture and destruction technologies are available for many QPS uses and that their adoption could reduce at least 70% of the existing emissions of MB for those uses.

Mandatory recapture and destruction for all remaining uses of MB for QPS, together with identification and stopping any unreported uses are considered important factors to return MB concentrations in the atmosphere to natural levels. Owing to the relatively short lifetime of MB in the atmosphere, recapture/destruction would have an immediate benefit in reducing MB levels in the atmosphere and an important step currently available to Parties of the Montreal Protocol to enhance ozone layer recovery.

1.8. Economic issues

In the case of most CUNs relatively simple partial budget analyses are sufficient to establish economic (in)feasibility.

Australian and Canadian Parties may shift the emphasis in their respective nominations to the issue of economic infeasibility. MBTOC also anticipates that it may be asked to comment on the type(s) of economic evaluation that will be required with QPS uses of methyl bromide.

2

Chapter 2. Introduction to the Assessment

2.1. Introduction

Under Decision XXVII/6 taken at the Twenty-Third Meeting of the Parties to the Protocol in 2015, the Parties requested the Assessment Panels to update their 2014 reports in 2018 and submit them to the Secretariat by 31 December 2018 for consideration by the Open-ended Working Group and by the Twenty Seventh Meeting of the Parties to the Montreal Protocol, in 2019.

The MBTOC 2018 Assessment reports on advances since 2014 to replace Methyl Bromide (MB), now exclusively used under Critical Use by both A5 and non-Article 5 Parties. It also reports on QPS uses, which are presently exempt from controls under the Montreal Protocol. It covers technically and economically feasible alternatives for non-QPS and QPS uses of MB and gives actual examples of their successful commercial adoption around the world. It shows trends in methyl bromide production and consumption in both Article 5 and non-Article 5 Parties, estimated levels of emissions of MB to the atmosphere, and strategies to reduce those emissions.

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. After these dates MB use for controlled uses is only allowed under the Critical Use Exemption (CUE). In 2003, nine non-Article 5 Parties have submitted nearly 150 applications for 18,700 tonnes for'critical uses' after 2005 for non-QPS purposes under Article 2H of the Montreal Protocol.By 2018 the number had declined to two applications for about 33 tonnes for use in 2018 and 2019. Use of methyl bromide under the 'Critical Use' provisions became available to Article 5 countries in 2015 and presently, two Parties have requested MB under the CUE for use in 2019, totalling 242 tonnes.

2.2. Global overview of methyl bromide uses

MB has been used commercially as a fumigant since the 1930's (MBTOC, 1994). It is a highly versatile product, used in many different applications, for the control of soilborne pests (nematodes, fungi, weeds, insects) in high-value crops, and for the control of insects, rodents and other pests in structures, transport and stored commodities. MB has features that make it a versatile biocidal with a wide range of 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 crop production or commerce.

2.2.1. MB uses identified in Articles of the Protocol

MB was listed under the Montreal Protocol as a "controlled substance" in 1992 (Article 1 and Annex E). The Articles of the Protocol refer to four main categories of MB uses, and each is subject to different legal requirements. Table 2-2 lists these four categories, and indicates those for which information is provided in this MBTOC report. Additional control schedules were agreed to in 1995 and 1997 for two of the categories - the non-QPS fumigant uses and laboratory and analytical (L&A) uses under Articles 2 and 5, with authorised Critical Use Exemptions (CUE). The phase-out schedules are summarized in Table 2-1 below.

TABLE 2-1: 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

Source: Montreal Protocol Handbook, UNEP, Ozone Secretariat 2018.

Critical and emergency uses may be permitted after phaseout if they meet agreed criteria. Emergency uses may be of up to 20 metric tonnes under Decision IX/7. Parties are urged to use stocks of MB for their critical uses. Such stocks need to be reported to the Ozone Secretariat, only when a Party has requested a CUN.

Quarantine and pre-shipment (QPS) uses and feedstock are exempt from reductions and phaseout 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. Laboratoty 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 Medical and Chemical Technical Options Committee (MCTOC).

Because the phase-out of controlled uses (non-QPS) of MB is now almost complete, QPS uses now comprise about 97.5% of MB use by the Parties of the Montreal Protocol (see Chapter 5). QPS use of MB has thus become the largest, non-controlled ODS emission (among the substances presently included in the Montreal Protocol).

TABLE 2-2: CLASSIFICATION OF MB USES UNDER THE MONTREAL PROTOCOL, INDICATING RELEVANT SECTIONS IN THIS ASSESSMENT REPORT

MB uses	Status under the Montreal Protocol	Relevant information in MBTOC 2018 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 in Article 5 and non-Article 5 Parties. Additionally some Parties have used small amounts of methyl bromide (< 20 t) after 2005 under the 'Emergency Use' provisions under Decicion IX/7 of the Montreal Protocol.	Chapters 1-2 and 6-7
QPS fumigant uses	Exempted from reduction and phase-out schedules. Subject to Article 7 data reporting requirements	Chapter 5
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 6^{th} Meeting of the Parties	L&A uses are covered in MCTOC 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

2.3. MBTOC mandate

The Methyl Bromide Technical Options Committee (MBTOC) was established in 1992 by the Parties to the Montreal Protocol to identify existing and potential alternatives to MB. MBTOC, in particular, provides recommendations and advice to the Parties on the technical and economic feasibility of chemical and non-chemical alternatives for MB.

Additionally, from 2003, MBTOC has had the task, under Decision IX/6 and others, of evaluating Critical Use Nominations submitted by non- Article 5 Parties to the Montreal Protocol and by Article 5 Parties from 2014. MBTOC provides recommendations on such nominations, for review and endorsement by the Technology and Economic Assessment Panel (TEAP) and then consideration by the Parties. MBTOC presently works as a single committee and its members have distinct expertise in the uses of MB and its alternatives following areas: Soils (pre-plant fumigation), Structures and Commodities 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. Information contained in MBTOC's reports contribute to the Parties' deliberations on appropriate controls for MB and its alternatives and for endorsement of use by the Parties for critical uses. Parties review MBTOC and TEAP's recommendations and may accept, reject of modify these recommendations when taking decisions on CUE requests.

2.4. Committee process and composition

At December 2018, MBTOC had 16 members; nine (56%) from non-Article 5 and seven (44%) from Article 5 Parties. These members came from seven Article 5 and eight 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. MBTOC members may nominated by their governments; MBTOC co-chairs also have the authority to appoint members in full consultation with the focal points from their country of origin.

In accordance with new and revised Terms of Reference for TEAP and its Technical Options Committees, (Decision XXIII/10 (9)) terms of service are now set at four years with the option of reappointment for ensuing terms.

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 8th 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 Melbourne, Australia (March, 2018) and Montpellier, France (September, 2018). 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 these formal meetings. The Assessment was finalised by email, to produce a consensus document of the Committee, which was submitted to the Ozone Secretariat for posting at their website.

2.5. MBTOC assessments on methyl bromide

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), the fourth in 2006 (MBTOC, 2007) the fifth in 2010 (MBTOC, 2011) and the sixth in 2014 (MBTOC, 2015). The 2018 Assessment Report is MBTOC's seventh.

MBTOC progress reports on advances in alternatives to methyl bromide and other issues related to methyl bromide are included in annual TEAP reports to the Parties. MBTOC further produces reports on its assessment of CUNs twice a year: one interim and one final report. These reports can be found on the Ozone Secretariat website at http://ozone.unep.org/science/teap.

Under Decision XXVII/6 (2) taken at the Twenty-Seventh Meeting of the Parties to the Protocol in 2015, the Parties requested the Assessment Panels to update their 2014 reports in 2018 and submit them to the Secretariat by 31 December 2018 for consideration by the Open-ended Working Group and by the Thirty-First Meeting of the Parties to the Montreal Protocol, in 2019. This MBTOC 2018 Assessment Report primarily provides an update on advances since 2014.

2.6. 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, however annually it reports on the Parties economic statements on MB and alternatives when requesting CUEs. As per Decision IX/6 and others, alternatives to MB must be technically and economically feasible. Additionally, it was recognised that regulatory requirements, environmental issues and social constraints may make an alternative unavailable in a specific country or region. MBTOC reports on CUNs do fully consider the availability or lack of availability in specific locations.

2.7. Report structure

In addition to the *Executive Summary* (Chapter1) and this Introductory Chapter (Chapter 2), the assessment report contains the following chapters:

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 four major parts. The first part provides a brief overview of the major trends, the second part discusses MB production and supply, the third provides a historic perspective of MB uses by crop or sector in non-A 5 and A5 Parties countries and the fourth provides specific insight on the phase-out process in Article 5 countries.

Chapter 4: Methyl Bromide Emissions and Emissions Reduction discusses:

- Atmospheric methyl bromide – Global sources and emissions
- Impact of Montreal Protocol control measures on global MB emissions
- Emissions from current uses for soil, commodities and structures
- Emission reduction through better containment, recapture or destruction
- Efficiency of recapture
- Developments in MB recapture with recovery and recycling systems

Chapter 5: Alternatives to methyl bromide for QPS applications covers MB and alternative treatments for Quarantine and Pre-shipment (QPS) of durable and perishable commodities, including discussion of:

- Trends in MB production and consumption for QPS purposes
- Categories of use
- Key quarantine pests controlled with MB
- International (IPPC) standards influencing MB use for quarantine
- Existing and potential alternatives to the main categories of MB use for QPS purposes.
- Reducing emissions and improving efficiency of MB treatments
- Constraints to adoption of alternatives

Chapter 6: Alternatives to Methyl Bromide for soil treatment covers a range of alternatives for pre-plant soil fumigation. Discussion includes:

- Alternatives adopted in key crops using MB in the past in A-5 and non-A5 countries
- Alternatives for remaining controlled uses
- Other issues and remaining challenges

Chapter 7: Alternatives to methyl bromide for structures and commodities comprises:

- A historic perspective on alternatives adopted for past key SC uses
- Alternatives for remaining controlled uses in the SC sector
- Regulatory considerations
- An update on MB alternatives research including for high moisture dates, cure pork and aircraft, plus a review on pest egg control with sulfuryl fluoride and Integrated Pest Management.

Chapter 8: Economic issues provides a brief description of economic information furnished by the Parties when submitting CUNs and the economic analysis undertaken by MBTOC, together with a review of recent publications on the matter.

Appendix 1 contains a list of MBTOC members, area of expertise, country of origin and affiliation.

Disclosure of Interest (DOI) statements can be found at the Ozone Secretariat website and are updated once a year at minimum, or sooner if a members' situation changes in a manner that is relevant to the DOI.

2.8. References

Anon (1994). Methyl bromide annual production and sales for the years 1984–1992, Methyl Bromide Global Coalition Washington, DC

MBTOC (1995). 1994 Report of the Methyl Bromide Technical Options Committee: 1995 Assessment. UNEP: Nairobi. 304pp.

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MBTOC (2011). Report of the Methyl Bromide Technical Options Committee. 2010 Assessment of Alternatives to Methyl Bromide. UNEP: Nairobi. 400pp.

MBTOC (2015). Report of the Methyl Bromide Technical Options Committee. 2014 Assessment of Alternatives to Methyl Bromide. UNEP, Nairobi. 224 pp.

3

Chapter 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 both non-exempted (controlled) and QPS uses.

The first part of 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, L&A uses and feedstock used in industrial processes. Chapter 5 of this Assessment Report makes reference to exempted or QPS uses, presently nearly ten times higher than controlled uses.

In the Montreal Protocol, *"Calculated levels of production"* refer to the amount of controlled substances produced, minus the amount destroyed by technologies approved by the Parties and minus the amount entirely used as feedstock in the manufacture of other chemicals. For methyl bromide, this does not include the amounts used by the Party for quarantine and pre-shipment applications.

Under the Protocol, MB consumption at the national level is defined as *'production plus 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 MB imported in a particular year for may be consumed in another. Further, stocks of MB already accounted for as consumption may be used in later years. As per Article 7 of the Protocol, Parties are obliged to report production and consumption of MB on a yearly basis (by 30 September of each year). At the time of writing this report, all Parties had reported consumption for 2017 to the Ozone Secretariat, which allows for thorough analysis of consumption trends.

3.2. 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 capacity from 10 kg to 200 kg, although MB can also be stored in much larger pressurised containers of more than 60 tonnes. In some countries, albeit fewer each year due to health and hazard concerns, MB is still supplied as disposable canisters of approximately 1 lb or 0.454 kg or 1.5 lb (0.75 kg).

3.2.1. Global production for all uses

The information on MB production is compiled from the ODS data reports submitted by Parties under Article 7. All tonnes stated in this chapter are metric tonnes. Table 3-1 below shows the trends in global production, as reported to the Ozone Secretariat by Parties, for all uses, for the years in which data is available (1991 and 1995-2017). (Production per intended use was not discriminated in the early days and it was presented as an aggregate amount). 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 3-1.

TABLE 3-1: REPORTED MB PRODUCTION FOR ALL PURPOSES, 1984-2017 (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 [a]	3,610	3,610	77,212	73,605 [a]
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		20,110		6,408		26,519
2010		19,271		7.340		26,290
2011		13,991		5,148		18,690
2012		12,729		4,446		16,639
2013		12,407		5,662		18,069
2014		11,123		4,829		15,952
2015		8,987		3,927		12,914
2016		9,660		4,326		13,986
2017		10,460		3,093		13,553

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

Sources: Data estimates from MBTOC 2002 and 2006 Assessment Reports and Ozone Secretariat data available for 1991 and 1995–2017

Table 3-2 shows the reported purposes of the total MB that was produced in 2017, compared to the 2013 data in the previous MBTOC Assessment Report. In 2013, about 10% of total global production intended for controlled uses (non-QPS fumigant), while 90% was intended for uses that are not controlled under the Protocol. For 2017, these figures have changed to 1.8% and 98.2% respectively.

Data on production and consumption of MB for QPS purposes became much more since reported information was made public after the 20th MOP (Dec XX/6). The non-QPS tonnage was calculated on the basis of the tonnage of CUE uses authorised by the MOP and amounts reported to the Ozone Secretariat under Article 7 of the Protocol. Similarly, amounts used for QPS purposes are those reported by Parties and posted at the Ozone Secretariat website.

TABLE 3-2: ESTIMATED CONSUMPTION OF MB FOR QPS AND NON-QPS IN 2005, 2013 AND 2017

Major sectors	Reported MB use in 2005 (mt)	% of total	Reported use in 2013	% of total	Reported use in 2017	% of total
QPS	10,825	34%	9,827	80%	9959	97.5%
Non-QPS comprising	20,968	66%	2,408	20%	245	2.5%
Total QPS & non-QPS	**31,793**	**100%**	**12,235**	**100%**	**10,194**	**100%**

Sources: Reported MB consumption for QPS in database of Ozone Secretariat of December 2018, CUE uses authorised by MOP Decisions and by Parties during licensing, and MBTOC survey of MB uses for exempted uses in selected Parties carried out in 2018.

3.2.1.1 Quarantine and pre-shipment

In 2017 the reported MB production for QPS was 10,215 tonnes. This represented about 98% of total global MB production for all purposes. Consumption for QPS uses was 9,960 tonnes, comprising 97.5% of total global uses (excluding feedstock). Detailed discussion on production, consumption and use of MB for QPS purposes can be found in Chapter 4 of this Assessment Report.

3.2.1.2 Non-QPS sectors (controlled uses)

Figure 3-1 shows the trend in reported global MB production for all controlled uses from 1991 to 2017 (excluding QPS and feedstock). MB production for controlled uses in 2017 continued the downward trend, totalling 245 tonnes or 0.4% of the baseline.

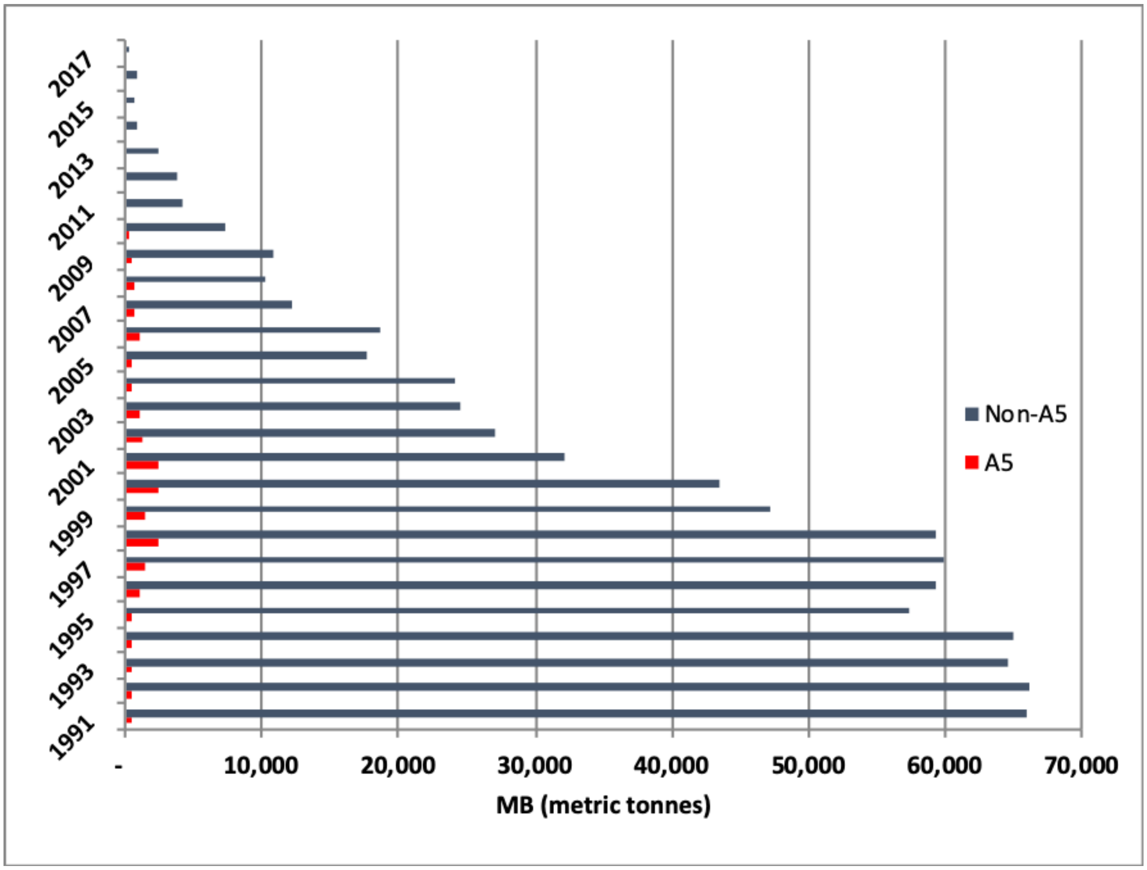
Non-A5 countries have reduced their MB production for controlled uses from about 66,000 tonnes in 1991 (non-Article 5 baseline) to zero in 2017. Israel reported "negative production" of 24 tonnes in 2015 and USA of 11.3 tonnes in 2017, most probably corresponding to exports of previously existing stocks. Production of these Parties for these two years was thus recorded as zero, for the purposes of Fig 3-1. Japan ceased production since 2014

Presently, the only A5 Party reporting production of MB for controlled uses (non-QPS) is China, at 90 metric tonnes in 2017. France, Ukraine and Romania, which produced MB in the past, have now closed down their factories entirely.

Production facilities around the world were analysed in previous MBTOC Assessment Reports (2007, 2011, 2015). MBTOC notes that MB is still offered on the internet for what appears to be free purchase for any use (including soil fumigation and treatment of stored products). Examples of this are Sartichem

Ltd. (www.sarthichem.com) and Uniworld Consultants (uniworldconsultant01@gmail.com) both based in India, and offering methyl bromide in 98:2 formulation in cylinders of several sizes for export around the world.

FIGURE 3-1. HISTORICAL TRENDS IN REPORTED GLOBAL MB PRODUCTION* FOR ALL CONTROLLED USES, EXCLUDING QPS AND FEEDSTOCK, 1991 - 2017 (METRIC TONNES)



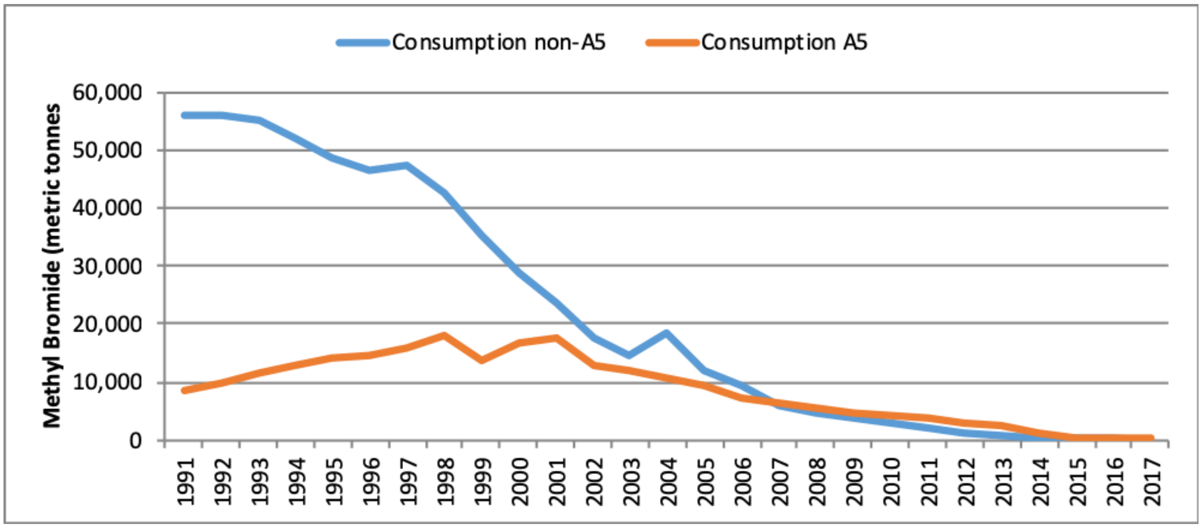
* Data for 1991 and 1995-2017 were taken from the Ozone Secretariat Dataset of December 2017. Data for 1992-94 were estimated from Table 3.1 of the 2002 MBTOC Assessment Report (MBTOC, 2003), Table 3.1 of the 2006 MBTOC Assessment Report (MBTOC, 2007) and Table 3-1 of the MBTOC 2014 Assessment Report (MBTOC, 2015).

3.3. Trends in global MB consumption (and phase-out) for controlled uses

On the basis of Ozone Secretariat data, consumption for controlled uses was estimated to be about 64,420 tonnes in 1991 and remained above 60,000 tonnes until 1998. It was reported to fall to about 8,148 tonnes in 2009, 2,953 tonnes in 2013 and 245 tonnes in 2017 as illustrated by Figure 3-2.

Consumption in Article 5 Parties was higher than that of non-Article 5 Parties for the first time in 2007 in view of the 2005 phase-out deadline for non-A5 Parties. With the phase-out deadline coming into force for A-5 Parties on 1st January 2015, these figures have now fallen dramatically, to 35 tonnes for non-A5 Parties and 240 for A5 Parties in 2017.

FIGURE 3-2: BASELINES AND TRENDS IN MB CONSUMPTION IN NON-A 5 AND A 5 REGIONS, 1991 – 2017 (METRIC TONNES)



Source: MBTOC estimates (for early years only) and Ozone Secretariat Data Access Centre 2018.

3.3.1. Global consumption by geographical region

An analysis of Ozone Secretariat data revealed that the end of 2017 global consumption of MB for controlled uses was reduced by over 99% with respect to the global aggregate baseline, as shown in Table 3-3 below.

TABLE 3-3: GLOBAL CONSUMPTION OF CONTROLLED METHYL BROMIDE BY GEOGRAPHIC REGION, 1991-2017 (METRIC TONNES)

Region	Regional baseline [a]	2013 consumption	% Reduction 1991-2013	2017 consumption	% Reduction in 2017
Africa	4,471	340	92%	55	98.7%
Latin America & Caribbean [b]	6,389	1,637	74%	95	98.5%
Asia & Pacific [c]	14,657	331	97%	120	99%
Europe [d]	21,472	0	100%	0	100%
North America [e]	25,729	601	97%	5	100%
TOTAL	**72,718**	**2,899**	**96%**	**275**	**99.2%**

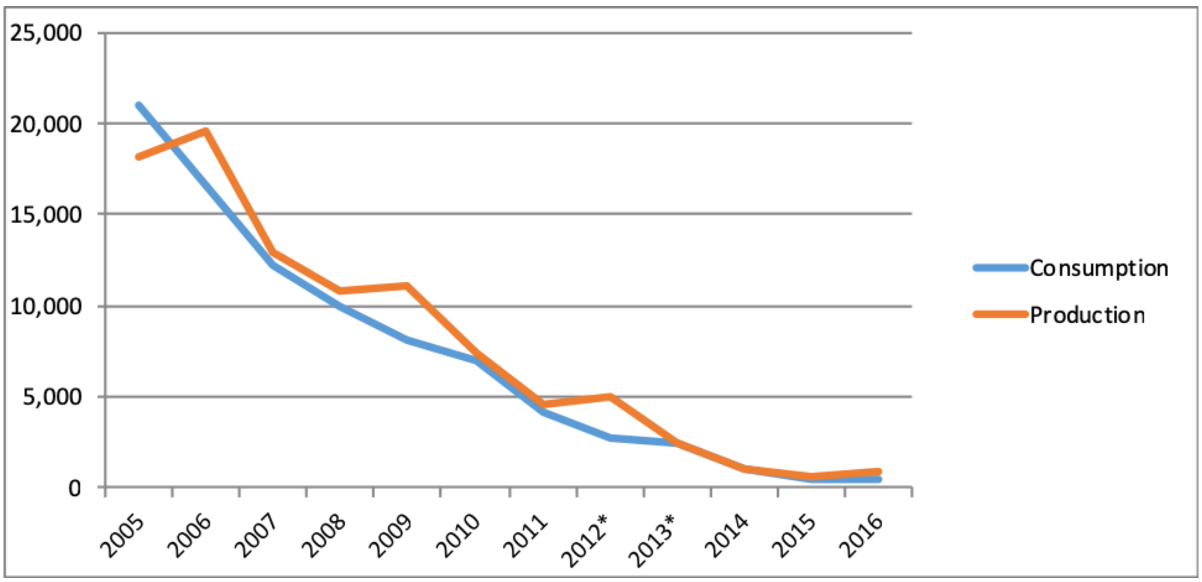
a. Aggregate regional baselines as provided in the database of Ozone Secretariat of December 2018, compiled from 1991 consumption in non-A 5 countries and 1995-1998 averages in A 5 countries.
b. Mexico, once among the 15 largest users in the world, phased out in 2016
c. The relatively high baseline in this region arises from the historical consumption in Japan and Israel. Asia & Pacific comprises Asian countries (including the middle East), plus Australia and New Zealand
d. The European region comprises the EU, Eastern Europe, Switzerland, Scandinavia and former CEIT countries.
e. The North American region comprises US and Canada.
Source: Database of Ozone Secretariat of December 2018.

3.3.2. *Production vs. Consumption*

When comparing production vs. consumption, it is found that since 2005, a surplus of about 8,160 tonnes of MB produced for controlled uses has accumulated during this period. This may be due to stocks or to lack of reporting of consumption in some countries or to stocks which have been produced and held for long periods and yet to be consumed. Figure 3-3 illustrates the comparison between global production and consumption of MB for controlled uses between 2005 and 2017 as reported to the Ozone Secretariat.

It can happen that apparent consumption reported by a Party (i.e. Israel for 2012, at 1082 tonnes) *"Production for export to A5 countries for their Basic Domestic Needs (BDN) that did not get exported in the year of production"*. Therefore the amounts would appear as consumption under Israel, but will be exported in future years. The reported amounts have thus been transferred to the production category since Israel's controlled consumption is presently zero. This information is usually presented in the *"Consolidated record of cases of excess production or consumption attributable to stockpiling in accordance with decision XVIII/17 and XXII/20"* which is included in the annual data report presented to the MOP.

FIGURE 3-3: GLOBAL PRODUCTION VS. GLOBAL CONSUMPTION OF MB FOR CONTROLLED USES 2005 - 2017



Source: Ozone Secretariat Data Access Centre, 2018

*See comment on Israel reported consumption below Table 3-4.

3.4. Trends in MB consumption (and phase-out) in non-Article 5 Parties

MB phase-out in Non-A 5 consuming countries is now very close to complete. The official baseline for Non-A 5 countries was 56,084 tonnes in 1991 and since then the consumption has declined steadily, down to 35 tonnes in 2017. 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 total MB consumption in Non-Article 5 countries.

- In the past, MB was consumed for controlled uses by 43 out of 48 Non-A 5 countries. Only two of these countries continue to use MB (Australia and Canada), which is being applied under CUEs (Table 2-5).

- The US was the highest consumer of MB for much of the period from 1991 to 2016, 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 less than 1% of its baseline in 2016. The last CUE use was in 2016 (for strawberry fruit). Re-categorisation of some controlled uses for preplant soil uses in nursery industries to QPS has assisted the US to meet this level.

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

- New Zealand, Israel and Japan reached 100% phase-out of MB for controlled uses in 2008, 2012 and 2013 respectively.

Reduction in MB consumption for controlled uses since 2005, when the CUE came into force for non-A5 Parties is presented in Table 3-4.

TABLE 3-4: METHYL BROMIDE CONSUMPTION[(A)] IN RELATION TO NATIONAL BASELINES IN NON-A 5 PARTIES THAT HAVE BEEN GRANTED CUES

Party	MB consumption [(a)], tonnes (percentage of national baseline)													
	1991*	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Australia	704	119 17%	55 8%	46 7%	41 6%	33 5%	34 5%	35 5%	33 5%	32 4.4%	30.5 4.3%	29.8 4.2%	29.8 4.2%	29.8 4.2%
Canada	200	54 27%	42 21%	38 19%	33 16%	28 14%	34 17%	21 11%	16 8%	5.6 3.5%	5.3 2.7%	5.3 2.7%	5.3 2.7%	5.3 2.7%
EU	19,735	2,341 13%	1,410 8%	354 3%	275 1%	0 0%	-105 [d]	-11 [d]	-8 [d]	-10 [d]	-2.5 [d]	-4.3 [d]	-7 [d]	-17.5 [d]
Israel	3,580	1,072 30%	841 23%	638 18%	600 17%	611 17%	14.6 0.4%	-951 0%	1082 [c]	16[c]	-395[d]	-173[d]	398[c]	117[c]
Japan	6,107	595 10%	489 8%	479 8%	393 6%	279 5%	267 4%	240 4%	220 3.5%	3.3 0.01%	0	0	0	0
NZ	135	30 22%	27 20%	7 5%	0 0%	0 0%	0 0%	0	0	0	0	0	0	0
United States [d]	25,530	6,755 26%	7,255 28%	6,48 25%	4,302 17%	3,028 12%	2,272 9%c	2,764 11%	1855 7%	923 4%	562 2.2%	411 1.6%	234 0.9%	0 0%
Switzerland	43	11 24%	4 9%	4 9%	0 0%	0 0%	0 0%	0 0%	0	0	0	0	0	0

Source: Ozone Secretariat database, 2018. *Baseline

a. Authorized levels of consumption as authorised by MOP decisions for 2010-2013 which do not always match reported consumption at the Ozone Secretariat for 1991-2009.

b. 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).

c. Israel reported has reported consumption for controlled uses since 2012, even though no CUEs were requested or authorised for these years. This was explained to be "Production for export to A5 countries for their Basic Domestic Needs (BDN) that did not get exported in the year of production". Therefore the amounts would appear as consumption but do not count as such as they will be exported in future years.

d. Negative amounts are recorded when a Party only exports MB amounts (they are not used internally). These are generally stocks.

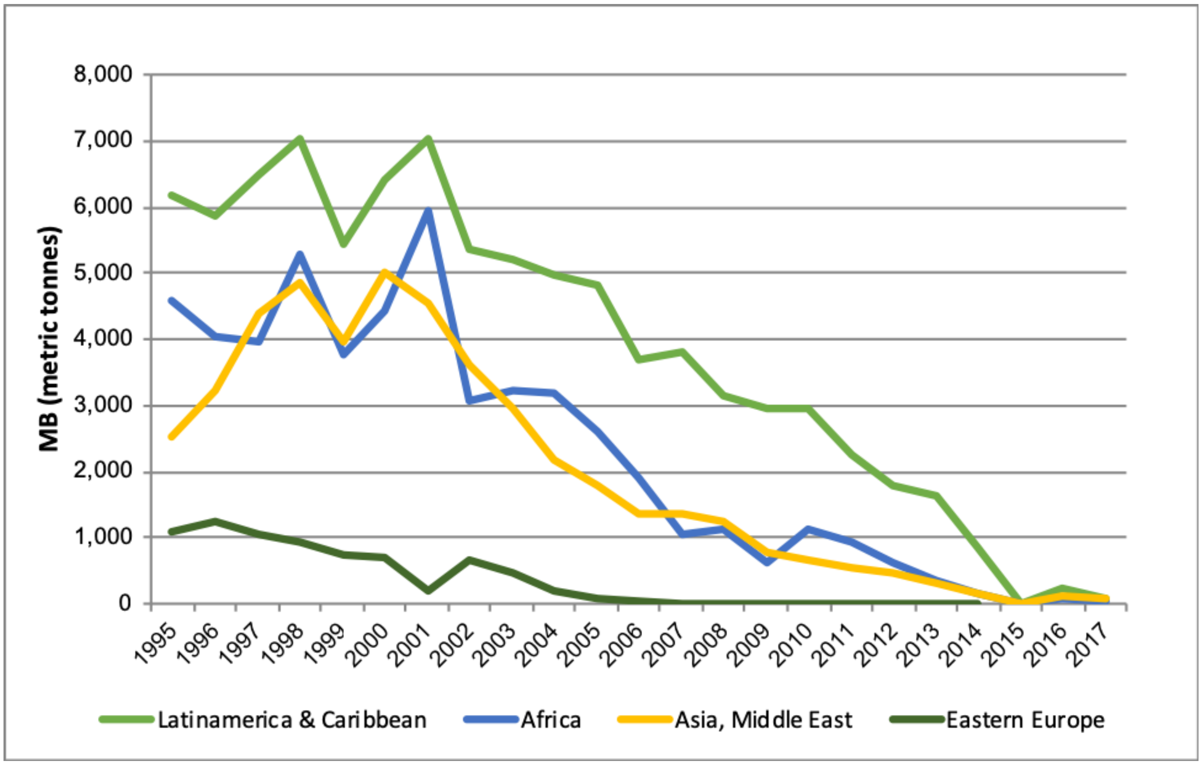
e. Since 2005, the US has recategorised MB uses for a number of sectors from non-QPS and this has influenced their proportion of consumption against their baseline.

3.5. Trends in MB consumption (and phase-out) in Article 5 Parties

The information about MB consumption in this section has been compiled primarily from the Ozone Secretariat database available in late 2017. At the time of making this analysis all Article 5 Parties had submitted national consumption data for 2017, which allows for a thorough analysis.

Figure 3-4 shows the trend in MB consumption in Article 5 countries for the period between 1991 and 2017. Phase-out occurred at different speed and with different challenges in A5 regions.

FIGURE 3- 4: MB REGIONAL CONSUMPTION TRENDS IN ARTICLE 5 COUNTRIES 1991 – 2017



Source: Ozone Secretariat database, 2018

Overall trends in relation to the phase-out 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. Article 5 consumption was reduced to 28% of baseline in 2009 (4,435 tonnes) and 2% of baseline in 2017 (204 tonnes).
- Fifty-six Article 5 Parties (38%) never used MB for controlled uses or reported zero MB consumption for such uses since 1991. The total number of Article 5 Parties that consumed MB (currently or in the past) is 91, or 62% of the total 148 Article 5 Parties. Of the 91 MB-user countries only 18 reported consumption in 2013 and 3 in 2017.
- The great majority of Article 5 countries achieved considerable MB reductions quickly. With respect to compliance, most 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 and all A5 Parties have entered in compliance with this step since 2009. The majority of A5 Parties then complied with complete phase-out by 2015 as per Montreal Protocol provisions.

- Since 2014, four A5 Parties have submitted CUNs: Argentina, China, Mexico and South Africa. In 2018, only two of these Parties requested CUNs (Argentina and South Africa).

3.5.1. Factors assisting MB phase-out in Article 5 Parties

By end of 2017 (the last date for which full official data were available at the time of writing this report), more than 98% of the controlled uses of MB in Article 5 Parties had been phased out. This was primarily achieved through MLF-funded projects implemented by the agencies of the Montreal Protocol, and took place at different speed in the different regions innvolved.

The pace at which MB has been successfully replaced seemed to be in direct relation to the consuming sectors involved, and particular circumstances present in individual countries, including developments concerning new crops (with challenging requirements, pests or diseases) or large expansion of existing crops where newcomers to such sectors (growers and other stakeholders) were not sufficiently trained on the use of alternatives. Regulatory issues (e.g. registration of alternatives) and political issues (e.g. difficulties in restricting MB imports and tracking their final use) may also contributed to this (UNEP, 2014).

In addition to MLF efforts, a number of MB projects were 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, now GIZ), Italy, Canada and Spain. In some countries farmers or exporters associations or private enterprises also financed trials aimed at identifying or adapting alternatives to MB, for example Morocco, Egypt, Jordan, Lebanon and Kenya.

The number and types of projects implemented together with the funds disbursed are presented in Tables 3-5 and 3-6 below. Thorough analyses of projects, alternatives implemented, kinds of users assisted, challenges encountered and measures taken to ensure sustainability of the phase-out achieved have been included in past MBTOC Assessment Reports (MBTOC, 2003; 2007; 20011; 2015), together with specific case studies illustrating the successful adoption of alternatives in various sectors around the world.

TABLE 3-5: NUMBER AND TYPES OF PROJECTS TO SUPPORT MB PHASE-OUT IN A5 PARTIES, FUNDED BY THE MLF UP TO 2018

Region	No. projects	Impact (ODP t)	Phased-out (ODP t)	USD approved
Investment	129	8,053.52	8,002.50	110,060,650
Demonstration	44	23.20	23.20	14,079,080
Technical assistance	75	297.85	428.60	7,963,362
Training	21	6.30	6.30	1,739,093
Project preparation	130	-	-	3,357,265
Total	**39**	**8,380.87**	**8,460.60**	**137,199,449**

Source: Multilateral Fund Secretariat, 2019

TABLE 3-6: PROJECTS IMPLEMENTED BY A5 REGION WITH MLF FUNDING

Region	No. Projects	Impact (ODP t)	Phased-out (ODP t)	USD approved
Africa	108	1,846.52	1,804.90	34,845,729
Asia and the Pacific	104	2,287.25	2,394.20	36,719,190
Europe	33	551.50	551.50	9,674,915
Latin America and Caribbean	129	3,695.60	3,710.00	54,955,552
Global	15	-	-	1,004,063
Total	**399**	8,380.87	8,460.60	137,199,449

Source: Multilateral Fund Secretariat, 2019

3.6. Trends in nominations for critical use exemptions

In addition to the quantities authorised for CUE consumption (production + imports), which have been described in some sections above, Table 3-7 considers quantities authorised for CUE uses (called 'critical use categories' in MOP Decisions) up to 2018. 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 3-7: TRENDS IN TOTAL TONNAGE OF CUNS SUBMITTED AND CUES AUTHORISED 2005-2018

Phase in procedure	2005	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Nominated amounts submitted to the MOP	18,704	8297.7	6244.5	4044.3	2692.4	1460.1	740.6	483.6	917.2	809.4	341.3	298. 7
Amounts authorised as CUE 'use categories' by MOP Decisions	16,050	6996.1	5254.9	3572.2	2343.0	1261.3	610.9	483.6	777.6	591. 8	290.0	249.6

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. Numbers have been rounded to nearest decimal

3.6.1. Trends for preplant soil uses

In the 2014 round, nine CUNs were submitted for pre-plant soil fumigation, three from non-A5 Parties (Australia, Canada and USA) and six from A-5 Parties (Argentina, China and Mexico). CUEs were approved for 269.801 tonnes for non-A5 Parties for use in 2016 and 333.257 for A-5 Parties for use in 2015. In the 2018 round six nominations were left, two from non-A5 Parties and four from A5s. One nomination was for 2020 and 5 for 2019. Amounts approved by the Parties totaled 1,261 t for 2012, 745.5t for 2015, 249.6 for 2018 and 75.55 for 2019 as illustrated in Table 3-8.

TABLE 3-8: SUMMARY OF CUES APPROVED IN 2011 TO 2017, BY COUNTRY, FOR PREPLANT SOIL USE OF MB (TONNES)

Country	CUEs Approved Amounts for 2011 to 2019								
	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Australia	**5.950**	29.760	29.760	29.760	29.76	29.76	29.76	28.98	28.98
Canada		5.261	5.261	5.261	5.261	5.261	5.261	5.261	5.261
Israel	224.497		-	-	-	-	-	-	-
Japan	234.396	216.120	-	-	-	-	-	-	-
USA		913.311	461.186	415.067	373.660	231.540	-	-	-
Argentina	-	-	-	-	170	129.25	102.94	76.7	41.31
China	-	-	-	-	114	111	92.98	92.98	-
Mexico	-	-	-	-	84.96	84.957	59.10	45.65	-
Total	**230.447**	**1164.452**	**496.207**	**450.088**	**777.641**	**591.768**	**290.041**	**249.571**	**75.551**

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

3.6.2. Trends in postharvest and structure uses

Four non-A5 Parties historically submitted CUNs for MB use in a variety of different structures and commodities; in 2015 one A5 Party submitted CUNs for these sectors. Table 3-9 shows trends in CUEs granted by the Parties for postharvest and structures since 2011.

TABLE 3-9: POST-HARVEST STRUCTURAL AND COMMODITY CUE 2011 - 2019

Party	**Industry**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Australia	Rice consumer packs	4.870	3.653	1.187	1.187	-	-	-	-	-
Canada	Flour mills	14.107	11.020	5.044	5.044	-	-	-	-	-
Canada	Pasta manufacturing facilities	2.084	-	-	-	-	-	-	-	-
Japan	Chestnuts	5.350	3.489	3.317	-	-	-	-	-	-
USA	Dried fruit and nuts (walnuts, pistachios, dried fruit and dates and dried beans)	5.000	2.419	0.740	0.740	-	-	-	-	-
USA	Dry commodities/ structures (processed foods, herbs and spices, dried milk and cheese processing facilities) NPMA	17.365	0.2	-	-	-	-	-	-	-
USA	Smokehouse hams (Dry cure pork products) (building and product)	3.730	3.730	3.730	3.730	3.24	3.24	-	-	-
USA	Mills and Processors	135.299	74.510	22.80	22.80	-	-			
South Africa	Mills	-	-	-	-	-	5.46	4.1	2.9	1
South Africa	Dwellings	-	-	-	-	-	68.6	55	42.75	40
TOTAL		**187.805**	**99.021**	**33.501**	**33.501**	**3.24**	**77.3**	**59.1**	**45.65**	**41**

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

3.7. Methyl Bromide use by sector – Controlled uses

3.7.1. Where Methyl Bromide was historically used

Since the beginning of the MB phase-out process some key sectors using this fumigant and which clearly needed alternatives became apparent. Sectors such as tomatoes, strawberries, peppers, eggplants, cucurbits, flowers, tobacco seedlings, various kinds of nurseries and stored grain of different kinds were particularly impacted by the MB phase-out in some countries. In many countries, structures such as mills and warehouses were often disinfested with MB fumigation.

Soil uses were traditionally much larger than uses for postharvest and structures (about 90% vs. 10% of total consumption) but technically and economically feasible alternatives were equally important for both sectors. Table 3-10 describes historic uses of MB for both controlled and exempted uses.

TABLE 3-10: HISTORIC USES OF METHYL BROMIDE WORLDWIDE

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 tobacco and some vegetables;
	As a treatment to control soilborne pests in the production of pest-free propagation stock, e.g. strawberry runners, nursery propagation materials, which in some cases need to meet certification requirements;
In durables:	As a treatment to control quarantine pests in import-export commodities or restrict damage caused by cosmopolitan insect pests in stored 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”	As a treatment to control cosmopolitan or quarantine insects, to prevent fermentation or inhibit sprouting and fungal development in products that have high (>25% wb) or very high (>90%) 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.

Source: MBTOC 2006, 2014 Assessment Reports

3.7.2. Present MB applications (controlled uses in 2018)

In the 4 years elapsed since the 2014 MBTOC Assessment Report, CUNs were requested for the following sectors: strawberry fruit, strawberry runners, raspberry runners, tomatoes, ginger, mills and dwellings.

The remaining controlled uses of MB in non-A 5 countries are allowed since 2005 as critical use exemptions only; the same applies for A-5 Parties since 2015.

CUEs have been authorised in the 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, dwellings (houses and churches)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.

3.7.3. Critical Use Nominations from Article 5 Parties

With the 2015 deadline for complete phase-out of controlled uses of MB entering in force for Article-5 Parties, nominations for critical uses were submitted for some sectors as shown in Table 3-12. As noted in previous sections, critical use nominations were also submitted in the past by non-Article 5 Parties in all of these sectors.

TABLE 3-11: CUES (TONNES) APPROVED BY A-5 PARTIES SINCE 2014 (METRIC TONNES)

Country	Sector	2015	2016	2017	2018	2019
Argentina	Strawberry fruit	70	58	38.84	29	15.71
	Tomato	100	71.25	64.10	47.40	25.6
China	Ginger (Field)	90.0	90.0	74.617	74.617	-
	Ginger (Protected)	24.0	21.0	18.36	18.36	-
Mexico	Raspberry nurseries	43.539	56.018	-	-	-
	Strawberry nurseries	41.418	64.960	-	-	-
South Africa	Mills	-	5.46	4.1	2.9	1.0
	Dwellings	-	68.6	55.0	42.75	40.0

3.8. References

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4

Chapter 4. Methyl Bromide Emissions and Emissions Reduction

4.1. Introduction

The large reduction in consumption of methyl bromide (MB) since 1999 has resulted in a significant decline in atmospheric emissions of MB, mostly in line with the reduction measures imposed on Parties) under the Montreal Protocol. Based on reported consumption data under Article 7 of the Protocol, MB emissions to the atmosphere from known current usage are expected to be around 8,500 tonnes in 2017 (see Table 3.2). Since 1998, MBTOC estimates that anthropogenic emissions of MB have declined by 80-85% from the peak emissions of around 48,000 tonnes in 1998. Owing to the reported phase-out of nearly all controlled uses of MB (i.e. for soil fumigation and domestic commodity and structural fumigation) the bulk (98%) of the present emissions should now only be from QPS (quarantine/pre-shipment) uses. These QPS uses are predominantly to support international trade of durable and perishable commodities and some structural fumigations, but also some pre-plant soil fumigation to produce high health nursery/turf products moving across jurisdictional boundaries in the US. MBTOC has estimated that most (i.e. nearly 80%, on average, with wide variation between different applications) of the MB used for QPS is presently emitted after treatment directly to the atmosphere. Some countries (e.g. New Zealand) have recently imposed regulations to prevent emissions and instead ensure that MB is recaptured/destroyed as much as practical from fumigation operations.

As anticipated, the decline in the atmospheric concentration of MB due to restrictions on MB consumption has slowed since 2015 as 98% of the reported consumption for controlled uses occurred prior to 2015, the final phase-out date for A5 countries. The remaining emissions are now supposedly only from the small amounts used for critical uses (Critical Use Exemptions – CUEs), i.e. 290 tonne of MB consumed in 2017 for CUEs and 10,100 tonnes from QPS use in 2017. The emissions from the 4,000 tonne used for feedstocks are considered insignificant (probably less than 100 tonnes).

Recently (2013 to 2017) global atmospheric MB concentrations do not appear to be fully explained by global production and consumption data (Figure 4.3). From 2013 to 2015 there appeared to have been a 5 ktonne rise in emissions of MB, followed by a similar magnitude fall in emissions (2015 to 2017). The reason for this are unclear and potentially indicates that there may be some consumption which is unreported or other sources of MB which are now more predominantly influencing emissions.

The Montreal Protocol has set several policy steps to minimise emissions of MB (Article 2H, Decisions VII/5(c), and XI/13(7), where Parties are encouraged to adopt emission control technologies. As a consequence, emission reduction steps have been developed for all controlled uses. For preplant soil uses, barrier films were widely adopted by the Parties for controlled uses and for commodity uses recapture technologies have been available but not widely used. MBTOC considers that barrier films should be mandatory for any remaining pre-plant soil use of MB globally, QPS and non-QPS, as part of measures to reduce MB emissins and that recapture/destruction technologies should be considered for all remaining commodity uses where practically feasible.

Since the last assessment, MBTOC estimates that alternatives to MB are available for approximately 40% of the MB used for QPS uses. Even if alternatives are not adopted and MB continues to be used, MBTOC considers that recapture and destruction technologies are available for many QPS uses and that their adoption could reduce at least 70% of the existing emissions of MB for those uses.

In recognition of this and to protect user safety, recently some key QPS user countries (e.g New Zealand, specific States in the USA) have implemented policies outside of the agreed Montreal Protocol control measures to reduce emissions and improve worker safety with MB fumigation. This is ensuring that technologies for recapture and destruction are being adopted/developed quickly to address some current QPS commodity treatments (e.g. logs, perishables, etc.).

Mandatory recapture and destruction for all remaining uses of MB for QPS, together with identification and stopping any unreported uses are considered important factors to return MB concentrations in the atmosphere to natural levels. Owing to the relatively short lifetime of MB in the atmosphere, recapture/destruction would have an immediate benefit in reducing MB levels in the atmosphere and an important step currently available to Parties of the Montreal Protocol to enhance ozone layer recovery.

This Chapter, as with the past Assessment Reports, continues to refine the best estimate of the level of emissions from current (2017) uses of MB, the most recent year for which good data on MB consumption and use is available. It also provides a summary of the impact of regulation of these emissions on the ozone layer, updates on developments in reducing emissions of MB, particularly use of barrier films for remaining soil uses and the potential for recapture, recycling and destruction for QPS and CUE commodity and structural treatments.

4.2. Atmospheric Methyl Bromide

4.2.1. Global Sources and Emissions

MB has both natural and anthropogenic sources, the latter contributing about 38% of the global MB emissions at its peak in 1998. Over the last 20 years or so, the basic understanding of the global annual budget (sources and sinks) for MB has not changed (Table 4.1, Figure 4.1). This indicates that the present understanding of the global MB budget is not balanced and that currently identified sinks exceed identified sources by at least 30 ktonnes (nearly 40% of identified sources). This imbalance has persisted from pre-Montreal Protocol phase-out (1995-1998) to recent times. Assuming the MB sink estimates are robust, this suggests that natural and/or anthropogenic MB emissions are underestimated in the UNEP/WMO scenarios reported globally (Fig. 4-3).

The natural sources of MB are dominated by the oceans (about 30 ktonnes per year) and terrestrial plants (about 10 k tonnes per year). The MB sinks include chemical losses in the atmosphere (about 60 k tonnes per year), loss to the ocean and to soils (each about 30 k onnes per year).

Historically, the largest anthropogenic source of MB emission was from fumigation of soils, commodities and structures, where about 68 k tonnes of consumption per year resulted in about 50 k tonnes emitted to the atmosphere between 1995 to 1998 from non-QPS MB use (85%: largely soil fumigation) and commodity and structural uses (15%: largely grain and wood products fumigation, including QPS).

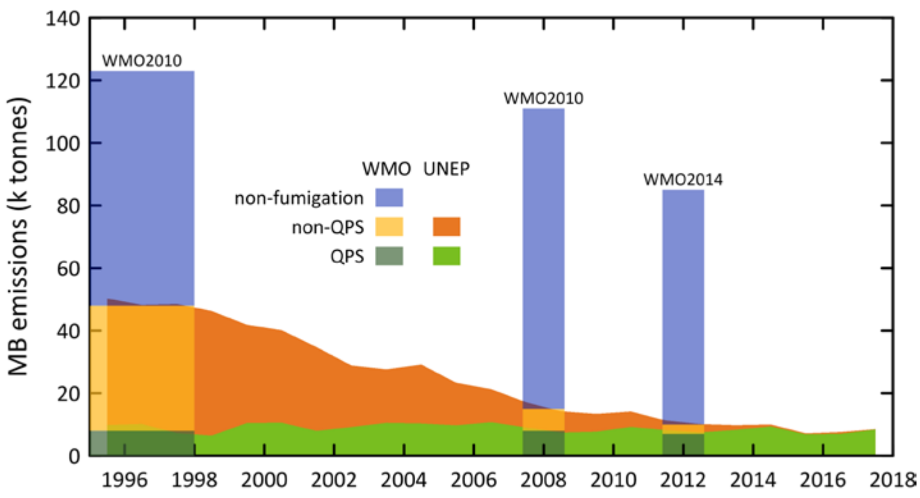
Today, the largest anthropogenically-influenced MB source is biomass burning in agriculture, estimated at approximately 25 k tonnes in reports over the last 20 years. This anthropogenic source has existed for a long time and it is difficult to determine what part of this emission is included in the natural baseline. This emission is not controlled under the Montreal Protocol. Agricultural crops (rapeseed, rice) reportedly release about 5 k tonnes of MB per year and leaded petroleum used to contribute about 2 k tonnes per year. Potential significant sources of atmospheric MB include fugitive emissions from use as chemical feedstock (MBTOC, 2014).

Based on atmospheric observations, overall total (natural and anthropogenic) MB emissions have declined from about 175 k tonnes per year in 1995-1998 to about 125 k tonnes in 2017, a fall of 50 k tonnes, consistent with the declining consumption of non-QPS MB (Table 4.1, Figure 4.1). Emissions from QPS and non-QPS consumption have fallen, based on a simple UNEP emissions model, similarly by about 50 k tonnes. However, recently (2013 to 2015) there appears to have been a 5k tonne rise in emissions of MB, followed by a similar magnitude fall in emissions (2015 to 2017), which are not explained by global production and consumption data (Figure 4.3).

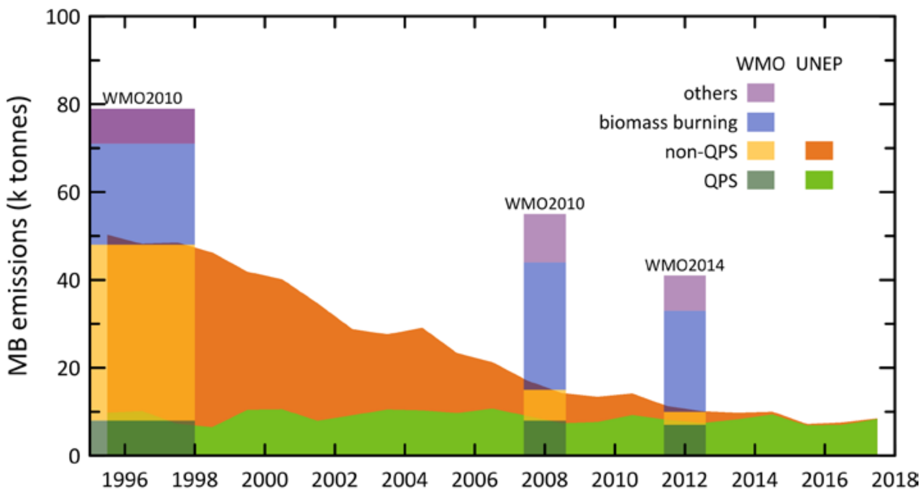
Emissions from current uses indicate that 8,500 t of MB could be reduced from the atmosphere, especially if emissions control technologies were adopted for QPS where implemented. The impact of the relatively recent and currently limited MB recapture on the global MB budget is presently estimated by MBTOC to be only small (less than 500 tonnes recaptured globally per annum (MBTOC, 2017).

Information supplied under Article 7 (Decision XXIX/4) (TEAP, 2018) has indicated substantial destruction of MB from time to time. Data has been incomplete, but cumulatively, between 1996 and 2016, 938 t of MB destruction was reported by six Parties[1]. In addition, in 2010 TEAP noted that the United States had destroyed 10,531 t of MB between 1996 and 2003 (UNEP, 2009). These quantities of MB destroyed appear to be from industrial processes, e.g. terephthalic acid manufacture, and surplus MB stocks, not from fumigation of soils, structures and commodities.

FIGURE 4.1: TOTAL (TOP) AND ANTHROPOGENIC (BOTTOM) GLOBAL MB EMISSIONS AS REPORTED IN WMO 2010 AND 2014*



[1]Brazil, Czech Republic, France, Germany, The former Yugoslav Republic of Macedonia, United States of America



*****(Montzka and Reimann, 2011; Carpenter and Reimann, 2014) and as derived from UNEP consumption data (http://ozone.unep.org/Data_ Reporting/Data_Access/, see text below) and a fumigation emissions model (UNEP: Montzka and Reimann, 2011). Current non-fumigation sources are largely oceans (40%), biomass burning (25%) and vegetation (20%).

4.3. Summary of impact of Montreal Protocol control measures and other regulations on global MB emissions

By 2017, the MB phase-out has led to about a 30% fall in MB (a fall of about 60% of anthropogenic MB) in the troposphere from the late-1990s to 2018as measured at Cape Grim, Tasmania, Australia (Figure 4.2). Owing to the short atmospheric lifetime of MB (half-life, 0.7 years), changes in emissions of MB at ground level are rapidly reflected in changes in tropospheric and stratospheric MB concentrations. This is in contrast to almost all other ODSs regulated under the Protocol, with the exception of methyl chloroform, as these have much longer atmospheric lifetimes.

In 2003, it was predicted that MB levels in the Southern Hemisphere would fall to about 7 ppt before levelling off (Fig. 4-3, A1 WMO, 2003). However, by 2015 the levels had continued to fall close to 6ppt, more than anticipated by recent scenario modelling (Fig 4-2 and 4-3, WMO 2011, WMO 2015). It is clear that the Montreal Protocol restrictions on the use of MB are having greater impact on atmospheric MB levels than thought possible 10 years previously and this has been supported by scientific observations by the SAP (Scientific Assessment Panel, Montzka *et al.* 2011).

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 stratosphere was around 5.5ppt (Figures 4-2 and 4-3). 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), but started falling in the late 1990s as a result of the MB reduction in use imposed by the Montreal Protocol. The rate of decline has been relatively constant and by 2017, this level has fallen to around 6 ppt as measured in 2017 (Figs 4-2 and 4-3). Recently (2015-2017), however, there has been an apparent flattening of the reduction in concentration of MB in the troposphere and possibly a small rise in concentration. This may be partly related to an increase in consumption for QPS from 8,300 tonnes in 2015 to 10,100 tonnes in 2017, but potentially also due to unreported or inaccurately reported consumption data under Article 7 reporting.

TABLE 4-1: ESTIMATED GLOBAL MB SOURCES (EMISSIONS) AND SINKS (K TONNES): 1996-1998, 2008, 2012 (MONTZKA AND REIMANN, 2011; CARPENTER AND REIMANN, 2014)

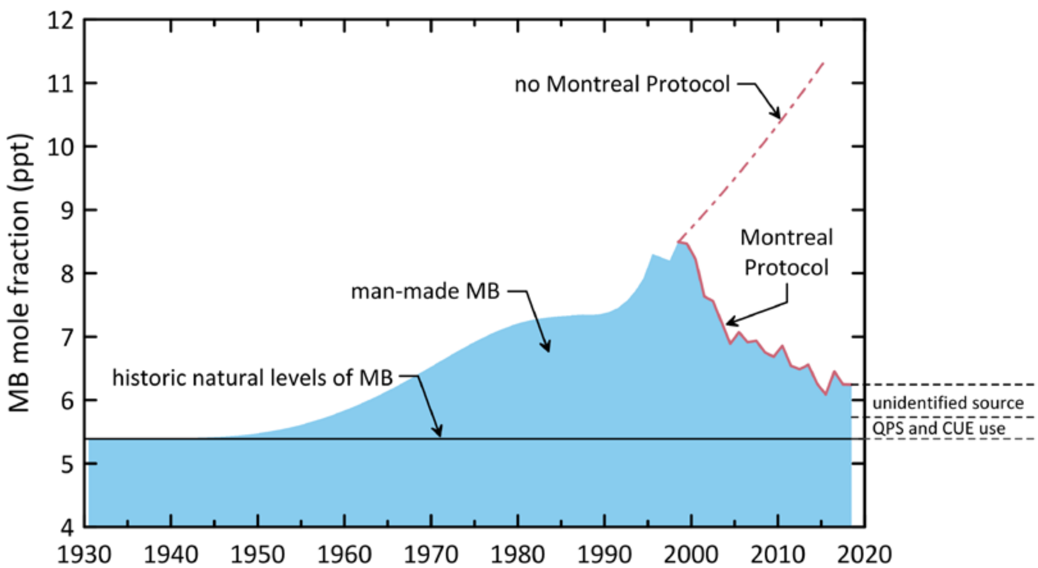
Sources	1995-1998[a]	2008[b]	2012[a]	Comments
Anthropogenic	**80**	**56**	**41**	
fumigation: non-QPS	40	7	3	only source controlled by MP
fumigation: QPS	8	8	7	exempted from control under MP
biomass burning	23	29	23	open-field, biofuels
rapeseed	5	5	5	
leaded petroleum	3	<6	<3	
rice agriculture	<1	<1	<1	
Natural	**43**	**54**	**44**	
oceans	32	42	32	
salt marsh	7	7	7	
plants	2	2	2	mangroves, shrubs
fungus	2	2	2	
wetlands	<1	<1	<1	largely peatlands
Total Sources	**123**	**111**	**85**	

Sinks	1995-1998[a]	2008[b]	2012[a]	Comments
oceans	-41	-49	-30	
atmosphere	-81	-67	-60	oxidation, photolysis
soils	-40	-32	-27	
Total sinks	**-162**	**-148**	**-117**	

[a]Carpenter and Reimann, 2014; [b]Montzka and Reimann, 2011

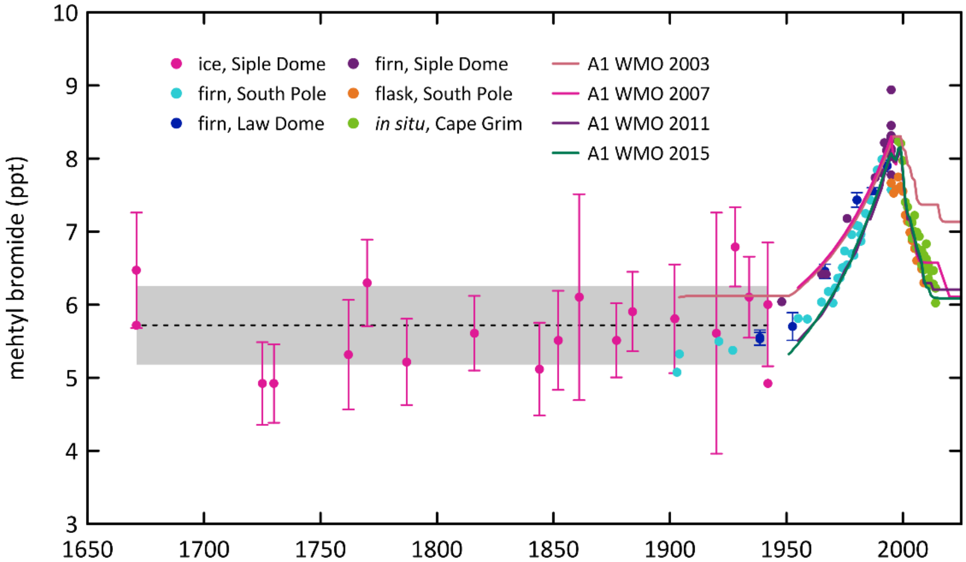
The latest WMO scenarios (Figure 4.3, A1 WMO, 2015,) suggest that further reductions in atmospheric concentrations are possible over the next few years, but will only occur if the remaining non-QPS uses in developing countries (A5 Parties) and the few non-A5 and A5 critical uses are phased-out. Also it requires that emissions from use of MB for QPS are reduced significantly. In 2017, the use and emissions of MB for QPS sources was more than thirty times the total reportedly used for non-QPS (CUE) in non-A5 and A5 countries.

FIGURE 4-2: THE IMPACT OF MB RESTRICTIONS IN NON- QPS USES ON MB CONCENTRATIONS IN THE TROPOSPHERE SINCE THE LATE1990S (RED LINE).



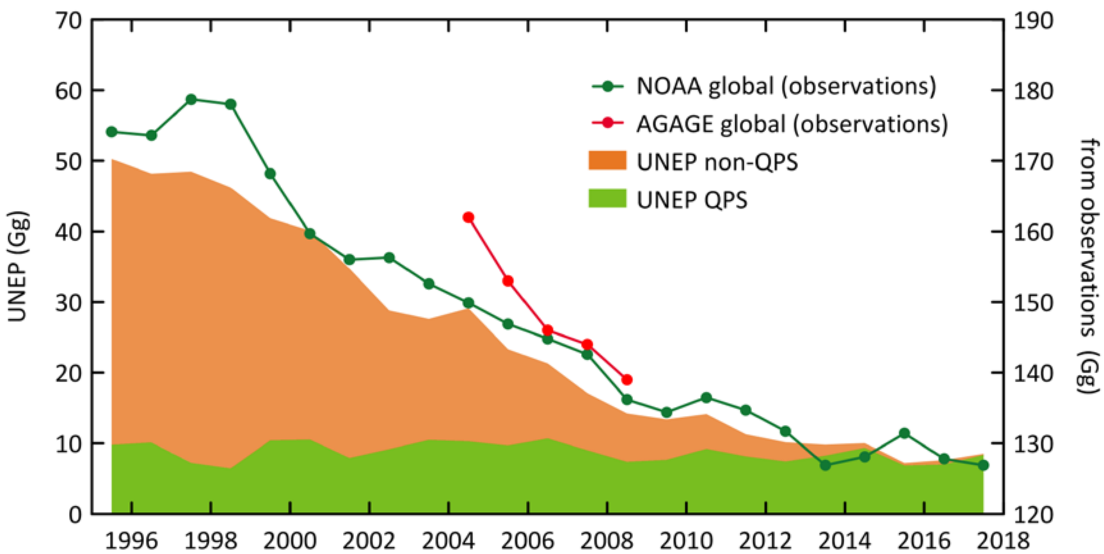
This fall represents around a 50,000 t reduction of emissions (see Fig 3.4). The *solid line* indicates the level of MB from natural sources (i.e. the historic baseline), which is assumed to be constant in time. Current MB levels are about 1 ppt above natural levels of MB. About 40% of this is from remaining QPS and CUE MB uses, the other 60% from unidentified sources. 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 4-3. HISTORIC MB LEVELS (PPT = PARTS PER10^{12}MOLAR) IN THE SOUTHERN HEMISPHERE OVER THE PAST 350 YEARS



The dashed line represents the approximate natural MB equilibrium). Data are from Cape Grim, Tasmania, and various atmospheric and ice/firn sampling sites in Antarctica compared to modelled MB levels (WMO 2003, WMO 2007, WMO 2011, WMO 2015) as reported in the past four Scientific Assessments of Ozone Depletion (SAP, https:/ozone.unep.org)

FIGURE 4-4. MAN-MADE (QPS + NON-QPS) AND TOTAL (FROM ATMOSPHERIC DATA) GLOBAL EMISSIONS OF MB



(i) man-made:from a simple emissions model, based on reported UNEP global QPS and non-QPS consumption data (Figure 1-8 in Montzka *et al*., 2011), left axis;(ii) total (man-made + natural) from atmospheric observations and a 1-box model (NOAA: green,AGAGE: red), right axis (Montzka and Reimann, 2011; S. A. Montzka, NOAA, unpublished data). The estimated MB emissions from QPS in 2009 are 8 Gg (8,000 tonnes, Table 4.1).

4.4. MB emissions from current uses for soil, commodities and structures

Past studies show that most of the MB applied during fumigation will be leaked or released to the atmosphere, except that which reacts irreversibly with treated materials (e.g. soil components, commodities or structural materials) or which is recaptured and destroyed. From the capacities of currently installed recapture equipment, it is estimated that the MB recaptured and destroyed in 2017 is small, less than 500 tonnes annually (MBTOC estimate).

Table 4-2 includes estimates for emissions from all current uses reported by Parties to the Montreal Protocol. The overall usage figures given in Table 4-2 are derived from a combination of reported 2017 global production for QPS, usage in 2017 in Article 5 and non A5 countries as authorised for CUE purposes (Chapter 2), 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 46 - 91%, 85 - 98%, 76 - 88% and 90 - 98% of applied dosage for current uses 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 67 - 91% overall emission from agricultural and related uses, with a mean estimate of overall emissions of 82%.

Best estimates of annual MB emissions from all sources of fumigation use in 2017 are 8,544 tonnes (Table 4.2) and are marginally lower than in 2013 which totalled 8,781 tonnes. During this period there have been substantial reductions in usage for soil fumigation for controlled uses, counterbalanced by increases in fumigation of timber and wood packaging materials treated to meet Quarantine and Preshipment requirements. The reported QPS consumption under Article 7 has been on an upward trend since 2015, increasing from 8,174 tonnes in 2015 to 9,960 tonnes in 2017.

Table 4.2: Estimated global usage of MB and emissions to atmosphere in 2017 for major use category, including QPS.

Type of fumigation and commodity/use	Estimated usage([a])		Estimated emissions	
	tonnes	%	tonnes	% (*b*)
CUE (Non QPS)				
Preplant soil fumigation	300	3.4	206	69 (46-91)
Structures, commodities and perishables	45	0.05	41	92 (85-98)
Sub Total- non QPS	***345***	***2***	***247***	***72***
QPS				
Preplant soil fumigation	1650	18	1130	69 (46-91)
Timber and wooden packaging	5180	49	4558	88
Durables and miscellaneous (timber/grains)	2450	22	1825	75 (51-98)

Perishables	856	8.0	783	92 (85-98)
Sub Total- QPS	***10136***	***98***	***8297***	***82***
Total estimated fumigant use	**10481**	**100**		**71- 91**
Best estimate over all categories			**8544**	82

*(a)*Estimated usage based on QPS consumption data (in this Assessment), authorised CUE use for 2017 and MBTOC survey of non A5 or Article 5(1) consumption and use, excluding feedstock. Reported use of stocks included. No allowance for unreported use. *(b)* For original sources of estimates, see MBTOC 1995 with minor subsequent adjustments

4.5. Emission Reduction through Better Containment, Recapture or Destruction

MB 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 or the packaging/palleting in commodity treatments or into the soil for preplant treatments. 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 non-volatile residues. Except for this portion, all the MB applied during fumigation will eventually be emitted to the atmosphere. During any fumigation operation there are four 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 unintentional discharge of some unreacted MB during applications when changing cylinders, lifting rigs from soil to reverse direction, etc.
iii. During international ‘off gassing’ or discharge of unreacted MB after completion of fumigation of commodities and structures after a set exposure period.
iv. Following treatment when the treated soil, commodity or structure emits any sorbed, unreacted MB, often over an extended period of time.

All but the third situation can be controlled or reduced by better containment (sealing and film permeability) of the fumigation site (Section 4.6.1 (soil treatments) and fumigation enclosure (Section 4.6.2 (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.

Reduction of emissions in intentional discharge can be controlled by a reduction in MB dosage applied or by recapture of the MB followed by recycling, reclamation or destruction (Sections 4.7). For most commodity and structural 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, although there are several operational factors that lead to reduced recapture efficiencies.

Even though only a small fraction and concentration of added gas may be present after venting/airing off of fumigant following termination of a fumigation exposure, this may be sufficient in some situations to present possible health hazards to workers and bystanders. Maximum worker exposure standards are set by many countries at 5ppm v/v or less, either as a time-weighted average or maximum tolerable concentration. Concentrations within the chamber during treatment of a commodity are usually greater than 10,000 ppm v/v. Venting or recapture of the MB including fumigant desorbing from treated materials must be carried to below set worker maximum exposure levels before fumigation enclosures can be entered and treated materials accessed.

4.5.1. Preventing Emissions From 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 edges when laying and venting injection rigs; 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).

4.5.1.1. Use of barrier films and other plastic covers to reduce emissions

Barrier films became a very effective measure to reduce emissions before MB was phased out for soil uses by all Parties in 2015. With proven efficacy, barrier films should be considered mandatory to reduce MB emissions for any remaining soil uses of MB (i.e. critical uses and QPS uses), unless technically proven not to reduce emissions in the particular situations. Emissions were shown to be reduced by up to 50% (Villahoz *et al.*, 2008; Gao *et al*., 2013; Qin *et al.*, 2011; Qin *et al.*, 2014). Since the 1998 Assessment Report there have been many studies looking at the advantages of a number of different types of barrier films. These have progressively included testing and application of virtually impermeable films (VIF films), semi-impermeable films (SIF) and totally impermeable films (TIF). VIF films typically comprise a LLDPE (Linear Low Density PE) sandwich containing nylon; SIF films include a LDPE sandwich containing HDPE and TIF comprise a polyethylene sandwich containing a number of adhesive layers and a central layer of ethyl vinyl alcohol. Studies under field conditions in a number of regions (MBTOC 2014), together with the large scale adoption of barrier films globally before methyl bromide was phased out for most preplant soil uses support the use of these films as a means to reduce MB dosage rates and emissions. They have also proven effective to improve the performance of alternatives used to replace methyl bromide (MBTOC 2014). Controlled studies have shown substantial reductions in MB emissions using a number of techniques in addition to changing film type (Yates, 2005; Fraser *et al.*, 2006; Chow, 2009; Ntow *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 off gassing becomes a greater issue when the tarp is lifted and this may pose concerns to worker safety.

4.5.1.2 Regulatory practices to reduce MB emissions from soil

There are a number of regulatory practices used in the past in various parts of the world that result in reduced MB emissions from soil treatments, including:

- Mandatory requirement to use barrier films.
- 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.
- Imposing permit systems which could ensure that only technically necessary fumigation would be carried out (e.g. The Netherlands in 1981, Belgium 2005).

- 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 2014).
- Regulating that only trained licenced fumigant contractors can apply MB.

4.5.2. Reducing Emissions from Structural and Commodity Fumigation

At this time (2018), almost all structural and commodity treatments with methyl bromide are carried out for QPS purposes. There are reportedly only two remaining non-QPS uses. These are covered by the South Africa CUE relating to structural fumigation in grain mills and domestic houses.

QPS post-harvest disinfestations of commodities and structures using MB are performed, or should be performed, under well sealed conditions that limit loss of the fumigant to atmosphere during the exposure period. A high standard of effectiveness is required for QPS and particularly Quarantine (biosecurity) treatments. Consequently they tend to be strictly regulated worldwide. Improving the gas tightness of fumigation facilities will minimise leakage of MB into the atmosphere. Simple test criteria have long been available to the industry for determining the gas tightness of chambers (e.g. Bond, 1984). 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. Theoretically, 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. However in QPS treatments, dosage rates are usually specified exactly with no flexibility for dosage adjustment to minimise emissions. 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.

Mandatory QPS fumigation requirements for goods and empty freight systems may be found in several national or regional manuals. See Chapter 5 for examples.

4.6. Fumigant Recapture and Destruction

4.6.1 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 a wide range of decisions including QPS decisions (Decisions VI/11 (1994),VII/5 (1995); X/11 (1998); XI/13 (1999); XXI/10 (2009) and fumigations carried out under CUEs (Decision IX/6). In situations where MB is used and alternative non-MB treatments are not feasible, 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.

One process involving thermal decay of MB from dilute sources of methyl bromide was recently approved as a Destruction Process under Decision XXIX/4 (TEAP Destruction Taskforce Reports (x3), TEAP 2018).

The technology is based on destruction of methyl bromide by thermal decay in a single pass destruction step, followed by conversion of the by-products through a water-based scrubbing system. The TEAP Destruction Taskforce determined that the DRE >99.99%, HBr, CO and particulate emissions met the performance criteria.

In view of this technology being approved by the Parties in 2018, a technology now exists, in addition to the recapture technologies, which can be considered for destruction of MB from the remaining controlled CUE uses and all QPS non-soil applications with potential for accessing credit for destroyed material.

4.6.2. 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 non-volatile products

The proportions contributed by items (i)-(iv) are strongly situation dependent. Leakage from item (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 (item (iv)) 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 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. During the ventilation period 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. Estimated emissions and ranges for various categories of fumigation, including commodity and structural fumigation, are given in Table 3.2 (above).

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 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 of 14% of applied dosage. In practice some leakage is inevitable and the time required for total desorption may be operationally 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 in individual situations will vary substantially from this estimate according to the particular circumstances.

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.

MBTOC in the past has concluded that most methyl bromide used for QPS purposes could have been prevented from entering the atmosphere by the fitting of recapture and destruction equipment (TEAP 2002). For the 8,297 tonnes of emissions from commodity and structural treatments in 2017(from Table 3.2), principally for QPS use, at 70% recapturable, 5,808 tonnes could have been prevented from entering the atmosphere by the fitting of recapture and destruction equipment on all QPS applications. It is acknowledged that 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 continue to be 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) and subsequent revisions, there is a residual gas level present after a fumigation. Table 4-3 gives the residual gas levels expected at various times.

TABLE 4.3: 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 2016) 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 24 h fumigation period (Table 4-4). 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, without top up, for some log fumigations carried out under gas proof sheets.

TABLE 4-4: ISPM 15 STANDARD FOR TREATMENT OF SOLID WOOD PACKAGING MATERIAL. DOSAGE RATES AND FINAL CONCENTRATIONS. (IPPC 2016).

Temperature	Dosage (g/m^3)	Minimum concentration (g/m^3) at 24h:	% retention at 24 h
21°C or above	48	24	50
16 - 20.9°C	56	28	50
10 - 15.9°C	64	32	50

4.7. 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 full scale, commercial use.

Research, developmental and industrial recapture and emission reduction systems for gas streams of methyl bromide fumigant diluted in air, as present at the end of a fumigation include:

- Capture on activated carbon, with subsequent treatment to destroy sorbed methyl bromide with aqueous thiosulphate solution or other reagents, disposal in secure landfill (Nordiko), or thermal (hot air or steam) desorption for reuse or further processing (Value Recovery, MBTOC 2002).
- Capture on specialised zeolite with subsequent thermal desorption and reclamation (Willis)
- Liquid (aqueous) scrubbing with various nucleophilic reagents (e.g. Insects Ltd), including thiosulphate, ammonia-based mixtures and ethylene diamine.
- Low temperature recondensation (see MBTOC 1994)
- Combustion systems (e.g. Ryan, Lisbon, Bartolo, Australia, pers. comm.)
- Gas phase reaction with ozone, sometimes assisted by sorption of the methyl bromide on to carbon (see MBTOC 1994).

The commercially available recapture and destruction systems available globally include:

- Recapture systems onto active carbon (e.g.. Australia and Pacific countries) –absorption of MB from gas emissions from chambers after fumigation. Despite commercial processes available to recover the methyl bromide for reuse, at present all MB recovered from the recapture process is deep buried. It is done so on the understanding that methyl bromide degrades in soil and it reduces emissions to the atmosphere (see section on deep burial of MB). At present the captured methyl bromide on carbon cannot be reused or recycled as there is no permit or licence to do so.

- Carbon sorption plus scrubbing using potassium thiosulphate or a proprietary scrubbing technology is being used in the US and under trial currently in New Zealand. In the US two systems as shown above have been commercially operating for 5 years and this has reduced the need for constant review by US regulators.

- Carbon sorption and regenerative scrubbing systems are currently in trial operation in NZ for recapture of MB from large scale log fumigations. The US carbon sorption and regeneration systems have been operating at two commercial installations for 4 and 5 years (MBAO 2014, MBAO 2016). Operations at the two sites have removed over 57 tonnes of methyl bromide from over 1,500 fumigations.

- In addition to the above technologies, New Zealand have imposed a policy to ensure all MB applications, including QPS use recapture systems by 2020. This is stepwise process which required all containerized MB treatments to use recapture by August 2017. The US has also recently (August, 2018) announced a new rule to make recapture of methyl bromide mandatory in North Carolina for QPS treatment of logs (http://www.wunc.org/post/nc-regulate-toxic-pollutant-methyl-bromide#stream/0).

- Trials in Australia (Mattner *et al.*, 2017) have successfully used the recaptured methyl bromide on carbon to fumigate soils in the strawberry runner industry which have an exemption to use MB under the 'Critical Use' provisions of the Montreal Protocol. These trials have presently not been scaled up for commercial use nor is the product registered for use.

- A combustion system, developed in Australia was recently approved as a Destruction Technology at the 30th MOP (2018) – this destruction system has been successfully trialled and is currently being scaled up for commercialization in US and Australia.

Economics will tend to favour destruction over recycling in situations where MB continues to be easily obtainable for QPS purposes and destruction technologies are relatively cheap, including allowance for disposal of products of the destruction system.

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 before 2018 specifically for ozone-layer protection, possibly excepting systems installed in Belgium prior to full phaseout of methyl bromide in the EU (e.g. Willaume, pers.com). 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.

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, such as those recently imposed in New Zealand. As New Zealand is a major user of QPS MB (5th largest user), technologies implemented there will have global implications.

In summary, recapture and recycling processes have the potential to provide a means of reducing MB 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. If more broadly adopted, these technologies offer the greatest means of reducing MB emissions to the atmosphere from all the remaining uses of MB.

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5

Chapter 5. Alternatives to Methyl Bromide for QPS Applications

5.1. Introduction

Article 2H exempts methyl bromide used for QPS treatments from phase-out under the Montreal Protocol control measures. Methyl bromide fumigation is often the preferred treatment for certain types of perishable and durable commodities in trade worldwide, as it has a well-established, successful reputation amongst regulatory authorities to prevent the spread of quarantine pests and .

Parties to the Montreal Protocol are nevertheless encouraged to minimize and replace Mcan be used with little disruption to tradeB for QPS whenever possible (e.g. Decision XI/13(7)). Considering that in the past MBTOC has identified opportunity for replacing between 30 and 45% of QPS uses with immediately available alternatives, Parties may wish to step up efforts to reduce and replace QPS uses, particularly those for pre-shipment uses.

Since the MBTOC 2014 Assessment Report (MBTOC, 2015), several Parties have made significant technical advances and taken policy decisions leading to reductions and even phase-out of MB for some QPS applications. Such policies are stricter to outside controls by the Montreal Protocol, and are mainly due to concerns for worker safety. In 2010, the European Union phased out all uses of MB, New Zealand has recently implemented a policy of no emissions from all QPS uses of MB and North Carolina in the US has also imposed recapture technologies. MBTOC regularly provides more detailed information on alternatives to MB for QPS uses through annual TEAP Progress Reports.

Quarantine treatments for host plants of notorious plant quarantine pests are generally approved on a pest and product specific basis following bilateral negotiations, which may require years to complete. This process helps ensure safety against the incursion of harmful pests. For this and other reasons, replacing methyl bromide quarantine treatments can be a complex issue. Many non-methyl bromide treatments are, however, published in countries' quarantine regulations, but they are often not the treatment of choice due to cost or availability.

Nevertheless, since the 2014 Assessment Report there has been acceptance under bilateral arrangements and IPPC regulations that a number of technical alternatives are as effective as MB for specific commodities.

Global production of methyl bromide for QPS purposes in 2017 was 10,217 tonnes, increasing by about 15% from the previous year, but within variations seen over almost two decades (Fig. 5-4). Production occurs in five Parties, China, India, Israel, Japan and USA. Although there are substantial variations in reported QPS production and consumption on a year-to-year basis. Total QPS consumption has started to show as decline in use from around 10,000 metric tonnes in 2010 to 8,284 in 2016 but increased to 9,959 metric tonnes in 2017 due to three countries reporting significant increases (China, India and the USA).

In 2009 the QPS comsumption exceeded non-QPS consumption for the first time, being 46% higher. This has been a result because of falling consumption for controlled used not change in QPS production. In 2017, reported QPS consumption was 70 times larger than non-QPS (controlled) consumption. In 2017, QPS use of methyl bromide contributed over 97% of the global emissions of methyl bromide (Chapter 4) which is approximately 34 times greater than the emissions from the consumption for critical uses controlled under the Montreal Protocol. Control of these emissions is the biggest immediate gain that can be made under the Montreal Protocol to the reduction of ODS substances in the stratosphere. Parties who have reduced emissions of MB for QPS have either regulations which speed up the uptake of alternatives or are adopting recapture technologies.

Improvements in recapture technologies and recognition by the Parties of the first approved Destruction Technology for methyl bromide (MOP 2018) mean that technologies are now available to reduce the use of MB emissions. As the implementation of these technologies imposes a cost on the user, their uptake will most likely only occur if Parties impose regulations mandating their use.

Of the 50 countries still regularly using for QPS, fourteen show significant reductions in their methyl bromide consumption for QPS but other countries (13) have shown sharp increases possibly due to increased pest risks and trade in commodities requiring treatment such as pulses and logs.

Reported consumption shows that QPS MB use now exceeds the baseline levels set for controlled uses in 16 countries, particularly for Australia, Pakistan, New Zealand and Vietnam. In addition some of these countries, five countries (El Salvador, Fiji, India, Korea and Nicaragua) never used methyl bromide for controlled uses, but now have significant uses under QPS.

Owing to this increase in use for QPS by some countries, the major reductions obtained in others (EU, USA, others) have been offset and there has been no overall reduction in QPS use in the last twenty years. From 2012- 2014 it appeared that there was a trend towards reduced QPS use, however over the last three years (since the global phase out for controlled uses) QPS consumption has increased substantially from 8,500 t to 9,960 tonnes.

In 2017, QPS consumption in A5 Parties (6,617 tonnes) represented 69% of global consumption; non-A5 Party consumption, at 3,343 tonnes was 31%. Overall, consumption in Article-5 Parties has trended upward over the past 15 years, whereas consumption in non-A5 Parties has a downward trend. Global consumption averaged 9,617 tonnes over the period 2010 to 2017 and in 2017 has increased to 9,959 metric tonnes.

On a regional basis, consumption in the Latin America and the Caribbean, Africa and Eastern Europe regions has remained much lower since 1999 than in Asia and North America. In 2017, an analysis of global consumption (including both A5 and non-A5 Parties in the regions where appropriate), Asia accounted for 55% of global QPS consumption.

Reporting (as noted by the sudden jump in use by India) and classification of use is still a major problem. Some Parties continue to express concerns over difficulties in interpreting the categories of MB uses between controlled and exempted uses. MBTOC also still has difficulty in determining the actual pests and commodities for which MB is used in QPS and Parties may wish to consider revisiting a means with which Parties are able to obtain and report this information. Useful publications are now available (e.g. UNIDO, 2015), but further work on this topic would be very beneficial.

5.2. QPS uses of methyl bromide

Quarantine and pre-shipment (QPS) treatments with methyl bromide (MB) are generally applied to commodities in trade between countries and between quarantine regions inside a country treatments. QPS with methyl bromide (MB) are intended:

- To kill pests on perishable and durable commodities listed as quarantine pests (quarantine);
- On durable and perishable commodities or in trade to render them “practically free” of noxious pests and other organisms (pre-shipment).
- On soils, and in structures and commodities to eliminate or control exotic organisms of quarantine significance.

Periodic QPS uses of MB are sometimes made within countries in trying to prevent spread of exotic pests 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.
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 and 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 tyres, household goods, and industrial goods.

Many perishable and durable commodities in trade and storage can be attacked by pests such as insects, mites and fungi, which cause loss of quality and value and which in some cases constitute a threat to agriculture, health or the environment. A wide variety of measures 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.
MB has been in routine use for decades, and is a well-developed system with a good record of success. Most current MB uses on durable and perishable commodities worldwide are highly specialised; detailed descriptions of specific treatments can be found in previous MBTOC reports. Some examples of current QPS uses are:

- Fumigation of cut flowers found to be infested on arrival in the importing country with quarantine pests (post-entry 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 (export 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 (quarantine treatment).

Alternatives for MB treatments are often compared with its inherent 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

However, MB also has a number of undesirable features for example:

- High toxicity to humans;
- Odourless, which makes 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;
- 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 to verify a high level of treatment efficacy for pests that are considered to be serious threats to the importing country. Intra-country quarantines are aimed at curtailing, containing or eradicating spread of quarantine pests that may be established in a limited area or region of that 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.

5.3. Quarantine and pre-shipment – definitions under the Montreal Protocol

5.3.1. Origin and original intent of the QPS exemption

At the 1992 Meeting of the Parties in Copenhagen that established MB 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 A5 and non-A 5 countries, there was a strong likelihood of disruption to international trade if the exemption for QPS were not available.

Invasions by new pest species into a country or region can have serious adverse effects economically and on agricultural production and natural resources. 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.

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. However there are many examples of successful eradication campaigns (MBTOC, 2011). MB treatment is considered an important tool for some eradication and containment attempts. For example, it was successfully used in the eradication of khapra beetle from western USA in the 1950s, *Hylotrupes* from eastern Australia in the 1960s and more recently to contain and possibly eradicate the exotic nematodes *Globodera pallida* and *R. rostochiensis* in parts of USA (TEAP, 2009) and *Trogodrema granarium* from an incursion in Western Australia (Day and White, 2016).

5.3.2. '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) has 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 definition of a quarantine pest under the Montreal Protocol differs from that under the IPPC (International Plant Protection Convention) 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 is analysed in further detail in MBTOC and TEAP reports (MBTOC, 2011, TEAP, 2010). Its definition of a quarantine pest relates to official control, 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 MB 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.

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 International Agreements and domestic regulatory bodies.

5.4. 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 when necessary. Now new Decisions specifically dealing with QPS uses of MB have been taken by the Parties to the Montreal Protocol since 2014.

Table 5-1 lists decisions relating to QPS uses of MB and summarises the main issues comprised by each. Reports prepared in response to such Decisions – when requested by the Parties – can be found at the Ozone Secretariat website.

TABLE 5-1: SUMMARY OF DECISIONS RELATING TO QPS USES OF METHYL BROMIDE

Decision No.	Decision title	Summary
VI/11(c) 1994	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 1995	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
X/11 1998	Quarantine and pre-shipment exemption	Requests TEAP to assess volumes and uses of MB under the QPS exemption, and to report on existing and potentially available alternatives, on the operation of the QS exemptions as per Decision VII/5 and on options that Parties might consider to reduce use and emissions of MB for QPS. Further to review and report on IPPC definitions for QPS.
XI/12 1999	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 1999	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 2004	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 2005	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 2008	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.

Decision No.	Decision title	Summary
XXI/10 2009	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
XXIII/5 2011	Quarantine and pre-shipment uses of methyl bromide	Invited Parties in a position to do so to report on the amount of MB used to comply with phytosanitary requirements of destination countries, and on phytosanitary requirements for imported commodities that must be met with MB. And requested TEAP/MBTOC to summarize article 7 data on QPS and provide regional analysis; provide guidance on procedures and methods for data collection on MB use for QPS; and prepare a concise report based on responses received.
XXIV/15 2012	Reporting on information on quarantine and pre-shipment use of methyl bromide	Requested Parties to comply with the reporting requirements of Article 7 and to provide data on the amount of methyl bromide used for quarantine and pre-shipment applications annually and invited Parties in a position to do so, on a voluntary basis, to supplement such data by reporting to the Secretariat information on methyl bromide uses recorded and collated pursuant to the recommendation of the Commission on Phytosanitary Measures. A possible request to TEAP to undertake a trend analysis of MB consumption in the QPS sector to be considered at the OEWG33 and MOP25

Source: Montreal Protocol Handbook and Ozone Secretariat website, 2018

5.5. Policies on QPS uses of methyl bromide

5.5.1. Legislation that requires methyl bromide use for QPS

Use of MB for QPS 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. 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 other borders. These relate to movement of quarantine pests from infested areas to ones that are known to be free of the pest or where it is subject to control or eradication within the state or country.

MBTOC has 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. Examples are MB log treatments for countries exporting to China and India, which are to be applied by the exporting country to control **quarantine pests** and requiring a phytosanitary certificate with the treatment details. For China MB fumigation is required for logs that have not been debarked, with either phosphine or MB. See https://www.mpi.govt.nz/law-and-policy/requirements/icpr-importing-countries-phytosanitary-requirements/forestry-icprs/china/

For India the alternative option to MB is heat treatment at 56°C and above (core temperature of wood) for 30 minutes which is not practical or cost effective for whole logs. See https://www.mpi.govt.nz/law-and-policy/requirements/icpr-importing-countries-phytosanitary-requirements/forestry-icprs/india/

In addition, 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 (post-entry quarantine) 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 cases where MB does not harm the commodity involved and treatment is relatively cheap, there may be little incentive to search for alternatives especially since these generally need to be developed in the exporting country, often lacking resources to do this.

Research to develop and confirm effectiveness of alternatives for quarantine treatments in 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 typically required for quarantine pests where methyl bromide fumigation is used as the major or sole control step.

5.5.2. 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 standards relating to methyl bromide 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. 15 (2006) Treatment of Wood Packaging Materials
- 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. 41 (2018) International movement of used vehicles, machinery and equipment

The main ISPM that specifically deals with a major volume use of MB is ISPM 15, as revised (IPPC 2016). The standard deals with the disinfestation of wood packaging material in international trade as a quarantine measure against various pests of wood and forests and contains specifications for both heat treatment and methyl bromide fumigation, whilst recognising that methyl bromide is an ozone-depleting substance (IPPC 2006, 2009ab, 2016). The ISPM 15 standard as revised in 2009 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).

ISPM 15 was updated at CPM-8 in April 2013, incorporating another heat treatment, the dielectric heating (e.g. microwave, radio frequency), for wood packaging material composed of wood not exceeding 20 cm that must be heated to achieve a minimum temperature of 60 °C for 1 continuous minute throughout the entire profile of the wood (including its surface). The prescribed temperature must be reached within 30 minutes from the start of the treatment. The Technical Panel on Phytosanitary Treatments (TPPT) accepted the treatment schedule without a thickness limit and recommended the IPPC Standards Committee to send it for member consultation.

Dielectric heating Radio frequency (RF) uses much lower frequencies than microwaves (MW), so the RF wave has a longer penetration depth than the MW, and can be used to treat wood with larger dimensions than the 20 cm accepted by ISPM 15. It is claimed characteristic of dielectric heating (DH) is the potential for selectively heat materials, offering an advantage over conventional heating for insect control due to the selective heating of insects due to their higher water content in relation to the wood itself. Another advantage of dielectric heating systems is that they are reported to convert 50–70% of the energy to heat, in comparison to 10% efficiency in conventional ovens.

More recently (see section 5.9.11) sulfuryl fluoride (SF) was approved by IPPC for compliance with ISPM-15, under specific conditions. This adds a new alternative option, however MBTOC considers it important to note the high GWP (global warming potential) of this fumigant.

Alternatives for logs still under consideration by IPPC include phosphine, ethanedinitrile (EDN, cyanogen), heat (including vacuum steam), and debarking. Ethanedinitrile is close to registration in several countries and with a growing body of efficacy data has potential to replace a significant portion of QPS use for non-food items. More information on alternatives is given in ensuing sections of this chapter.

5.6. Production and consumption of MB for QPS uses

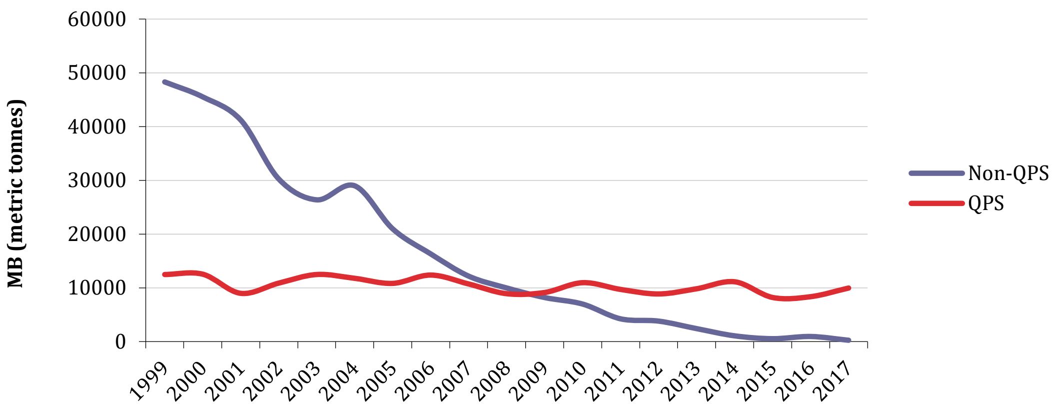
5.6.1. Introduction

Since 1999 a continuous reduction in controlled uses of MB (non-QPS) has occurred, as alternatives have been adopted for virtually all previous uses in observance of the phase-out deadlines agreed under the Protocol. By the end of 2017, 98% of global controlled uses had been replaced with alternatives.

In contrast, QPS consumption has not decreased but remained relatively constant over the last decade, as shown in Figure 5-1. In 2009 the QPS use exceeded non-QPS for the first time, being 46% higher. This was partly due to the continued decrease in the non-QPS uses, as well as re-categorisation by some Parties of uses previously considered non QPS to QPS. Since 2003 an amount of methyl bromide included in the initial baseline estimates for controlled MB uses, (an estimated 1400 to 1850 tonnes), has been re-categorised to QPS MB use for the pre-plant soil treatment of propagation material.

Presently, only 2.5% of total global MB uses are for controlled uses, with the remaining 97.5% corresponding to QPS (exempted uses).

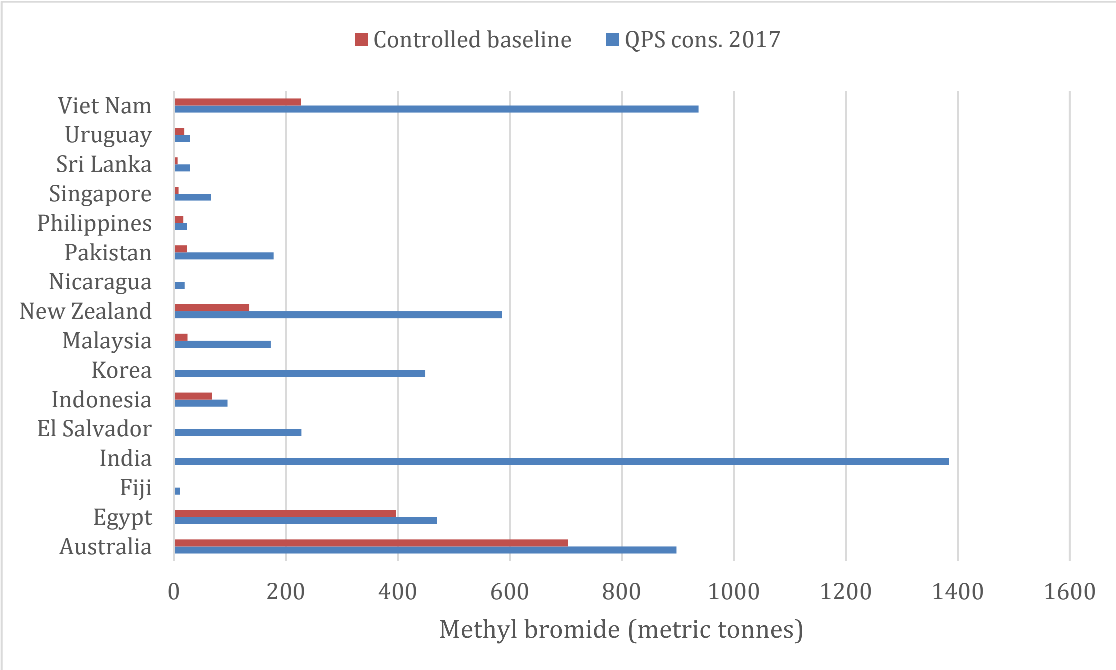
FIGURE 5-1: COMPARISON OF NON-QPS AND QPS CONSUMPTION OF MB IN THE PERIOD 1999 TO 2017



Source: Ozone Secretariat data centre, 2018

On occasion of the 2018 Assessment Report, MBTOC has conducted a historical analysis, revealing that in a number of countries, QPS consumption now exceeds the controlled baseline (Fig 5-2), sometimes by several orders of magnitude. This is true mostly in A5 Parties, but also in some non-A5s (the baseline for non-A5 Parties is the 1992 reported controlled consumption; for A5 Parties the average consumption for the period 1995-1998). Such increases could be due to increased international trade, increased risks from quarantine pests and others including illegal trade or erroneous classification of MB uses (i.e. as exempted, when they are actually controlled). Parties may wish to request further analysis in this respect to help clarify this situation.

FIGURE 5-2: COMPARISON CONTROLLED BASELINES VS. QPS CONSUMPTION OF MB IN 2017**

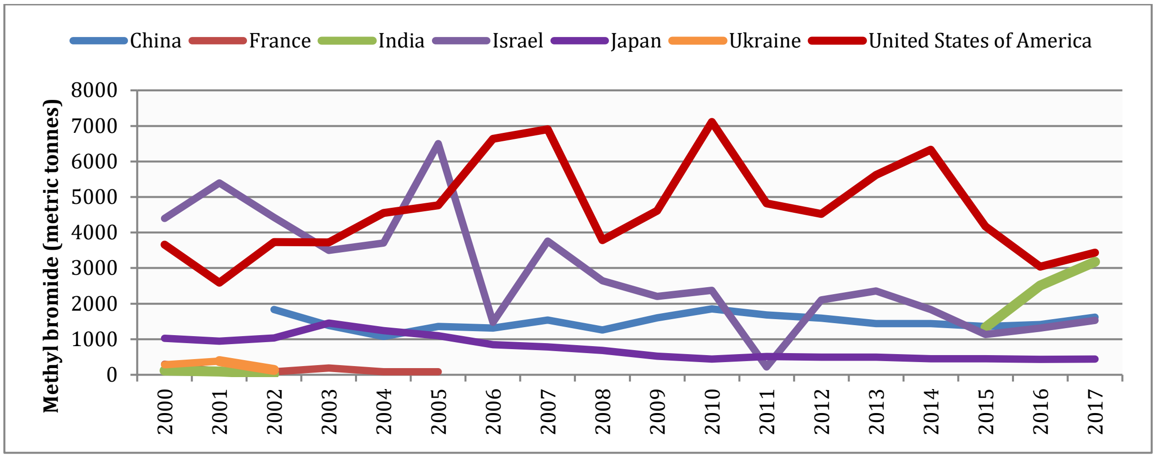


Source: Ozone Secretariat Data Access Centre 2018. ** Baseline: 1991 consumption for non-A5; 1995-1998 average consumption for A5.

5.6.2. QPS Production trends

Global production of methyl bromide for QPS purposes in 2017 was 10,217 tonnes, increasing by about 15% 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. QPS production currently occurs in five Parties (USA, India, Israel, China and Japan), as indicated in Figure 5-3. Two more countries - France and Ukraine - reported production in the past, but according to Article 7 data, ceased QPS production of MB respectively in 2003 and 2006. India, which had last reported MB QPS production in 2002 started reporting again in 2015. China's production each year has ranged from about 1,100 to 1,850 tonnes since 2002. Japan shows a reduction trend, whereas the USA and Israel have shown relatively large annual fluctuations over the last 15+ years as shown in Fig. 5-3.

FIGURE 5-3: METHYL BROMIDE PRODUCTION FOR QPS PURPOSES, PER PARTY 1999 TO 2017



Source: Ozone Secretariat Data Access Centre, 2018

5.6.3. Global QPS Consumption trends

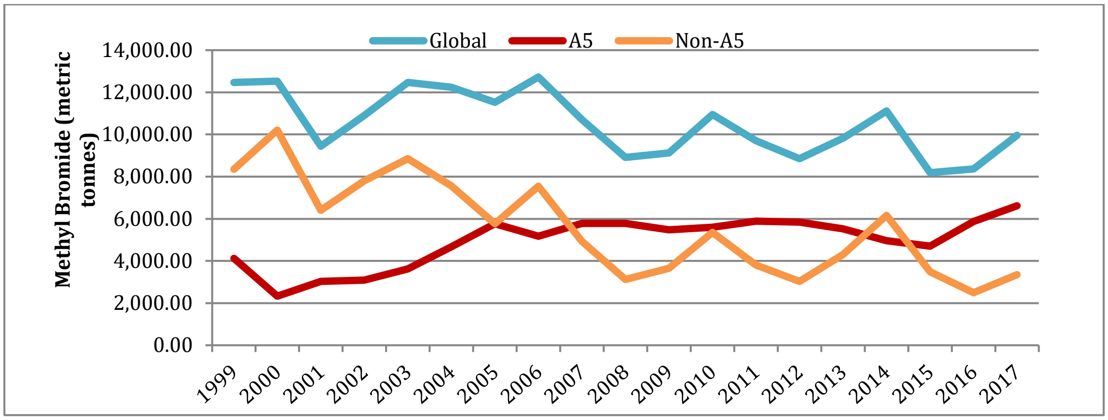
In 2017, global consumption amlounted to 9,960 tonnes. A5 Parties accounted for 69% of global MB consumption for QPS purposes (6,617 tonnes); non-A5 Party consumption, at 3,343 tonnes was 31%. Consumption in A5 Parties has trended upward over the past 15 years (Fig. 5-4), whereas consumption in non-A5 Parties has trended downward over the same time period, although global QPS consumption remaining relatively stable overall.

MBTOC notes that despite some Parties reducing consumption for QPS by more than 50%, these reductions has been offset by other parties that have increased use substantially, and this means that there has been no overall reduction in global consumption. Table 5-2 illustrates this

TABLE 5-2: CONSUMPTION TREND IN SELECTED COUNTRIES (MT)

Country	Consumption average 2006 - 2008	Consumption average 2015 -2017	% reduction
Brazil	208	52	75.0
Chile	121	67	44.6
EU	243	0	100
Indonesia	300	149	50.3
Japan	1021	442	56.7
Thailand	548	180	67.2
USA	3077	1,255	59.2
Totals	6,891	3,288	56.6

FIGURE 5-4: GLOBAL, NON-A5 AND A5 CONSUMPTION OF QPS FROM 1999 TO 2017

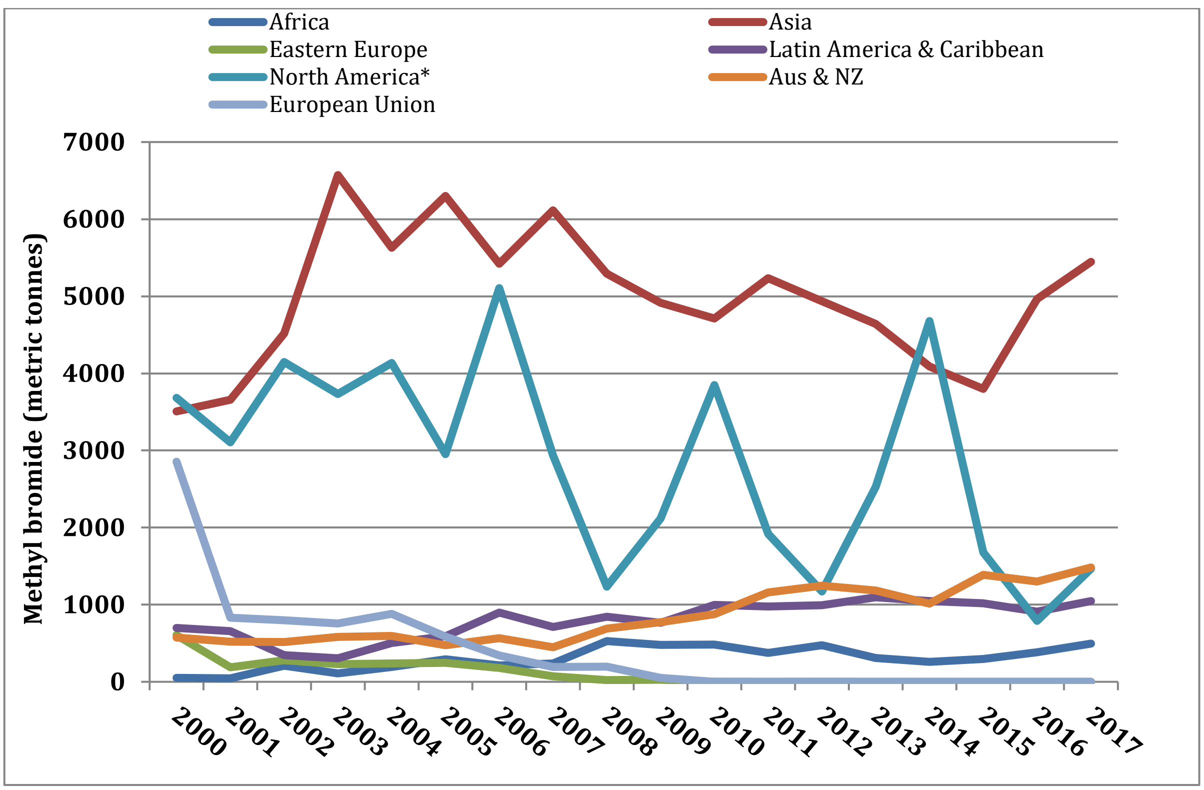


Source: Ozone Secretariat Data Access Centre, 2018

5.6.3.1. Regional consumption

Regional consumption of MB for QPS purposes over the past ten years was analysed on the basis of data reported by Parties until 2017. The regions shown in Figs 5-5 and 5-6 include both A-5 and non-A5 Parties when these are located in the same region (as an example, the Asia region includes Japan, Israel, China, Indonesia and others). Wide variations are noted for North America (the USA comprises over 99% of this consumption since Mexico has been included in the "Latin America & Caribbean region). An continued upward consumption trend is noted in Asia, which corresponds mainly to A5 countries in that region.

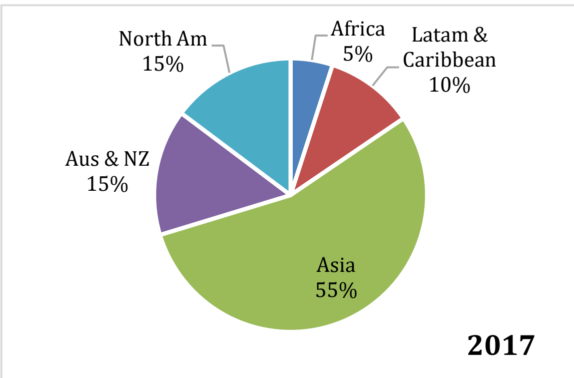
FIGURE 5-5: REGIONAL CONSUMPTION OF QPS FROM 2010 TO 2017

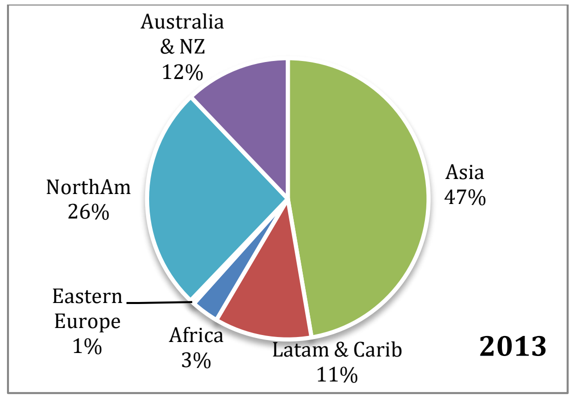


Source: Ozone Secretariat Data Access Centre, 2018. * North America comprises USA + Canada

Consumption in the Latin America & Caribbean and Africa regions has traditionally been much lower than in Asia and North America. Between 2013 and 2017, proportions in other regions changed: In 2017 Asia consumed 5,445 tonnes, (including both A5 and non-A5 Parties in the regions where appropriate), which corresponds to 55% of global QPS consumption, an increase from 47% in 2013; this is directly related to India reporting consumption since 2015. Australia and New Zealand increased participation from whilst North America (US + Canada) reduced from 26% to 15% (Fig 5-6).

FIGURE 5-6: REGIONAL CONSUMPTION OF QPS IN 2017 (LEFT) AND 2013 (RIGHT)



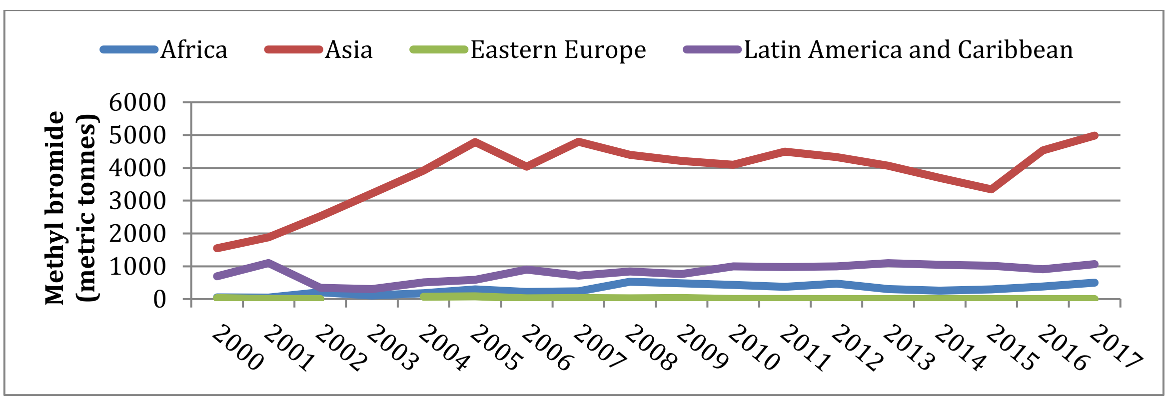


Source: Ozone Secretariat Data Access Centre, 2018

5.6.4. QPS consumption in Article 5 Parties

When considering A5 regions only, Asia emerges once again as the largest consuming region (Fig. 5-7), with a renwed upward trend since 2014. This region contains large consumers like China, Viet Nam and the Republic of Korea. Since 2010, Latin America continues an upward consumption trend, and Africa, which had previously decreased, has also increased consumption over the past four years.

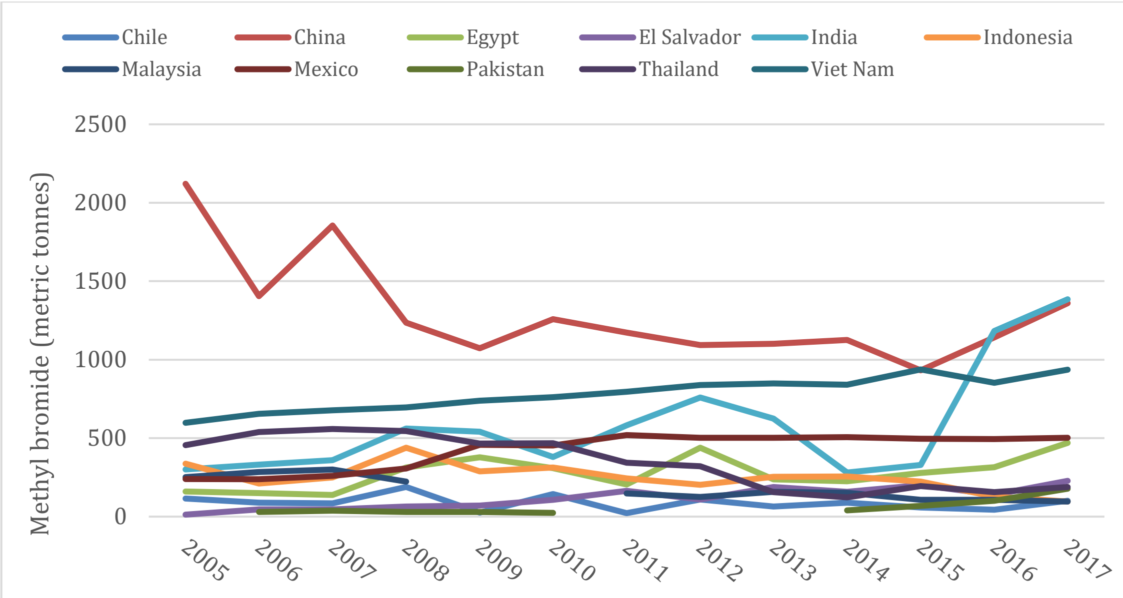
FIGURE 5-7: MB QPS CONSUMPTION IN ARTICLE 5 REGIONS 2000-2017



Source: Ozone Secretariat Data Access Centre, December 2018

The Ozone Secretariat database shows that 73 A5 Parties have reported consumption of QPS at least once in the period 1999 to 2013. A further 74 (51%) A5 Parties have never reported QPS consumption during this period. During the past decade, consumption has varied substantially in some A5 Parties, decreasing in some and significantly increasing in others. Eleven A5 Parties accounted for about 85% of the total A5 QPS consumption in 2017. India was the largest consumer in 2013 (1,385 t) followed by China (1,360 tonnes), Viet Nam (937 tonnes), and Mexico (502 tonnes) as shown in Fig 5-8.

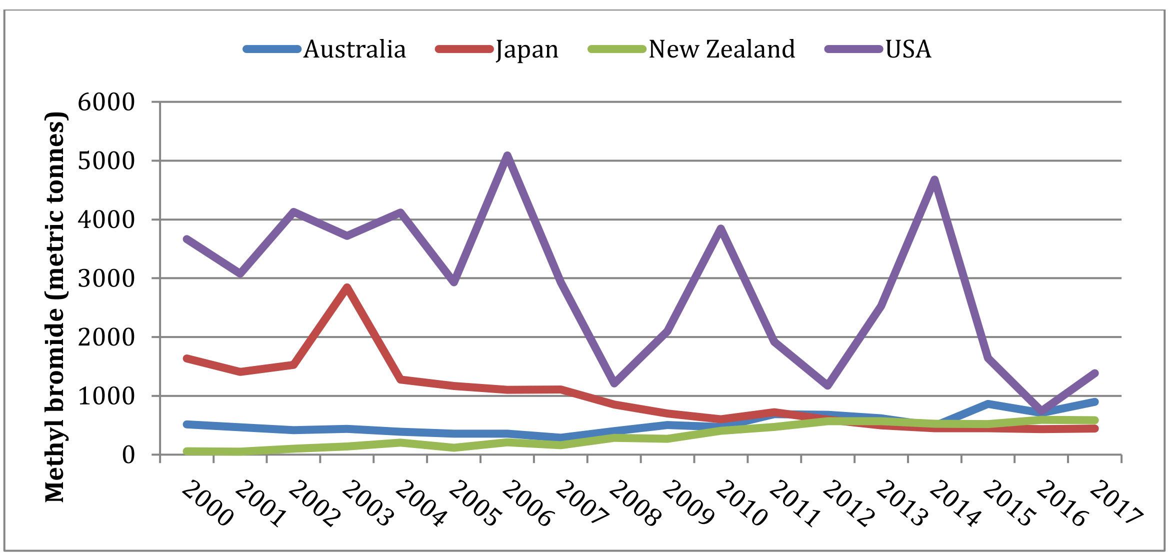
FIGURE 5-8: QPS CONSUMPTION TREND IN A5 PARTIES REPORTING CONSUMPTION > 100 TONNES IN 2017



5.6.5. QPS consumption in non-A5 Parties

The Ozone Secretariat database shows that 24 non-A5 Parties have reported consumption of QPS MB at least once in the period 1999 to 2017 and that for this last year (2017) aggregate consumption of non-A5 Parties was 3,346 tonnes. Four non-A5 Parties consumed 99% of the QPS reported by non-A5 Parties in 2017: United States, New Zealand, Australia and Japan. Fig. 5-9 shows the consumption by the highest-consuming four non-A5 Parties from 2004 to 2017.

FIGURE 5-9: TRENDS IN QPS CONSUMPTION IN NON-A5 PARTIES THAT REPORTED CONSUMPTION OF MORE THAN 100 TONNES IN 2013



5.7. Main Uses of Methyl Bromide for QPS purposes

5.7.1. 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, 2011, 2014). In 2018, MBTOC conducted a new survey on QPS uses amongst Parties reporting QPS consumption of 25 ODP (42 metric tonnes) or larger, with help from the Ozone Secretariat; this provided a list of 13 A-5 Parties and 5 non-A5 Parties. Responses were received from about half of these Parties, providing very helpful information. MBTOC notes that several Parties indicated not having such information available, either because such information on specific uses is not kept by phytosanitary authorities, or because resources to conduct this kind of analysis were not available.

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 5-3. The additional categories marked with an asterisk in were added to cover areas not covered by the IPPC.

TABLE 5- 3: 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

5.7.2. Quantity of methyl bromide used

A general analysis on categories of use by volume was conducted, on the basis of information received from Parties in response to the survey conducted by MBTOC in 2018 amongst key Parties, supplemented by information contained in past QPS reports (TEAP, 2009, MBTOC, 2011, 2015, TEAP, 2012).

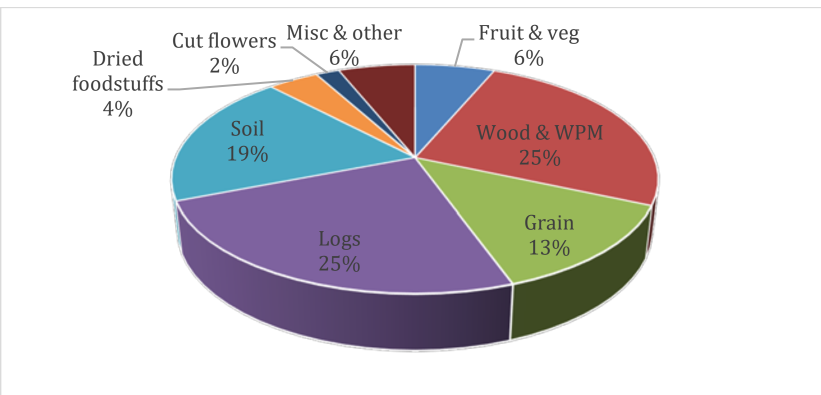
Previous analyses indicated that the five largest consuming categories of MB for QPS:

1. Sawn timber and wood packaging material (ISPM-15)
2. Grains and similar foodstuffs
3. Pre-plant soils use
4. Logs
5. Fresh fruit and vegetables

The current survey shows that these continue to be the primary categories of use, although fresh fruits and vegetables show a more prominent presence whilst use for wood packaging materials (ISPM-15) seems to have decreased. This could however be influenced by specific countries responding the survey and those who did not; it was noted that several countries indicated not having the information on categories of use available, and/or lacking the resources to gather it.

Clearly, more detailed information on actual categories of MB use for QPS purposes, and whether these are intended for quarantine or pre-shipment is needed in order to conduct a more relevant analysis of feasible alternatives.

FIGURE 5-10: ESTIMATED GLOBAL CATEGORIES OF MB USE (QPS PURPOSES) IN 2017



Source: MBTOC surveys 2014 and 2018

5.8. Key quarantine pests controlled with methyl bromide

Target pests for QPS treatments vary from country to country even for the same commodity, and the procedures for handling the issue of defining the target pests may also differ.

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 countries publish master lists of regulated pests, being recognised quarantine pest species. These can be found through the IPPC portal. 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 5-4 shows the main target pests of quarantine significance in the major classes of methyl bromide use, by volume, for QPS purposes.

TABLE 5-4: 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 materials	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, spiders.
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 'free from nematodes' to be considered QPS.

Key quarantine pests that are sometimes controlled in international trade with MB 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).

5.9. Existing and potential alternatives for the major QPS use categories

Previous MBTOC and TEAP reports have provided details of existing and feasible alternatives for various QPS uses (e.g. MBTOC 1995, 1998, 2002, 2007; TEAP 1999, 2007, 2009, 2011, 2015). Previous MBTOC Assessment Reports (MBTOC 2002, 2007, 2011, 2015) provide detailed discussion of alternatives to QPS methyl bromide use on commodities in specific circumstances. Detailed reports on QPS and alternatives are further 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.

Existing alternatives to MB for QPS treatment of perishable and durable commodities are based on pre-harvest practices and inspection procedures, and various non-chemical (physical, ie cold, heat, modified atmospheres) and chemical treatments.

Quarantine treatments can be applied ‘post-entry’, for example when inspection finds a quarantine organism in the shipment at arrival or when treatments have been insufficient to adequately manage the risk of importing quarantine pests. 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. This avoids the need for post-entry quarantine measures, including methyl bromide fumigation.

Treatment options are often more restricted for post-entry quarantine treatments than for pre-shipment. In many post-entry situations, fumigation with MB is the only technically and economically available and approved process to meet quarantine standards to allow importation, due to limited infrastructure to apply alternative. Cargos are often containerized and removal (unpacking and treating) from the container is uneconomic. MB fumigation may be ordered before the commodity can be released for distribution and rejection or destruction remains the default option if the treatment is not carried out.
NPPOs may publish listings of approved treatments for imports, with specifications varying according to phytosanitary requirements of receiving countries and pest risk. MB may be specified as a quarantine treatment, but often there are also 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 5-5.

TABLE 5-5: EXAMPLES OF POTENTIAL PHYTOSANITARY TREATMENTS THAT CAN REPLACE OR REDUCE METHYL BROMIDE USE FOR QPS PURPOSES (IPPC 2008)

List of articles fumigated	Examples of phytosanitary treatments to consider to replace or reduce MB[2]
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

[2] 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 phytosanitary treatments to consider to replace or reduce MB[2]
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 atmospheres (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, now including dielectric heating (contained in Annex 1 of ISPM No. 15 and its revisions). 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
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
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

5.9.1. Alternatives to MB for nurseries exempted as QPS

In the US, MB continues to be used as a pre-plant soil fumigant for the production of various types of nursery materials under the QPS exemption. This exemption applies to a range of nursery industries, including strawberry runners, ornamental plants, turf, fruit and nuts.

This exemption also includes the forest nursery industry in the Pacific Northwest in States such as Washington and Oregon (Weilland *et al.*, 2013; Weilland *et al.*, 2016). Research into MB alternatives and into reducing fumigation rates with the use of high barrier films has reported that reduced rates of metham sodium and 1,3-D applied under Totally Impermeable Film® (TIF) were comparable to MB (also at reduced dosage under TIF) in particular for controlling *Fusarium* and *Pythium*, two of the most troublesome diseases affecting forest nurseries. Some additional adjustments in rates are still necessary, but it is apparent that these alternative fumigants can provide equivalent results for this application (Weilland *et al,* 2016).

In all other countries such a QPS exemption is not allowed and industries have sought alternatives. For instance, in the EU (MB was banned for all uses including QPS in 2010) the strawberry runner industry, which includes Spain, one of the largest producers of runners in the world, mainly use crop rotation, dazomet and metham sodium for pest and disease control, with good results (López-Aranda, 2016).

5.9.2. Cold Treatments

Cold treatments for controlling fruit flies in fresh produce are becoming more popular in the international trade for fruit and vegetables and were adopted by the IPPC CPM (Commission of Phytosanitary Measures). See those listed under the section on IPPC.

5.9.3. Heat

Heat, in the form of hot water, was first used as a disinfestation treatment to treat seed potatoes for late blight in 1882. Heat treatment has been used to control fungal, bacterial and viral diseases, plant-parasitic nematodes, and insect pests, but was shelved for about 50 years with the advent of nerve poisons (DDT, diazinon) and chemical fumigants including MB.

Heat treatments not only control pests and diseases, but are a benefit to certain plants by increasing rooting, budding, and vase life. Plants, sensitive to heat injury, can also be conditioned to tolerate heat treatments.

Hot water treatment for 45 to 49°C for 10 to 15 min disinfests flowers, foliage, potted plants, propagative cuttings, and media of many pests of quarantine significance, including ants, aphids, mealybugs, scale insects, plant-parasitic nematodes, snails, and slugs. Hot water dips of tropical propagative cuttings can be used to disinfest cuttings of insects, nematodes, and pathogens with the side benefit of increase in rooting.

Hot air at 40°C conditions plants, foliage, and flowers to tolerate hot water, and at 44°C controls thrips and other insects. Use of steam to pasteurize (65°C for >30 min) or sterilize (85°C for >30 min) plant media will disinfest the media of fungal and bacterial pathogens and plant-parasitic nematodes. Hara (2013) concluded that heat is an effective and sustainable postharvest pest and disease disinfestation treatment for export horticultural crops.

A serious postharvest pest of grain in much of Asia and quarantine pest for many countries of the world is *Trogoderma granarium* (khapra beetle). Wilches (2017) found the most cold- and heat-tolerant life stages were diapausing-acclimated larvae and diapausing larvae, which can be controlled to the highest quarantine level (Probit 9) with an exposure of 70 d to −15°C or 1.2 h to 60°C.

It is difficult to heat treat logs and some firewood because of the relatively large cross-sectional dimension. Compared with hot air, steam has a greater heat capacity, and the condensation, without reducing the moisture content of wood, results in more efficient heat transfer. Also, the pressure gradient created by vacuum accelerates heat transfer through the wood cross section. The vacuum–steam system consists of a vacuum source, a controlling device, a flexible container, and a steam generator. Chen (2016) treated ash log diameters from Virginia that ranged from 16.5 to 27.9 cm on the small end in lengths of 1.82 m. A vacuum of 300 or 500 mm Hg inside the container and steam was injected into the container. The steaming continued until the target 56°C was reached at the centre of the lengths. The treatment time for all the logs varied from 5.5 to 14.5 hours, including a vacuum and a holding time of 30 minutes (ISPM 15). The 1.82-m logs were cut into 40.6-cm-long bolts and then split into firewood, rarely larger than 15.2 cm on the wider side. The treatment time for firewood varied from 80 to 137 minutes, including a vacuum and a holding time at 56°C for 30 minutes at the core. There is no effect on quality, and the process can be tailored to different treatment capacities and is easily portable.

Chen also tested five high value hardwood veneer export log species in an effort to ascertain the feasibility of continued treatment development. Relative heating rates to log centre, damage and value loss assessment due to treatment, and overall energy used during treatment were recorded for logs treated individually in a flexible polymer chamber. At 200 mm Hg vacuum, time to reach 56 °C for 30 min to core ranged from 17 to 29 h, depending on density and log diameter. End checking varied by species, but veneer sawn from logs was largely unaffected in terms of yield and value. Energy used during treatments ranged from 54 to 205 kWh for individual logs. Results suggest that vacuum and steam as a phytosanitary treatment for hardwood veneer logs has potential.

5.9.4. Ethanedinitrile (EDN)

Trials demonstrate that EDN is a potential phytosanitary (QPS) alternative to methyl bromide for timber in several forms ansd situations.

Trials with EDN achieved 100% mortality of the European house borer *Hylotrupes bajulus* within 24 h, under an environment of 25°C and75% relative humidity (Emmery et al., 2015).

Najar-Rodriguez et al. (2015) compared the toxicity of EDN in the laboratory to that of reduced rates of MB, using different life stages of the burnt pine longhorn beetle, *Arhopalus ferus*. Naked insects were fumigated with MB at 10°C and 20°C for 4 h or with EDN at the same temperatures for 3 h. The mortalities achieved and the CT products calculated indicate that (1) a reduction in MB usage may be possible for the treatment of logs exported from New Zealand and that (2) EDN has potential as a phytosanitary alternative to MB for the treatment of logs. Pranamornkith et al (2014 ab) tested the control of burnt pine longhorn beetle (*Arhopalus ferus*) adults using a range of EDN concentrations. The LD99 for adults after a 3 h exposure at 15°C was 12.6 g/m3. Changes in the dosage of EDN did not affect the sorption pattern. Increased moisture content and end-grain sealing both reduced sorption, but these effects were relatively small and the differences in sorption patterns caused by moisture content or end-grain sealing decreased over time.

The sorption characteristics of EDN (syn. cyanogen, EDN Fumigas®) were quantified by Hall *et al*. (2015) for recently harvested pine logs, and a proposed EDN sorption model developed for sawn timber was tested, showing a high sorption rate as compared to other fumigants such as MB. A proportional drop in headspace concentration over time was consistent for the two doses evaluated (20 and 50 g/m3), confirming that EDN sorption is influenced by the dose applied. Bark cover did not significantly influence EDN sorption.

Pranamornkith *et al.* (2014a) studied EDN at dosages of 20 g/m3 or 50 g/m3, timber moisture content (green or kiln dried sawn timber), end-grain sealing (sealed or unsealed timber end-grain) and load factor (11% or 44%) on sorption of EDN by sawn timber at 15°C. This was quantified using headspace samples taken from 28-litre fumigation chambers. Chamber loading significantly influenced sorption, with higher loading resulting in greater sorption. Changes in the dosage of EDN did not affect the sorption pattern. Increased moisture content and end-grain sealing both reduced sorption, but these effects were relatively small and the differences in sorption patterns caused by moisture content or end-grain sealing decreased over time.

These same researchers tested the efficacy of ethanedinitrile for controlling burnt pine longhorn beetle adults (*Arhopalus ferus*) using a range of EDN concentrations. The LD99 for adults after a 3 h exposure at 15°C was 12.6 g/m3. The results demonstrate that EDN is a potential phytosanitary alternative to methyl bromide for disinfesting burnt pine longhorn adults from sawn timber exported from New Zealand.

In Japan, the pinewood nematode *Bursaphelenchus xylophilus* is a quarantine pest often associated with beetles of the genus *Monochamus* (pine sawyers) particularly *Monochamus alternatus*, which can disperse the nematodes to long distances causing widespread losses in pine forests. Park *et al*. (2014) conducted two fumigation trials on logs naturally infested with *M. alternatus* and *B. xylophilus*. The logs were treated with EDN at low temperature (-7-25.7°C and -3.7-23.1°C) for 3 days in winter and early spring. Results suggest that 97 g/m^3 of EDN gives complete control of *M. alternatus* in pine wood and that dosages above 158 g/m^3 are required for eradication of *B. xylophilus* at low temperature fumigation.

Bong-Su *et al*. (2015) verified the efficacy of EDN under different temperature conditions (5, 5-15, >15℃) and monitored its TLV (Threshold limited value) post-fumigation for worker safety. Fumigation doses of 30, 40 and 50 g/m^3 for 24hr for controlling ordinary pests of wood such as Japanese termite (*Reticulitermes speratus*) and bark beetle (*Cryphalus fulvus*), showed >99% efficacy at 5, 5-15 and >15℃, respectively. Doses of 100, 120 and 150 g/m^3 for 24 hr were also successful in achieving the required efficacy at 5, 5-15, >15℃, respectively, meeting quarantine guidelines for wood related pests such as the Japanese pine sawyer (*Monochamus alternatus*) and the pine wood nematode (*Bursaphelenchus xylophilus*). Recommended ventilation times with atmospheric conditions at ports were > 1 and > 2 hr under fully uncovered and partially uncovered tent conditions, respectively.

Monochamus alternatus Hope is an important vector of nematode pests of timber in Korea, particularly *Bursaphelenchus xylophilus*. Previously, Lee reported that ethanedinitrile (C_2N_2) has the potential to replace methyl bromide and Metham sodium to control *M. alternatus* larvae and B. xylophilus under low-temperature (<5C) conditions. Herein, Lee conducted fumigation trials of C_2N_2 over a 3-yr period (February 2013–October 2015) at higher temperatures. The trials were conducted under 24 different conditions that incorporated varying fumigation chamber types (plastic sheeting-enclosed chambers of differing construction or an ISO shipping container, interior size: 5.90 m length by 2.35 m width by 2.40 m height), log water content (24.1–43.5%), filling ratios (5, 20, and 40%), and temperatures (10.5–17.3º C). Highest concentration x time (Ct) product values were obtained with the ISO shipping container followed (in order of decreasing Ct values) by a 0.1-mm-thick, low-density polyethylene tarpaulin enclosure, a 0.1-mm-thick polyvinyl chloride (PVC) tarpaulin enclosure, and a 0.05-mm-thick PVC tarpaulin enclosure. The correlation between Ct product value and mortality of *M. alternatus* larvae was calculated with all treatment combinations. From this, the L (Ct) 50 and L (Ct) 99 values for C_2N_2 were determined to be 73.19 and 194.90g h m/3, respectively. Ethanedinitrile showed promise as a practical alternative fumigant for use on fresh pine logs infested by *M. alternatus* larvae.

The pinewood nematode *Bursaphelenchus xylophilus* and its insect vectors from the *Monochamus genus* are major global quarantine pests of timber products. Owing to the phase-out of methyl bromide for plant quarantine and preshipment treatments, an alternative fumigant is essential. Based on preliminary laboratory studies on the efficacy of ethanedinitrile (C_2N_2) to *B.xylophilus* and *Monochamus alternatus*, Lee *et. al.,* (2107ab) conducted three quarantine trials at three dosages and three temperatures. Potential for in halation exposure was assessed by monitoring atmospheric C_2N_2 in relation to the threshold limit value. Concentration time products (Ct) of 398.6, 547.2 and 595.9ghm−3 were obtained for each trial. A 100% mortality of *B.xylophilus* and *M.alternatus* larvae at 23±4∘C and 10±4∘ C occurred with a load factor of pine logs of 46% and at 3±1∘C with a load factor of 30%. During all fumigations, atmospheric levels of C_2N_2 20m downwind were below the TLV. During aeration, levels 10 and 5m downwind were below the TLV after 0.4 and 1h respectively.

For the purpose of quarantine or phytosanitary treatment, specific doses of C_2N_2 at the trial temperatures could control *B.xylophilus* and *M.alternatus* larvae without significant inhalation risk to workers.

Draslovka, a Czech-based firm, has applied for approval in 2018 to register and import ethanedinitrile (EDN) into New Zealand as an alternative to the fumigant methyl bromide which is used for export logs and timber at New Zealand ports. If agreement can be obtained from two main export markets some 500 tonnes of MB may be able to be replaced if registered.
https://www.epa.govt.nz/public-consultations/in-progress/new-fumigant-for-logs-and-timber/

5.9.6. Ethyl formate

Ethyl formate (EF) is a Generally Recognised as Safe (GRAS) plant volatile compound. It has been used in trials to reduce incidence of external pests on apples to acceptable rates for export markets. Mealybugs, scale insects, thrips and apple leaf curling midge on packed New Zealand apples are a concern for export markets. A treatment of 0.3% EF +CO_2 for 1 h controlled 99% of onion thrips and latania scale, and 0.81% EF + CO_2 for 1 h controlled obscure mealybug. Jamieson *et al*. (2015) found treatment concentrations and times required to control apple leaf curling midge (4.94% EF for 4 h) were beyond the apple quality tolerance level.

Yang *et al*. (2016) conducted a study to compare the effects of EF and phosphine (PH_3) as individual treatments, and of EF mixed with PH_3 as alternatives to MB for controlling citrus mealybug (*Planococcus citri)* adults, nymphs, and eggs. The combined treatment was significantly more effective; it was observed that the eggs were more tolerant than the nymphs and adults. In pineapples, a mixed treatment of EF + PH_3 achieved complete control of eggs at concentrations of 25.1/1.0 (EF/PH_3) mg/litre at 8º C with a 4 h exposure time. This combined treatment could offer shorter exposure times and less damage to perishable commodities at low temperatures, and could potentially be extended to controlling other quarantine pests of fruit and vegetables for which MB is currently used. Lee *et al*. (2016) investigated synergistic effect between EF and PH_3 for control of cotton aphid, *Aphis gossypii* in quarantine and preshipment treatment and result showed that 0.5g/m^3 of PH_3 combined with different levels of EF from 1.6 to 16.3 g/m^3 at 5 and 20º C for 2 hours, $L(Ct)_{50}$ and $L(Ct)_{99}$ values were greatly reduced in comparison with a single dose of EF or PH_3. The synergistic ratio (L(Ct) of EF alone/L(Ct) of EF+PH3) values of $L(Ct)_{50}$ and $L(Ct)_{99}$ for adult A. gossypii at 5º C were 4.55 and 2.33, at 20º C the ratio values of them were 2.22 and 1.45, respectively. Chhagan (2013) exposed New Zealand flower thrips (NZFT), *Thrips obscuratus* to a range of EF and pyrethrum-based postharvest treatments on apricots. The trials showed that EF+CO_2 or EF+N_2 were effective treatments against NZFT and caused negligible damage to apricot fruit quality. However, pyrethrum dipping did not effectively control NZFT and caused significant internal damage to apricot fruit.

Codling moth (CM, *Cydia pomonella*) is a pest of quarantine concern on apple exports to Asian markets. Apples exported to Japan must be fumigated with MB and then cold stored. Jamieson *et al*. (2016)

investigated EF as an alternative to MB, to control an internal pest such as CM by determining the responses of key insect stages without fruit and inside apples. Trials without fruit in a 2 h fumigation showed that late-stage CM eggs and third instar CM larvae were the most tolerant life stages, requiring a mean concentration of 1.34–1.94% EF to achieve 99% mortality, but 100% mortality of 4th/5th instar CM larvae. Trials with CM in fruit in a 2 h fumigation showed that 1.13% EF resulted in 53.4% mortality of $4^{th}/5^{th}$ CM larvae inside apples. Increasing the mean concentration to 2.4% EF increased the mortality of $4^{th}/5^{th}$ larvae inside apples to 85.2%.

Jamieson (2015) examined the tolerances of different life stages of tomato potato psyllid to EF, finding that eggs were considerably more tolerant than adults and nymphs. Complete elimination of egg hatch was achieved after a 1-h exposure to 1.19% EF. In contrast, all nymphs and adults were killed after a 1-h exposure to 0.12% and 0.06% EF, respectively. Assessment of egg mortality was altered to better reflect the post-hatch treatment effects on nymph survival. In a subsequent egg age tolerance trial, mean lethal concentrations for 99% mortality ranged from ca 1% EF for young and older eggs to ca 1.5% EF for mid-aged eggs.

Export of Pink Lady apples from Australia has been significantly affected by infestations of adult eucalyptus weevils (*Gonipterus platensis* Marelli). These weevils cling tenaciously to the pedicel of apple fruit when selecting overwintering sites. As a result, apples infested with live *G. platensis* adults are rejected for export. Agarwal *et al*. (2015) conducted laboratory experiments using a wide range of concentrations of ethyl formate. Complete control (100% mortality) was achieved at 25–30 mg/liter of ethyl formate at 22–24°C for 24-h exposure without apples. However, with 90–95% of the volume full of apples, complete control was achieved at 40 mg/liter of ethyl formate at 22–24°C for 24-h exposure. No phytotoxicity was observed and after aerating for one day, residue of ethyl formate declined to natural levels (0.05–0.2 mg/kg). Five ethyl formate field trials were conducted in cool storages and 100% kill of eucalyptus weevils were achieved at 50–55 mg/litre at 7–10°C for 24 h. Long-tailed mealybug (*Pseudococcus longispinus*) and citrus mealybug (*Planococcus citri*) are sometime present in Australian table grapes and grapefruits. Quarantine restrictions in some markets require MB fumigation but phytotoxicity and reduced shelf life make MB treatment unattractive. Fumigations with EF and CO_2 for 2.5 hours in export cartons in simulated cool down from 15 to 10º C were found to control mealybugs without damaging the produce (Lima (2015). Insects hiding in longkong (*Aglaia dookoo* Griff.) clusters cause a serious problem in exporting the fruit. Pannasee *et al.* (2015) showed EF at 75g/m^3 for 6 hours completely eradicated black ants (*Technomyrmex* sp.) and mealybug (*Exallomochlus hispidus*). EF at 25 g/m^3 in combination with 50% CO_2 was also found to completely eradicate the black ant and the mealybug. However, the combined treatment reduced the effect of 1-MCP in controlling postharvest fruit abscission.

Vapormate was also evaluated in South Africa. Grout and Stoltz (2016) reported that South African fruit is sometimes rejected for export due to the presence of live arthropods that are not considered pests of the fruit concerned. They fumigated *Macchiademus diplopterus* at a dosage of Vapormate 250 g/m3 for 4hrs resulting in no survivors out of >35,000 *M. diplopterus* fumigated. A small-scale trial using the same ethyl formate treatment also killed the arboreal mite *Siculobata sicula*. The treatment conditions did not appear to have phytotoxic effects on pears or oranges, unless they had prior mechanical injuries that were accentuated.

Bessi et al. (2016) reported results of fumigating dates of the Deglet Nour variety with EF. A laboratory scale test revealed that the most efficient combination was 143 g/m3 of EF for 2 h, which led to 98.12% mortality of the most resistant larvae stage of the carob moth (*Ectomyelois ceratoniae*). In a semi-industrial scale treatment with Vapormate, the mortality rate was further improved, reaching 100%. No changes in fruit quality were observed after fumigation.

Ethyl formate vapour is highly flammable with a lower flammability limit of 2.8% in air. While this is above typical fumigation concentrations, it needs dilution in practice to below the flammability limit from its liquid or concentrated form. This may be done by dilution with CO_2 as in the Vapormate formulation or in a stream of CO_2 as described by Navarro and Navarro (2016) in their full scale trials with ethyl formate on grain. Alternatively the ethyl formate may be volatilised in a stream of nitrogen gas, as per Yang et al. (2016), who describe this technique as used for disinfestation of oranges imported into South Korea.

Ethyl formate (EF) has been categorised as a full control fumigant with action against citrus mealybugs, adults of the Californian red scale and all stages of Fuller's rose weevil within 6 h, at dose rates of 20 g/m³, 61.8 g/m3 and 60.1 g/m³, respectively at 15°C and a fill rate of 40%. Eucalyptus weevils attacking Pink Lady apples did not survive a 24 h treatment with 30g/m³ of EF at 25°C or 50 g/m³ at 4-8°C (Agarwal et al. 2015).

5.9.7. Irradiation

E-beam (electron beam) irradiation systems have progressed to the point that they might make irradiation more available for phytosanitary uses in the near future. Essentially, x-rays are generated electronically, and therefore, the radiation source can be turned on and off at will, a fact that makes e-beam technology more acceptable than cobalt-60, and require less oversight and regulation. This technology has been available since the late 1990's, but is finally moving into the early implementation stages for phytosanitation in the United States. However, phytosanitary regulatory agencies sometimes require rates that are damaging to the goods, and more research is needed to improve technical data on the minimal rates actually required for adequate phytosanitation (Hallman 2016). Although radiation has been around a long time, its use was somewhat limited in the United States, partly due to low consumer acceptance of irradiated goods, and economic cost. Whether the new e-beam technology will have higher acceptance and economic feasibility is not yet clear.

More companies are now offering improved and new machines. The manufacturers endeavour to cover a broad spectrum of energy and power and improve the reliability and durability. In order to reduce the initial investment, they are also offering a modular approach by which the power of the machine can be increased by steps, for example by adding another power supply unit. Many are now portable.

Melbourne Market, Australia is to build a new X-ray treatment for phytosanitary treatment measure against fruit flies, using cutting-edge new technology for fresh horticultural produce that enables growers to meet export market access requirements. It is also a viable alternative to chemical treatment or prolonged cold storage of product.

Irradiation is a postharvest treatment option for exported berries and berry-like fruits to prevent movement of the quarantine pest European grape vine moth, *Lobesia botrana* (Denis & Schiffermüller) (Lepidoptera: Tortricidae). The effects of irradiation on egg, larval, and pupal development in *L. botrana* were examined by Nadal (2018) . Eggs, neonates, third and fifth instars, and early- and late-stage pupae were irradiated at target doses of 50, 100, 150, or 200 Gy or left untreated as controls in replicated factorial experiments, and survival to the adult stage was recorded. Tolerance to radiation generally increased with increasing age and developmental stage. A dose of 150 Gy prevented adult emergence in eggs and larvae. Pupae were more radio tolerant than larvae, and late-stage pupae were more tolerant than early-stage pupae. In large-scale validation tests, 150 Gy applied to fifth instars in diet prevented adult emergence, but some survival occurred in fifth instars irradiated in table grapes; however, 250 Gy prevented fifth instar survival in grapes. For most commodities, the fifth instar is the most radio tolerant life stage likely to occur with the commodity; a minimum radiation dose of 250 Gy will prevent adult emergence from this stage. For traded commodities such as table grapes that may contain *L. botrana* pupae, 325 Gy applied to mature female pupae sterilized emerging adults and may provide quarantine security. Radio tolerance in *L. botrana* is comparable to other tortricids, and the data reported here support a generic dose of 250 Gy for eggs and larvae of this group.

5.9.8. Methyl iodide

In Japan, methyl iodide is still under study as a potential fumigant for controlling superficial pests such as aphids (*Aphis craccivora*, *Myzus persicae*), mealybug (*Planococcus citri*), mites (*Tetranychus urticae*, *T, kanzawai*) and thrips (*Frankliniella intonsa*, *Thrips tabaci*) on fresh fruit and vegetables. 20-30 g/m^3 for 2 h at 10°C or higher and 40-61 g/m^3 for 3 h at 10°C or higher were recommended to control those insect pests as quarantine treatment schedules (Naito *et al*. 2014 and Naito *et al*. 2015). For controlling granary weevil (*Sitophilus granarius*), susceptibilities of pupa and adult stages were investigated in fumigated with methyl iodide for 24 hours at 15º C and found that pupal stage was seemed to be less susceptible than adult. Under 24 hours fumigation, dosages of 2.0 mg/l to 3.5 mg/l were required to kill all individuals of pupal stage tested at 10 to 20º C, and fumigations with dosages of 1.6 mg/l to 2.8 mg/l at 10 to 20º C were able to kill all individuals of adult stage (Nishizaki *et al*. 2017).

5.9.9. Phosphine

Variations of conventional phosphine fumigation are under investigation as treatments against quarantine pests and miscellaneous pests often associated with various perishable commodities. Approaches include treatments with cylinderised phosphine in CO_2 (ECO2FUME®), phosphine at low temperatures (e.g. 5°C) and treatments with phosphine under raised oxygen concentrations.

Indonesia has projects for replacing MB used for QPS (reported usage is >150 tonnes per year) with the phosphine + CO_2 mix known as ECO2FUME®. This is used to treat exported woodchips as well as coffee, cocoa beans and other exported commodities requiring QPS treatments (Tumambing 2013). Indonesia has developed a QPS phosphine fumigation protocol manual (Salazar, 2014).

ECO2FUME® has recently been registered in Morocco (ONSSA 2015) for grain fumigation.
In Turkey, ECO2FUME® efficacy trials have been conducted to establish QPS fumigation protocols for export cut flowers (carnation, gerbera and roses) against thrips (*Frankliniella occidentalis*) and mites (*Tetranychus cinnabarinus*) at 4°C.Trials with ECO2FUME® for dried fruits have been also conducted to control saw-toothed grain beetle (*Oryzaephilus surinamensis*) and raisin moth (*Ephestia figulilella*), where100% mortality of all stages of these pests was achieved using 1000 ppm PH3 (70 g ECO2FUME®/m3) for 24 h at 23°C or higher (Salazar, 2014).

In Korea, efficacy trials withECO2FUME® have been conducted to control eggs and adults of various insects on strawberries (1,100 ppm, 24 h, 2°C or 600 ppm, 24h, 10°C), cherry tomato (25 ppm, 24 h, 13°C), paprika (30 ppm, 24 h, 13°C), cut flowers (1,400 ppm, 24 h, 8°C) and nursery trees (1,400 ppm, 48 h, 15°C) (Salazar, 2014)

Sitophilus granaries is a quarantine pest in Japan, though widely distributed elsewhere. Whenever live specimens of granary weevil (*Sitophilus granarius*) are detected, consignments are fumigated with MB as this is the only fumigant specified for such events in Japanese import plant quarantine regulations. Fumigation with PH_3 is not permitted, as its efficacy against pupal stages of Sitophilus spp is low (Mori and Kawamoto, 1966). Research aimed at reducing MB use for this QPS application is being conducted. Ishige *et al*. (2017) have worked on a PH_3 fumigation standard to kill *S. granarius* which considers treatment conditions, sorption onto stored grains and preliminary mortality tests, in order to establish a treatment schedule. Mortality tests showed complete kill of *S. granarius* at a dose of 2.0 mg/l with a loading factor of 0.5 kg/l or below for 24 days at 10–15C, for 16 days at 15–20º C, for 7 days at 20–25º C and for 5 days at 25–35º C. Negative effects were stringently assessed but not found. Nishizaki *et al*. (2016) studied the survival of *S. granarius* on grain and beans when using PH_3. Twelve different products were examined (corncob meal, corn gluten feed, cotton-seed, flax-seed, rapeseed, rapeseed meal, safflower seed, sesame seed, sorghum, soybean, soybean meal and wheat-bran pellets) and it was found that a new generation of adults occurred in wheat-bran pellets and sorghum, but not in the other materials. The pest also survived in impurities from corncob meal, flax seed and safflower seed. The study further showed that in a single generation, adult *S. granarius* survived more than 40 days on wheat-bran pellets and sorghum, but only 20 days or less on the 10 remaining grains or foodstuffs.

In Thailand, all orchid cut-flowers are normally fumigated with MB for postharvest control of thrips before export. Therefore, in the project that is aimed to evaluate MB alternative, Deewattnanawong *et al.* (2017) found that there was no damage to orchid cut-flowers (*Dendrobium Sonia* 'No. 17') in PH_3 fumigation and PH_3 4 g/m^3 for 1 hour was sufficient to obtain 100% mortality of second instar larvae of thrips.

Kim *et al.*(2015) investigated effect of PH_3 and synergistic effect of PH_3 under controlled atmospheres of 50 and 80% oxygen to all developmental stages of the potato tuber moth (*Phthorimaea operculella*) and resulted that larval stage was the most susceptible to fumigation with PH_3 at both 5º C and 20º C. All of the developmental stages showed greater susceptibility to PH_3 at 20º C than at 5º C whereas the susceptibility of adult was not affected by the temperature. Toxicity of phosphine toward all developmental stages at both temperatures was increased at higher oxygen concentrations.

Liu (2015) subjected light brown apple moth, *Epiphyas postvittana* (Walker), eggs to oxygenated phosphine fumigation treatments under 70% oxygen on cut flowers to determine efficacy and safety. Five cut flower species: roses, lilies, tulips, gerbera daisy, and pompon chrysanthemums, were fumigated in separate groups with 2,500 ppm phosphine for 72 h at 5°C. Egg mortality and postharvest quality of cut flowers were determined after fumigation. Egg mortalities of 99.7–100% were achieved among the cut flower species. The treatment was safe to all cut flowers except gerbera daisy. A 96-h fumigation treatment with 2,200 ppm phosphine of eggs on chrysanthemums cut flowers also did not achieve complete control of light brown apple moth eggs. A simulation of fumigation in hermetically sealed fumigation chambers with gerbera daisy showed significant accumulations of carbon dioxide and ethylene by the end of 72-h sealing. However, oxygenated phosphine fumigations with carbon dioxide and ethylene absorbents did not reduce the injury to gerbera daisy, indicating that it is likely that phosphine may directly cause the injury to gerbera daisy cut flowers. The study demonstrated that oxygenated phosphine fumigation is effective against light brown apple moth eggs. However, it may not be able to achieve the probit 9 quarantine level of control and the treatment was safe to most of the cut flower species.

5.9.10. Review of log treatments

Armstrong *et al.* (2014) have reviewed over 30 fumigants for treating logs; the review did not include PH_3 as it is already being used for around 65% of New Zealand export logs needing treatment, saving an estimated 1,200 tonnes of MB per year. The review identified:

- *EDN*, which is currently under study as a MB alternative for export logs in New Zealand, was recommended for further study. Studies determining the efficacy of EDN on the life stages of Burnt pine longhorn beetle, *Arhopalus ferus* (Mulsant) and the effects of dosage, moisture content, end-grain sealing, and load factor on EDN sorption rates have been carried out.

- *Sulfuryl fluoride*, a common timber and structural fumigant for termites, was a distant second possibility. Environmental issues and the difficulty with efficacy against insect eggs cannot be overlooked. However, if EDN is rejected registration sulfuryl fluoride has positive characteristics that make it the only additional fumigant alternative to MB that can be recommended for further study.

- Research in New Zealand is addressing the potential for using reduced rates and/or fumigation times when MB is used to control forest insects. Although this research obviously is not a "methyl bromide alternative", positive results from this research could translate into significant reductions in MB use and cost savings to the log export industry. Hence, continued research on reduced MB rates was recommended.

The review further looked at non-chemical treatments and methods, including controlled and modified atmospheres, energy treatments (irradiation, microwave, electrical, and infrared), physical treatments (cold, heat, pressure, and vacuum), log debarking, pest management systems, and systems approaches.

The most relevant recommendations were: *Combined heat and modified atmosphere*: Based on work done in 1997 by Dentener *et al*. that showed significant efficacy of CO_2 or nitrogen at 40°C for controlling *Prionoplus reticularis* in less than 7 h, modified atmospheres plus heat should be further studied as a non-toxic treatment for New Zealand export logs under commercial conditions. *Debarking*: A significant proportion of logs are already debarked for export and further studies are needed to determine if in-forest debarking at point of harvest can meet phytosanitary requirements. This would establish a technological and economic baseline from which to compare the costs of alternative treatments.

5.9.11. Sulfuryl fluoride

Sulfuryl fluoride was subject of investigations as a suitable quarantine treatment fumigant against the khapra beetle *Trogoderma granarium* (Myers and Ghinmire, 2014).

In 2018 the use of sulfuryl fluoride fumigation for insects and nematodes in debarked wood approved as a treatment for wood packaging in trade under ISPM 15.The ISPM 15 standard had approved treatments besides MB fumigation before 2018 (heat treatment) however limitations to their adoption may exist, for example the need of electric power supply or tempetature control devices. The approval of SF as another chemical option provides a new tool for compliance with ISPM 15. There are two schedules of sulfuryl fluoride treatment in ISPM 15 which prescribed minimum required CT (g·h/m3) are 1,400 g h m-3 for 24 hours and 3,000 g h m-3 for 48 hours at 30º C or above and at 20º C or above, respectively.

SF was also approved by both Australia and New Zealand for the quarantine treatment of the brown marmorated stink bug (*Halyomorph halys)* associated mainly with imported vehicles and machinery from multiple countries (see Facilities and Pathways Group (2018) for discussion of treatment options).

5.9.12. Other treatments

Promising non-chemical alternatives include irradiation (Hallman 2016; Nadel *et al.* 2018), heat and cold treatment, bark removal and vacuum/ controlled atmospheres (UNEP, 2016)

A process treatment which is a treatment using a process of heating in food process at a factory that is considered enough to kill insect pests. A process treatment is utilized in Japan since 2004 for imported corn or maize seeds destined to be processed to a cornstarch. Basically, imported corn or maize seeds must be fumigated with MB or aluminium phosphide when plant quarantine pest is detected in the import plant quarantine inspection. However, corn or maize seeds exclusive use for corn starch producing are not required the fumigations and the process those corn or maize seeds gone through is approved as an alternative treatment. In the process treatment, the seeds need to be securely treated with hot water immersion at either 40ºC for 24 hours or 45ºC for 5 hours, and impurities collected during the process must be also properly treated with incineration, fumigation or other approved methods (MAFF, 2004). This process treatment is expected to expand to food processing for extracting edible oil from imported grains such as wheat, maize and soybean because the oil extracting process is also includes heating process.

5.10. Reducing emissions and improving efficiency of MB treatments

For discussion on implementation of recapture of MB after completion of fumigations as a means of reduction of emissions to atmosphere see Section **.

Research continues to optimize MB treatments in QPS situations to reduce emissions while maintaining efficacy.

A research program was instigated to develop a new protocol for the export of Australian capsicums to New Zealand. Australian capsicums are currently exported to New Zealand with MB fumigation at a dose of 40g m^3 methyl bromide for 2 hours at 17°C, however this treatment results in reduced fruit quality. Wyatt (2015) investigated the efficacy of fumigating with lower concentrations of methyl bromide applied over longer treatment times with the aim of determining a dose efficacious against fruit flies and within the tolerances of the fruit.

Capsicums (*Capsicum annuum*) were fumigated with MB at a nominal treatment dose of 18g m^3 at 18°C for 5 hours as a quarantine disinfestation treatment against Queensland fruit fly, *Bactrocera tryoni* (Diptera: Tephritidae). Three large scale trials were conducted against each of the four immature life stages, eggs, first, second and third instars. There were no survivors from the estimated 35,551 eggs, 53,720 first instars, 40,371 second instars and 43,901 third instars treated in capsicums, thereby resulting in an efficacy of >99.99% mortality at the 95% confidence level for each life stage.

Commercial fruit were also fumigated under the same conditions and then held at 6°C for 16 days or 6°C for 10 days followed by 10°C for 6 days. This simulated transport at 6°C followed by retail display at 10°C. Fruit quality parameters of weight loss, total soluble solids and external quality including, visual appearance, skin wrinkling, skin pitting, and incidence and severity of rots were assessed and no significant adverse treatment effects were present.

The new protocol uses roughly half the concentration of fumigant but applied for double the treatment time to maintain the efficacy against Queensland fruit fly, a significant quarantine pest in Australia. Whilst the reduction in quantity of methyl bromide used is environmentally beneficial, the research was instigated to improve out-turn quality of the treated capsicums. The existing protocol for capsicum impacts fruit quality while the lower dose tested in our research had no significant effects on the range of fruit quality attributes tested.

Subsequent research in nectarines and peaches achieved complete mortality of all life stages with a dose of 18g m-3 methyl bromide at 18°C for 5.5 hours and has resulted in a new protocol for the export of Australian nectarines to China. The research has now been extended to develop low-dose fumigation schedules for apple, pear, table grape, mango, plum, strawberry and citrus.

5.11. Changes in fumigation regulations for imported goods

India used to fumigate imported goods with MB on arrival but is now imposing a rule whereby these will need to be treated at origin, before export. This rule is impacting trade in several commodities, for example teak log exports from Latin American countries, and exports of pulses from Canada, where MB use is minimal or no longer exists, even for QPS (see for example https://www.fcc-fac.ca/en/ag-knowledge/marketing/tricky-trade-situation-with-india-averted-for-now.html). India has continually extended the on arrival fumigation permit due to difficulty in fumigating at origin due to low temperatures for pulses.

Ecuador has come to a bilateral agreement with India whereby Indian authorities have accepted pre-shipment fumigation of teak logs with 3g/m^3 of phosphine gas (aluminium phosphide/ magnesium phosphide of 56% or more, 3 tablets/ m^3) for 7 days. Ecuadorian fumigators conducting the treatment must be accredited by the Indian NPPO, which takes place through a direct technical visit (India Min of Agric. 2017).

5.12. International Plant Protection Convention (IPPC)

With the aid of the Ozone Secretariat, MBTOC has taken steps to reactivate the Memorandum of Understanding (MOU) between the Ozone Secretariat and the International Plant Protection Convention (IPPC), which was drawn in 2012 to *"Promote and facilitate collaboration between the Montreal Protocol and the IPPC through joint participation of technical experts in the technical panels and committees of both treaties, such as the Methyl Bromide Technical Options Committee, the Technical Panel on Phytosanitary Treatments and the Expert Working Group on Alternatives to Methyl Bromide, to enhance communication and advice consistent with the aims of both agreements."*

On the basis of MOU, MBTOC maintains regular communication with relevant bodies of IPPC dealing with phytosanitary measures and standards where MB is of interest.

The IPPC has now approved and published 26 international approved treatments in recent years for use on a combination of fresh produce, wood or pest specific treatments through the work of the Technical Panel on Phytosanitary Treatments. Treatments can take three to nine years to progress through to approval depending on the quality of the data presented. Once approved it allows international trade to occur for that pest and or commodity combination.
Irradiation treatment for *Anastrepha ludens*, *Anastrepha obliqua*, *Anastrepha serpentine*, *Bactrocera jarvisi*, *Bactrocera jarvisi*, *Bactrocera tryoni*, *Cydia pomonella*, fruit flies of the family *Tephritidae* (generic*), Rhagoletis pomonella, Conotrachelus nenuphar, Grapholita molesta, Grapholita molesta under hypoxia, Cylas formicarius elegantulus, Euscepes postfasciatus , Dysmicoccus neobrevipes, Planococcus lilacinus and Planococcus minor, Ceratitis capitate* and *Ostrinia nubilalis*.

Cold treatment for *Bactrocera tryoni* on *Citrus limon*, Bactrocera tryoni on *Citrus reticulata* x C. sinensis, *Bactrocera tryoni* on *Citrus sinensis*, *Ceratitis capitata* on *Citrus sinensis*, *Ceratitis capitata* on *Citrus reticulata* × *C. sinensis* and *Ceratitis capitata* on *Citrus limon*.
Vapour heat treatment for *Bactrocera melanotus and Bactrocera xanthodes on Carica papaya* and *for Bactrocera cucurbitae* on *Cucumis melo var. reticulatus.*
Sulfuryl fluoride fumigation treatment for insects in debarked wood and treatment for nematodes and insects in debarked wood.

The full list and descriptions of the treatments are available at: https://www.ippc.int/en/core-activities/standards-setting/ispms/

The Technical Panel on Phytosanitary Treatments (TPPT) evaluates data submissions from NPPOs and RPPOs and reviews, revises and develops phytosanitary treatments. The TPPT also provides guidance to the Standards Committee (SC) regarding specific phytosanitary treatment issues. The TPPT evaluates treatment submissions against requirements in ISPM 28 (Phytosanitary treatments for regulated pests). TPPTreports are available under: https://www.ippc.int/en/core-activities/standards-setting/expert-drafting-groups/technical-panels/technical-panel-phytosanitary-treatments/

Other lists of quarantine treatments are available at:
https://www.eppo.int/RESOURCES/eppo_standards/pm10_phytosanitary_treatments
https://www.aphis.usda.gov/import_export/plants/manuals/ports/downloads/treatment.pdf

https://www.mpi.govt.nz/.../1555-approved-biosecurity-treatments-for-risk-goods

http://www.pps.go.jp/english/law/list2-2.html
http://www.inspection.gc.ca/plants/horticulture/imports/treatment-schedules/eng/1501526269211/1501526560731
Systems approach is increasing being used such as this example with controlling Pests of Korean Concern associated with Chilean Blueberry:
http://www.sag.cl/sites/default/files/plant_quarantine_import_requirements_for_fresh_fruits_of_blueberry_from_chile_20170623.pdf

The IPPC Standards committee has two quarantine treatment related documents out for consultation:
2018 Second Consultation: Draft ISPM: Requirements for the use of fumigation as a phytosanitary measure
2018 First Consultation: Draft ISPM: Requirements for the use of modified atmosphere treatments as phytosanitary measures

5.13. Remaining challenges

As stated earlier, confusion persists with the correct classification of QPS uses under the definitions of the Protocol. The preshipment definition is unique to the Protocol and does not apply to the control of quarantine pests: "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. Official requirements are those which are performed by, or authorized by, a national plant, animal, environmental, health or stored product authority;"
The IPPC "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.

Cox (2017) undertook a survey of QPS and non-QPS used in Australia over the period 2013 – 2016 inclusive and identified total methyl bromide use over this period was approximately 2,841 tonnes (693 tonnes in 2016) of which, 50% was used for export shipments, 7% for import and 43% for pre-shipment purposes. The survey shows that methyl bromide use as a percentage of trade has decreased by approximately 6% over the period, a saving of 42t in 2016.

Cox concluded that the impediments to uptake of MB alternatives are the requirements for proof of efficacy and approval of alternatives for quarantine purposes by regulatory authorities, and concomitant acceptance by trading partners. This is in addition to cost, operational and logistical inconvenience, commercial competitive pressure and lack of regulatory or financial incentives to install recapture systems or change to methyl bromide alternatives. Manufacturers are actively engaged in proving efficacy of a number of alternative fumigants (notably sulfuryl fluoride and ethanedinitrile).

Recently sulfuryl fluoride has been approved for the international trade in wood packaging by the IPPC, however the high dosage (120g/m3) and the high global warming potential of sulfuryl fluoride with a high global warming potential similar to CFC-11 (Muhle 2009) it is unclear why MBTOC and the IPPC continues to promote such as fumigant given the Protocol is now addressing other GWP gases.

Existing and near market alternatives to methyl bromide for various QPS applications include sulfuryl fluoride, phosphine, ethanedinitrile, low oxygen treatments, heat and cold treatments and irradiation. Of these sulfuryl fluoride and ethanedinitrile have the potential to replace almost 210 tonnes (2016 usage) of methyl bromide for timber treatment and the manufacturers are engaged in the process of obtaining appropriate approvals for quarantine use.

Recapture technologies currently exist that over the survey period would have been capable of recapturing 1538 tonnes of the methyl bromide that was used during the period 2013-2016 for disposal.

The uptake of recapture to prevent the emissions reaching the ozone layer will be addressed in part through regulatory controls on fumigant emissions to meet air quality standards as they have the potential of creating a level commercial playing field that will facilitate uptake of recapture technologies and alternatives. This is the situation in New Zealand where a ban on emissions from any use of MB will come into force in 2020 and all Parties involved in are working to meet the impending standard.

5.14. References

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6

Chapter 6. Alternatives to Methyl Bromide for Pre-plant Soil Treatment

6.1 Introduction

The first use of methyl bromide (MB) as a soil fumigant occurred simultaneously in France, Australia and the USA (California) in the 1930s. Since its discovery and implementation, MB has been consistently effective for control of nematodes, fungi, insects and weeds and has been used on more than 100 crops worldwide. Its high vapour pressure allows for rapid and thorough distribution through the soil, which enhances its effectiveness as a fumigant and allows for a relatively short plant-back interval, giving growers great flexibility.

Past MBTOC Assessment Reports (MBTOC 2003, 2007, 2011 and 2015) have included detailed information and analysis on alternatives to MB for virtually all controlled uses. The reader is encouraged to refer to these publications. Given that at present, over 98% of such controlled uses have been successfully replaced, this chapter focuses more specifically on remaining uses and also provides a historical perspective of alternatives adopted by countries which were large MB users in the past.

Since MBTOC's 2014 Assessment Report (MBTOC 2015), implementation and performance of MB alternatives has been improved and new options have been developed. However, there are instances where regulatory barriers, cost and environment conditions (e.g. soil types and temperatures) may restrict their adoption. A few cases have proven particularly difficult to replace: in non-A5 Parties strawberry runners (Canada and Australia) and in A5 Parties strawberry fruit and tomato (Argentina) (MBTOC 2018).

January 1st 2015 marked the phase-out deadline for controlled uses of MB in A5 Parties, ten years after non-A5 Parties. As of that date, controlled uses of MB have been only allowed under the Critical Use Exemption (CUEs). By the end of 2017, official reporting indicated that about 99% of the global consumption baseline (all Parties) for controlled (non-exempt) uses had been replaced with alternatives (with some re-categorized to QPS).

Since 2005, the total amount of MB requested for critical use nominations (CUNs) has fallen from 18,700 t to 150 t for 2019/2020. In 2005, more than 120 critical uses were requested by 10 non-A5 Parties plus the European Union; in 2018, now with A5 Parties included, MBTOC received six nominations totalling 123.761 tonnes of MB for use in 2019 (five nominations) and 28.98 tonnes for 2020 (one nomination) (TEAP, 2018). This shows a clear trend towards successfully replacing MB for controlled uses globally.

This chapter focuses on economically and technically feasible chemical and non-chemical alternatives for pre-plant soil fumigation. Over the years, MBTOC has identified a range of key chemical alternatives that perform consistently across most regions and sectors. 1,3-D/Pic, Pic alone, a 3-way treatment involving 1,3-D, Pic and metham sodium, DMDS and new formulations and mixtures of chemicals are now in wide use. Non-chemical alternatives have also been developed and include resistant cultivars, grafting, substrates, steam, solarisation, biofumigation, organic amendments, anaerobic soil disinfestations (ASD) and biological control.

There are numerous examples of key productive sectors around the world in both A5 and non-A5 countries previously using MB, which have successfully adopted alternatives over a wide range of cropping systems. It has become clearly evident however, that no single chemical or non-chemical alternative will fully replace MB as a soil fumigant, and that a combination of treatments within an IPM program most often yields the best results. Soil treatments may be limited in their efficacy in specific areas due to, for example the availability of active ingredients, climatic factors, cultural practices, regulatory constraints and economic issues. Since the 2014 Assessment Report, a large number of research and review articles on alternatives to MB have been published, providing Parties with information on their relative effectiveness for a wide range of productive sectors.

6.2. Alternatives for soil uses – general overview

6.2.1 Chemical alternatives

Chemical fumigants (e.g. Metham sodium, dazomet, 1,3 D alone or combined with cholopicrin (Pic,) dimethyl disulfide (DMDS) and others) are widely used around the world and have successfully replaced MB. In Europe for example, strawberry runner production continues to increase even though MB was restricted to critical uses in 2005 and then entirely banned for all uses in 2010 (Meszka and Malus, 2014; Wu *et al.* 2012, López-Aranda, 2016, Yucel *et al* 2018).
DMDS has been researched extensively and is now labeled for preplant soil fumigation in many countries. It can be applied by shank injection or drip application and has proven effective for controlling a broad spectrum of soil-borne weeds, pathogens, and nematodes. In the USA, DMDS is commonly mixed with chloropicrin prior to application and this combination is very effective. Biofumigants are also beginning to be used by growers in many countries (Hansen 2014; Khaduri *et al*. 2017).

Metham sodium (MS) can be used as a substitute for Pic in locations or seasons where it is allowed but Pic is not. Where nutsedge (*Cyperus* spp) infestations are high, a combined application of DMDS and MS, was found more effective than DMDS alone, and in addition controlled other weed species. DMDS, when registered in EU, will thus be an effective chemical for nutsedge control in field crops and nurseries. In all cases, DMDS solutions proved comparable to 1,3 D/Pic in both shank and drip applications and, where registered, is an effective option for controlling nematodes, soil fungi and weeds in strawberry production. (Freeman *et al* 2018, Myrta *et al* 2018, Le Roch 2018, Zanon *et al* 2018).

6.2.2 Non-chemical alternatives

A wide range of non-chemical alternatives to MB continue to be trialled around the world. Many researchers report successful results with different options in a variety of crops, for example:

- Disease-resistant cultivars and grafting desirable varieties onto resistant rootstocks: (Arwiyanto *et al.,* 2018; Bogoescu *et al.,* 2018; Lemonakis, 2018; Koufakis and Kintzonidis, 2018; Besri, 2008; Chandrasekar *et al*., 2012; Erin *et al.*, 2013).

- Soil-less culture : (Thomas *et al*., 2011; Fennimore *et al*., 2013 ; Evenhuis *et al.,* 2014; Colla *et al*., 2012; Pugliese *et al*., 2014; Marcic and Jakse, 2010).

- Anaerobic soil disinfestation: (Muramoto *et al,* 2017; Kobara *et al.*, 2017; Mazzola *et al.*, 2017; Momma *et al.*, 2017; Rosskopf *et al.*, 2018; Muramoto *et al.*, 2018; Shennan *et a.,l* 2018; Meints 2018; Kobara *et al.,* 2018).

- Biofumigation and organic amendments: (Argento *et al*., 2013; Arnault *et al*., 2013; Avato *et al.*, 2013; Gilardi *et al.*, 2018[a]; Pugliese, 2018; Fernandez Bayo *et al*., 2018; Cao, 2018).

- Solarisation : (Katan and Gamliel, 2010, 2012; Tjamos *et al.*, 2018; Gamliel *et al*., 2018).

- Biosolarisation: (Chamorro *et al.,* 2015; Tjamos *et al*., 2018).

- Trap cropping: (Cerruti *et al.*, 2010; Westerdahl, 2018).

- Hot water: (Fujinaga *et al.,* 2005; Gyoutoku*et al*., 2007; He, 2018).

- Biological control: (Hu *et al.*, 2016; Kokalis-Burelle, 2014; Roberts *et al*., 2014; Dara *et al.,* 2018; Gilardi *et al.,* 2018).

- Microwaves (Vintila, 2018).

A combination of treatments within an IPM program continues to be reported as the most effective approach (Gamliel *et al.*, 2018; Gamliel, 2018; Cao, 2018; McDonald *et al.*, 2018; Gilardi *et al.,* 2018).

6.3 Alternatives adopted in key crops using MB in the past

This section includes tables showing alternatives adopted by key sectors where MB was once used, in both A5 and non-A5 countries, namely vegetables (tomato, peppers, eggplants), cucurbits (melon, watermelon, cucumber), strawberry fruit, ornamentals (cut flowers, pot plants), nurseries (strawberries, raspberry, forest and fruit trees, ornamentals) (MBTOC, 2018).

6.3.1. A5 countries

The following tables summarise the main alternatives adopted in different A5 regions for key crops using MB in the past, and approximate amounts of MB phased-out in the process.

6.3.1.1. Latin America

Table 6-1 illustrates on alternatives adopted in Latin American countries, namely Argentina, Brazil, Chile and Mexico, which were amongst the largest MB users in the past.

TABLE 6-1: MAIN ALTERNATIVES TO MB ADOPTED IN SOME LATIN AMERICAN COUNTRIES FOR PRE-PLANT SOIL FUMIGATION

Country	MB (t) phased out 2000 - 2017	Single or combined alternatives taken up in 2017/ proportion of previous MB use replaced **	Key references
Argentina Baseline: 686t	Tobacco 230 t	Floating trays + metham sodium/ 100%	Biaggi *et al.*, 2011
	Tomatoes and peppers (protected) 350 t	Solarisation + steam + metham sodium + biofumigation + others/ 82%	Adlecreutz, 2009
	Strawberry fruit 202 t.	1,3-D/Pic+ metham sodium/ 80%	Adlercreutz, 2009; Kirschbaum *et al.*, 2017; Sordo *et al.*, 2017
	Total*	680 t	
Brazil Baseline: 1186t			
	Tobacco 350 t	Floating tray system/100%	Ministerio do Meio Ambiente *et al.*, 2015
	Cut-flowers & ornamentals 230 t	Steam, solarization, IPM practices/100%	Ministerio do Meio Ambiente *et al.*, 2015
	Total*	718	DiarioOficial da Uniao, 2015
Mexico Baseline: 1885t			
	Melons, tomatoes, cut flowers, peppers, cucurbits	Grafting; 1,3-D/Pic+ metham sodium	SEMARNAT, 2018
	Strawberry fruit&raspberry	1,3-D/Pic+ metham sodium	SEMARNAT, 2018
	Total*	1,445 t	
Chile Baseline: 354t			
	Nurseries	1,3D-Pic+ metham sodium+dazomet/100%	MinisterioAmbiente *et al.*, 2014
	Strawberry fruit	1,3D-Pic+ metham sodium+dazomet/100%	INIA, 2017; ONUDI *et al.*, 2015
	Tomatoes&peppers	Grafting+ alternative fumigants + biofumigation/100%	FIA, 2008
	Total*	404 t	

*: Ozone Secretariat, ODS Consumption Database **Available proportion of adoption
Valeiro (2018) Personal communication

6.3.1.2. Asia

China was amongst the ten largest MB consumers for controlled uses in the past with a baseline consumption of 1837 t, and several sectors depended on this fumigant for soilborne pest and disease control. Fumigants registered and in use in China in various sectors appear in Tables 6-2 and 6-3.

TABLE 6-2: PRE-PLAN FUMIGANTS REGISTERED IN CHINA FOR SOIL PATHOGEN CONTROL

Alternative	Strawberry	Tomato	Cucumber	Eggplant	Ginger	Cut flowers
Chloropicrin	x	x	x	x	x	x
Dazomet	**x**	**x**			**x**	**x**
Metham sodium (MS)	**x**	**x**	**x**			
Sulfuryl Fluoride (SF)			**x**			
Allyl isothiocyanate (AITC)		x				
DMDS		x	x	x		

Source: Cao (2018): Personal communication

TABLE 6-3: POST-PLANT NEMATICIDES REGISTERED IN CHINA

Nematicides	Cucumber	Tomato	Tobacco	Potato	Watermelon
Abamectin	x	x	x		x
Fosthiazate	x	x	x	x	x
Oligosaccharins	x				
Paecilomyceslilacinus		x			
Verticillium chlamydosporium			x		
Bacillus firmus			x		
Bacillus cereus		x			

Source: www.chinapesticide.gov.cn; Cao (2018): Personal communication

Table 6-4 presents the main chemical and non-chemical alternatives to MB adopted in China to produce different crops.

TABLE 6-4: MAIN ALTERNATIVES TO MB ADOPTED IN CHINA AND QUANTITIES PHASED OUT

Crop	MB (t) phased out from 2000 to 2017	Single or combined alternatives to MB	Key references
Strawberry	324.35t	Chloropicrin (310.51t); dazomet (14.84t)	UNIDO reports (2008-2015-2018)
Cucumber	32.9t	Grafting (15t); calcium cyanamide (3.4t); metham sodium; fosthiazate (1.6t); Grafting+ calcium cyanamide (8.436t), Grafting+ MS(4.464t)	
Tomato	25.28t	Resistant cultivars (6.83t) Dazomet (6.39t); calcium cyanamide(6.06t) ; MS (6t);	
Eggplant	7.07t	Grafting (3.52t) calcium cyanamide (3.55t)	
Ginger	491.31t	Chloropicrin (438.82); dazomet (26.89); calcium cyanamide (18.31t); Other (7.29t)	
Tobacco		Floating tray	

Cao (2018): Personal communication

In addition, flame soil disinfestation (FSD) is a novel, promising non-chemical method to control soilborne nematodes, fungal and bacterial pathogens presently trialed in China. (Mao *et al*., 2016)

Turkey was another key MB consumer in the Asian region, with a baseline of 800t. The country phased out ahead of the 2015 deadline with assistance from the MLF. The main chemical alternatives registered and used in Turkey are reported in Tables 6.5 and 6.6. A list of chemical and non-chemical alternatives adopted in sectors using MB in the past, particularly vegetables, cucurbits, ornamentals and strawberry was not available.

TABLE. 6-5: PRE PLANT FUMIGANTS REGISTERED AND USED IN TURKEY FOR SOILBORNE PATHOGEN CONTROL

Fumigant	Formulation (%)	Crops where registered
Allyl isothiocyanate	963 g/l	Tomato (*Meloidogyne* spp.)
Dazomet	97 %	Vegetables (*Meloidogyne* spp.) Eggplant (*Fusarium* spp., *Verticillium* spp. *Meloidogyne* spp.) Tomato (*Meloidogyne* spp.)
Dimethyl disulfide (DMDS)	1000 g/l	Strawberry, cucumber, carnation (*Fusarium* sp., *Macrophomina* sp., *Phytophthora* sp., *Rhizoctonia* sp.) Eggplant, tomato, pepper (*Meloidogyne* spp.)
Iodomethane	2229,8 g/l	Eggplant, tomato, pepper (*Meloidogyne* spp., *Fusarium oxysporum, Fusarium solani*) Strawberry (*Rhizoctonia solani, Macrophomania phaseolina*)
Metham potasium	690 g/l	Eggplant, cucumber, tomato, pepper (*Meloidogyne* spp.)
Metham potasium	510 g/l	Tomato (*Rhizoctonia solani, Fusarium oxysporum*)
Metham sodium	500 g/l	Soil borne pathogens and nematodes

1,3-D, Pic and 1,3-D/ Pic are no longer registered in Turkey.
Erturk (2018, personal communication)

TABLE 6-6: FUMIGANTS AND RATES USED IN TURKEY FOR STRAWBERRY RUNNER PRODUCTION

Fumigant	PE (l/ha)	VIF (l/ha)	Reference
Metham Sodium	1250	625	Yucel *et al.*, 2018
Metham Potassium	1250	625	
Pic	400	200	

PE: Polyethylene
VIF: Virtual impermeable film

6.3.1.3. Africa

The main pre-plant fumigants registered and used in **Morocco** (baseline 1162t) are reported in Table 7 below. Information on the relevance of each alternative is not available and varies with the crop, the key pathogens, the inoculum density and seasonal environmental conditions. For example, in the case of 1,3-D/Pic, a higher rate of 1,3-D is used when nematode populations are high. MS, MK, Dazomet and DMDS are used when soil inoculum densities are low.

TABLE 6-7: PREPLANT CHEMICALS REGISTERED AND USED IN MOROCCO FOR SOILBORNE PATHOGEN CONTROL

Fumigant	Formulation (%)	Registration
1,3 D	93.0- 97.5	Soil disinfestations 30-35 days month before plantin:: Bananas, vegetables, strawberries, ornamentals, aromatic plants,
Pic	98	
1,3D+Pic	36.7/52.8	
	38.0/57.0	
	55.4/32.7	
	57.0/3/8.0	
	60.8/33.3	
Metham Na	50	
Metham K	50 or 70	
Dazomet	97	
DMDS	94.4	Bananas, strawberries, Beans, tomatoes, ONSSA, 2018.

Methyl iodide: registered but not used; Besri (2018) personal communication)

In addition, post-plant chemicals are registered and used for the control of soil borne pathogens attacking bananas, vegetables, strawberries, ornamentals and aromatic plants in Morocco. These include Abamectin, Cadusaphos, Fluopyram and Ethoprophos.

Biocontrol agents are also registered and in use, for example *Bacillus subtilis* on beans and *Peocilomyces lilacinus* on bananas, strawberries and vegetables.

The main pre-plant chemical and non-chemical alternatives used on various crops appear in Table 6-8.

TABLE 6-8: MAIN PRE-PLANT ALTERNATIVES TO MB ADOPTED IN MOROCCO AND AMOUNTS OF MB PHASED-OUT THROUGH THEIR ADOPTION

Sector	MB (t) phased out in 2008*	Single or combined alternatives taken up in 2008 and the proportion of previous MB use replaced *	Key references
Strawberry fruit	159	MS: Drip irrigation, 200-253 g/m2 (99 % of strawberry area) Soil less culture: Less than 1% Others: DMDS registered and in use	Besri 2004, 2008 ab, 2011, 2014 Chtaina 2006, 2008
Cut flowers	42	Drip application of 1,3-D/Pic (100 %)	
Tomato	585	Resistant cultivars and grafting + 1,3-D/ Pic in drip irrigation (100%) IPM: Resistant varieties and grafting, *Tagetes* spp, solarisation, biofumigation, ASD	
Eggplants	25		
Peppers	29		
Cucurbits	32		
Bananas	45	Combining soil solarisation and drip fumigation with 1,3 D EC (5%) Post plantation nematicides e.g. fenamiphos, cadusafos, oxamyl and fosthiazate in granular or liquid formulations . More that 90 % DMDS: 2%	
Total	917		

*Estimated. Besri (2018, personal communication)

Many chemical alternatives which are registered in Morocco are not registered in Europe, which confronts Morocco to European pesticide *regulatory* controls, with serious repercussions on exports of certain crops. This places a restriction on the alternatives that can be used.

6.3.2. Non-A5 countries

6.3.2.1 European Union (EU)

Methyl bromide was completely banned in the EU in 2010, for both controlled and exempted uses, and this has had a significant impact. Key alternatives such as 1,3-D and Pic were also banned in 2010 and 2013 respectively, while dazomet, metham sodium and metham potassium were re-approved with stringent restrictions on rates and frequency of application (Table 6-9). Currently a Member State of the EU may get authorization for using 1,3-D and Pic for 120 days/year as a national emergency use, and only once every 3 years in the same area (Regulation (CE) 1107/2009 article 53). In recent years, this exemption has been used for strawberry (fruit and nursery production) and other crops in Spain, Italy, Belgium, France, UK, Cyprus, Malta, and Greece. However, the future of such limited authorizations is very unclear, even in the short term.

A new fumigant, dimethyl disulfide (DMDS) is currently under registration process in Europe; it has performed as well as or even better than the best chemicals used to control nematodes and nutsedge (*Cyperus* sp) (Greco *et al* 2018) and its efficiency has been shown to increase when used in combination with dazomet, MS or Pic. DMDS emergency use derogation was granted in Italy and special trials have recently been permitted in Spain (Greco *et al.*, 2018).

TABLE 6-9: PRE PLANTAT FUMIGANTS PENDING OR REGISTERED IN EU FOR THE CONTROL OF SOIL BORNE PATHOGENS

Name	Status under registration	Date of Approval	Expiration of Approval
1,3-Dichloropropene	Not approved except for emergency uses		
Chloropicrin	Not approved except for emergency uses		
Dazomet	Approved	01/06/2011	31/05/2021
Metham (incl. -potassium and -sodium	Approved in 15 countries	01/07/2012	30/06/2022
Dimethyl disulphide	Pending		
Sulfuryl fluoride	Approved	01/11/2010	31/10/2023

Source: https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/203.htm

Other post planting nematicides approved and used in Europe are listed in Table 6-10.

TABLE 6-10: POST PLANT NEMATICIDES APPROVED IN EU

Name	Status under registration	Date of Approval	Expiration of Approval
Fenamiphos	Approved	01/08/2007	31/07/2019
Oxamyl	Approved	01/08/2006	31/01/2019
Fosthiazate	Approved	01/01/2004	31/10/2018

Source : EU Pesticides date base : http://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/?event=homepage&language=EN
Pesticide properties data base : https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/203.htm

Tables 6-11 and 6-12 show an estimate of the key alternatives - and for some sectors the proportion - used in Europe to replace MB by 2014, four years after the EU banned all uses of MB. Alternative fumigants like MS, dazomet and 1,3-D were the key alternatives adopted in most sectors in both **France** and **Italy**, two countries which previously used large volumes of MB for soil fumigation.

In some sectors however, IPM systems and/ or methods to avoid or reduce the need for fumigation are widely adopted. Resistant rootstocks for tomato, eggplants, melon and watermelon are widely used in both field and protected cultivation. Soilless culture has also become a major production system in ornamental and vegetable production, and solarisation has been adopted for cut flowers and vegetables.

TABLE 6-11: MAIN PRE PLANT CHEMICAL AND NON CHEMICAL ALTERNATIVES TO MB ADOPTED IN FRANCE IN 2014

Sector	MB Used (t)	Chemical and non chemical alternatives	
Carrots	10	Dazomet	Crop rotation, resistant varieties
Cucumber	60	1,3-D and dazomet	Grafting, soil less, ASD, steam
Cut-flowers	75	Metham/dazomet alone or combined with solarization	Soil less, soil solarization
Forest tree nursery	10	Metham/dazomet	Substrate
Melon	10	1,3 D and Metham sodium	Grafting – rotation, ASD, steam
Orchard replant	25	Metham sodium (Dazomet	rotation
Pepper	27.5	Metham sodium Dazomet	Rotation ,green manure, grafting, ASD, steam
Strawberry fruit	90	Metham Na, , Dazomet	Soil less systems
Strawberry runners	40	Metham sodium Dazomet	Soil less
Tomato	135	Metham, 1,3 D dazomet	Grafting, soil less , solarisation, ASD, steam
Eggplant	27.5	Metham sodium and dazomet	Grafting , crop rotations, solarisation, ASD, steam

Source:Porter 2018, Personal communication

TABLE 6-12: MAIN PRE PLANT ALTERNATIVES TO MB ADOPTED IN ITALY

Sector	Maximum MB amount requested for CUNs in 2005(t)	Alternatives taken up in 2014	
		Chemical	Non Chemical
Tomato protected	1300	1,3-D/Pic; 1,3 D + Rootstocks; 1,3-D and Metham Metham or dazomet	Resistant rootstocks Soilless , ASD, steam
Cut flowers (protected)	250	1,3-D/Pic 30%; Metham/solarisation	Soilless , ASD, steam
Eggplant (protected)	280	Non fumigant nematicides + Rootstocks , metham	Rootstocks; Soilless , ASD, steam
Watermelon (protected)	180	Non fumigant nematicides + Rootstocks	Rootstocks , ASD, steam
Pepper (protected)	220	Metham , Dazomet	Rootstocks, Solarization, Soilless , ASD, steam
Strawberry Fruit (Protected)	510	1,3-D/Pic , Pic , Dazomet	Solarization , ASD, steam
Strawberry Runners	100	Metham , 1,3-D/Pic , Dazomet	Soil less culture

Porter 2018, Personal communication

López-Aranda *et al.*, (2016) conducted a comprehensive survey of 41 European and other strawberry industries (fruit and nursery). With respect to strawberry nurseries (more than 5,755 ha identified, with different soil and climate situations), the survey showed that 32% were fumigated with MS (spading), 31% used crop rotation with cereals, grasses, oilseed crops, legumes, and other crops i.e. green manures like oil radish, mustards, winter rye, and buckwheat and/or change of location; 19.3% were fumigated with 1,3-D and/or 1,3-D/Pic; 8.6% relied on non-chemical methods (cover/catch crops, soil solarisation, and ASD), 7.2% were fumigated with dazomet (Mix-Tiller), and the remaining 1.9% used other chemical options. The survey showed that MB has been completely phased out in strawberry fruit and runner production.

Many other authors have shown that Pic and 1,3-D/Pic are effective alternatives to MB for controlling soilborne pathogens attacking strawberry runners, such as *Phythophthora fragariae*, *Verticillium dahliae* and V. *albo-atrum*, *Fusarium* spp. and *Colletotricum* spp (De Cal *et al*., 2004; García-Méndez *et al*., 2008; Porter *et al*., 2006).

6.3.2.2 USA

Over the past fifteen years, many alternatives to MB have been trialed and adopted, and research on chemical and non-chemical options continues. The USEPA and the US Agricultural Research Service continue to prioritize the registration of alternatives to MB.

Table 6-13 identifies a selection of chemical alternatives for different productive sectors. This list was last updated in 2012.

TABLE 6-13: CHEMICALS REGISTERED AND NOT REGISTERED IN THE USA FOR SOIL PEST CONTROL

Crop	Alternatives registered	Alternatives Under Development (not registered)
Cucurbits	1,3-D, Pic, 1,3-D/Pic, DMDS Glyphosate, Halosulfuron, MS, Paraquat	Furfural, Propargyl Bromide, Sodium Azide
Eggplants	1,3-D, Pic, DMDS, Halosulfuron, MS, Napropamide, Trifluralin, 1,3-D + Napropamide + Trifluralin, 1,3-D/Pic, MS + Pic	Furfural, Propargyl Bromide, Sodium Azide
Peppers	MS,1,3-D, Pic, DMDS, Halosulfuron, Glyphosate, Paraquat, MS + Pic, 1,3-D/Pic, 1,3-D + MS	Furfural, Sodium Azide, Propargyl Bromide
Forest Seedlings	1,3-D, Pic, Dazomet, DMDS, MS, MS + Pic, 1,3-D/Pic	Propargyl Bromide, Sodium Azide
Ornamentals	1,3-D, Dazomet, DMDS, Chloropicrin, MS, 1,3-D/Pic, Dazomet + Pic, MS + Pic	Furfural, Sodium Azide, Potassium Tri-iodide, Propargyl Bromide
Strawberry fruits	1,3-D, Pic, Dazomet, DMDS, MS, Terbacil, 1,3-D/Pic, 1,3-D/Pic + MS, MS + Pic, Pic	Furfural , Propargyl Bromide
Strawberry Nursery	1,3-D, MS	DMDS, Furfural, Propargyl Bromide
Tomatoes	1,3-D, Pic, Dazomet **, DMDS, Fosthiazate, Glyphosate, MS, Paraquat, Halosulfuron-methyl, s-Metolachlor, Trifloxysulfuron-methyl, Rimsulfuron, MS + Pic, 1,3-D + MS, 1,3-D/Pic	Furfural , Pebulate, Propargyl Bromide , Sodium Azide

Adapted from
https://www.epa.gov/sites/production/files/2015-07/documents/alternatives_for_specific_commodities_0.pdf
* **The registration for Dazomet is limited to California only.

Table 6-14 reports the main pre plant chemical and non chemical alternatives to MB adopted to control many soilborne pathogens and weeds in various sectors in the USA.

TABLE 6-14: MAIN CHEMICAL AND NON-CHEMICAL ALTERNATIVES TO MB ADOPTED IN THE USA

Crops	Maximum Amount of MB Requested under past CUEs (t)	MB Alternatives taken up	
		Chemical replacements	Non Chemical
Chrysanthemum. Cuttings/roses	29	MS; 1,3-D; Pic; crop rotations; Dominus*	ASD, biosolarization, resistant varieties; crop rotations
Vegetables (e.g. cucumbers, eggplant, peppers, and tomatoes)	1498	Pic-Clor 60 with herbicides for nutsedge; Dominus	Plastic mulches, ASD, and disease resistant varieties. All methods require herbicides for nutsedge control.
Forest tree seedlings[1]	193	Pic-Clor (Telone C35) at 392 kg/ha; MS:Pic at 137 kg/ha	Container production
Orchard replant disease	828	1,3-D:Pic (Telone 35); Pic-Clor 60	Season of Sudan grass or fallow combined with use of nematode-resistant rootstock
Nursery stock (fruits and ornamentals)	211	MS; 1, 3-D; Pic; Dominus	Container production
Strawberry fruit – field	2469	MS: Pic at 700 L/ha; 1,3-D at 372 kg/ha; Pic at 224 kg/ha; Dominus	Disease-free stock planted annually; crop rotations with lettuce or brassica vegetables
Strawberry runners[2]	55	MS: Pic at 700 L/ha; 1,3-D at 372 kg/ha; Pic at 224 kg/ha;	Soilless production; disease and nematode-resistant varieties

[1]Approximately 70% forest seedlings systems use MB: Pic under QPS for bare-root production.
[2]Approximately 50% strawberry runner production systems use MB:Pic under QPS.
James (2018). Personal communication
https://www.epa.gov/sites/production/files/2015-07/documents/alternatives_for_specific_commodities_0.pdf
**The registration for Dazomet is limited to California only.
* Biofumigant

For strawberry runner production in CA, methyl bromide is still being used under the QPS exemption. However, in 2016 methyl bromide use decreased by 26%. For strawberry fruit production, MS (700 l/ha), 1,3-D (372 kg a.i./ha) and Pic (224 kg a.i./ha) are used. Chemicals containing 1,3-D/Pic are also used. In 2016, MS use decreased by 69%, while 1,3-D increased by 5% and chloropicrin use increased by approximately 2%. A biofumigant, Dominus, is also available, but it is used in strawberry fruit production and not in strawberry nurseries (James 2018, personal communication).

6.3.2.3 Asia and Middle East

Table 6-15 reports the fumigants registered and used in **Japan** for the control of soil borne pathogens.

TABLE 6-15: FUMIGANTS REGISTERED IN JAPAN FOR THE CONTROL OF SOIL BORNE PATHOGENS

Fumigant	Formulation (%)	Amount used in 2017 (t)	Registration
1,3 D	50 92	8,531	Strawberries , ornamentals and vegetables (cucumber, pepper, watermelon, tomato) ginger
Pic	80 99.5	7,459	
Pic + 1,3D	40/52 35/60	536	
MITC	20	601	
Metham sodium	30 40	679	
Dazomet	98	3,087	
Fosthiazate	1 1.5 10 30	5,613	

Information on the relevance of each alternative is not available. Sources: Food and Agricultural Materials Inspection Centre Japan (2018) Search for registration information of agricultural chemicals. Available at http://www.acis.famic.go.jp/search/vtllg103.do. Japan Fumigation Technology Association (2018) Delivery amount of methyl bromide and major alternatives in Japan March 31 2018 No. 131 Page 7

According to the Ministry of Agriculture, Forestry and Fisheries Fluensulfone granule was not used in 2017 even though it was registered in Japan as Nema-shot® on April 11 , 2017 to control root-knot nematodes of sweet potato, cucumber, tomato, tomato, pepper, eggplant, pumpkin, melon and watermelon.

In Japan, soil borne pathogens are controlled by various chemical and non-chemical alternatives (Table 6-16)

TABLE 6-16: MAIN PREPLANT ALTERNATIVES TO MB ADOPTED IN JAPAN

Crops	MB (t) for 2012 CUE *	Pathogen to be controlled in CUE	Chemical alternatives	Non-chemical
Melon	67.936	Soil transmitted viruses, Cucumber Green Mottle Mosaic Virus, Pepper Mottle Mosaic Virus	No chemical alternative available to control soil borne viruses	Certified seeds, field sanitation , resistant varieties, grafting on resistant rootstocks, steam, soil less, paper pots to avoid root contact.
Watermelon	12.075			
Cucumber	26.162			
Pepper (green and hot)	61.154			
Ginger (field)	42.235	Rhizome root rot disease (*Pythium zingiberis)*	(a) Registered alternative pesticides for soil treatment prior to planting; Pic, 1,3 D/ Pic, 1,3 D + MITC, Dazomet, and MS (b) Registered alternative pesticides for application during crop cycle; Cyazofamid, Metalaxyl, and Propamocarb	
Ginger (house)	6.558			

*MB for soil treatment was completely phased out in 2013.
Tateya (2018), personal ccommunication)

In **Israel,** vegetable crops are grown intensively in closed structures (plastic and net houses), and are largely intended for export. A nematode control approach has recently been developed to control *Meloidogyne incognita* on pepper, which combines sanitation (root destruction) at the end of the previous crop aimed at preventing the establishment of a new generation of nematodes. Soil disinfestation using 1,3-D or DMDS (Paladin) combined with solarisation is applied during the summer. Sanitation (root destruction) at the end of the previous crop together with soil disinfestation and a specific fertigation with a phosphate/nitrogen based formula reduces the number of nematode eggs in the soil to a negligible level. Fertigation applied periodically to the crop improves plant tolerance to nematode infection (Gamliel *et al.*, 2018).

6.4. Alternatives for the remaining MB uses in the soil sector

Since 2003, quantities of MB requested for critical use have fallen from 18,700 t for use in 2005 to 150 t for 2019/2020. In 2018, MBTOC received 4 critical use nominations for soil fumigation from 3 Parties (Argentina, Australia and Canada) totalling 139.98 t.

Technically and economically feasible chemical and non-chemical alternatives to MB have been found for virtually all soils applications for which MB was used in the past, and comprehensive information is available for these uses (MBTOC, 2015; TEAP 2018).

6.4.1. Strawberry fruit in Argentina

According to the Party, alternatives to MB for strawberry fruit production in critical areas (Lules and Mar del Plata provinces) are not economically and technically feasible for the following reasons: Soil type characteristics, MS does not control soil borne pathogens, 1,3 D/Pic gives inconsistent results and causes phytotoxicity, more efficient application techniques for 1,3D/Pic are not available, steam is not economically feasible and others.

Chloropicrin is not registered in Argentina, but combinations of 1,3-D/Pic products are registered. Dazomet is not registered for edible crops. A decree currently in force in Mar del Plata prohibits use of alternatives and allows only MB for soil fumigation; however this is expected to change in the near future.

In 2018, Argentina reported that a combined treatment of solarisation plus biofumigation works well in north east and west Argentina during hot summers, in protected and open field strawberry fruit production (ARG02 CUN2019, strawberry). These alternatives however do not work in the central areas of Mar del Plata and La Plata. Steam is used in Argentina, but its use is restricted to nurseries substrates. Soil less culture has been tested, but this alternative is so far not economically feasible. Research on biological control has been conducted showing that this technology cannot be considered as alternative to MB (ARG02 CUN2019, strawberry).

6.4.2. False root knot nematode of tomato: Nacobbus aberrans .

The false root-knot nematode, *Nacobbus aberrans,* is one of the top 10 nematodes based on economic importance (Jones *et al.*, 2013), is endemic in the Americas and is particularly prevalent in Mexico, Argentina, Bolivia, Chile, Ecuador and Peru (Sher, 1970; Canto-Sáenz *et al.*, 1996; Lehman, 1985; Stone and Burrows, 1985). It is of quarantine importance in some countries (EPPO, 2009). In Argentina, *N. aberrans* has been reported in several provinces (Chaves and Sisler, 1980; Costilla and Ojeda, 1985; Del Toro *et al.*, 2004; Doucet and Lax, 2005), causing particularly high damage in greenhouse crops. Populations with different host preference have evolved in various geographical areas. (Inserra *et al*., 1985; Manzanilla *et al*., 2002 ab, 2008). The false root knot nematode, *Nacobbus aberrans*, has a very wide host range, the most significant being tomatoes and potatoes, but also including Brassica crops, peppers, carrots, cucumbers, lettuce, sugar beet and various weeds. Several pathotypes of *Nacobbus* have been reported (Lax *et al*., 2011, 2016)

Although, the false root-knot nematode, is endemic to the American continent, it justifies the attention granted by international qurantine regulations due to its broad host-range and economic importance in crops such as potato, tomato and sugar beet.

Control of the false root-knot nematode is difficult under protected cultivation conditions in Argentina (plastic greenhouses). The nematode only moves short distances (around 1m) but may be spread with plants and soil moving activities.

Research conducted in Argentina has identified chemical (1,3 D/Pic, MS, Dazomet, fluensulfone) and non-chemical (solarisation, steam, biofumigation) alternatives for other tomato producing regions but not for La Plata and Mar del Plata because due to prevalent low soil temperatures, heavy soils, phytotoxicity of 1,3 D /Pic and its long plant back planting period, lack of varieties or rootstocks resistant to *Naccobus* and inefficiency of MS (ARG02 CUN2019, tomato).

Control of *Nacobbus* is complex due to its wide host range and variable behaviour between populations (Costilla, 1990; Doucet and Gardenal 1992, Boluarte and Jatala 1999; Lax *et al*., 2011), which typically leads to frequent treatments with MB. Research and experiment to develop non-chemical and chemical alternatives in the critical regions has been conducted (Hidalgo *et al.*, 2015).

In greenhouse tests conducted in Argentina, applications of the strain *Pseudomonas protegens* CHA0 and its isogenic derivative ARQ1 (used as a control) at a rate of 10^8 cfu ml^{-1} suppressed infection and reproduction of *N. aberrans* on tomato roots (Lax *et.al.*, 2013).

Hidalgo *et al*., (2015) reported significant reduction of population density, reproduction rate, and root galling of *N. aberrans* in tomato crops with fluensulfone (Nimitz®) a contact nematicide. Results were similar to those obtained with 1,3-D/Pic, and they concluded that fluensulfone, which poses less risk to human health and the environment than fumigants, could be considered a good alternative to MB for tomato and cucumber crops affected by *N. aberrans*. Fluensulfone has also been identified as an effective alternative to MB for nematode control on different crops including tomato (Castillo *et al* 2016). Results were comparable to those obtained with Pic-Clor 60 (Pic + 1,3-D) (Castillo *et al.*, 2016).

Commercial tomato cultivars and rootstocks with high resistance to *N. aberrans* are not yet available, although they have been sought for many years for tomato and pepper (Sisler and Pelicano de Casaurang, 1983; Manzanilla-Lopez *et al*., 2002ab; Thies and Ariss, 2009; Djian-Caporalino *et al.*, 2009). Recent research is yielded encouraging results (Lax *et al.*, 2016; Gomez *et al.*, 2017) reported some pepper lines with resistance to *N. aberrans*, whilst Garita *et al.*, (2018) have shown that the Maxifort tomato rootstock has an invigorating effect on the Santa Clara scion, stimulates apical growth and has good tolerance to nematode attack.

Since in Argentina over 90% of the tomato and pepper farms are managed by migrant families of Bolivian origin who mostly rent out the land, long term investments are an exception and grower are reluctant to develop soilless culture except for seedling production (Argerich *et al.*, 2010).

An Integrated Management program to control *Nacobbus* was developed by Cristobal-Alejo *et al*., (2006) in Mexico, comprising fertilisation schemes, nematicide applications (ethoprop) and biofumigation with chicken manure and resulting in significant increases of plant height, foliage dry weight, stem diameter and crop yield. Similar successful schemes involving various chemical (carbofuran) and non-chemical control methods – biofumigation, biocontrol with *Pochonia chlamydospore* are also reported (Pérez-Rodríguez *et al.,* 2010).

6.4.3. Alternatives for strawberry runner production in Australia

In the past, many strawberry runner industries around the world relied on MB soil fumigation to produce disease-free transplants, but most of them have phased-out MB and successfully implemented alternatives (García-Sinovas *et al*., 2014; López-Aranda, 2016). In Europe, strawberry runner production for export continues to increase even though MB use has been banned (Meszka and Malus, 2014; Wu *et al.* 2012) and key technically and economically feasible chemical and non-chemical alternatives to MB have been adopted.

Two countries still use MB under the CUE exemption and continue to seek alternatives (Australia, Canada); another (US) classifies this use as QPS, which is exempted under the Montreal Protocol .

Since 2005, the strawberry nursery sector in Victoria, Australia, has applied annually for continued MB use under the critical-use exemption. Research has shown that registered alternative fumigants are not as efficacious as MB/Pic in controlling soil-borne pathogens. Further, some of these cause phytotoxicity leading to yield losses of up to 40%. This is related to the high organic matter (5-10%) and clay content (>50%) of soils where most of the nurseries are located, combined with low soil temperatures at time of fumigation, which result in long retention times of substitute fumigants in soil (>12 weeks) (Mattner *et al*., 2017ab).

Research is currently underway to evaluate different application techniques for substitute fumigants aimed at improving pathogen control - e.g. deeper injection, co-application of different fumigants, and co-application with biofumigation. In addition, the economics and efficacy of thermal soil disinfestation methods, such as microwave and steam are being analysed (Mattner *et al.,* 2017). Ways of minimising crop phytotoxicity when using substitute fumigants are also studied. Results show that decreasing the concentration of 1,3-D in mixtures of 1,3-D/Pic (i.e. 20:80 formulations) reduce the persistence of 1,3-D in soil, and thus the risk of phytotoxicity. EDN and DMDS/Pic do not cause phytotoxicity, but are not yet registered in Australia. In the future, it is likely that 1,3-D/Pic (TriForm-80®, 20:80), EDN, and/or DMDS/Pic become key substitute fumigants for nursery growers, however they generally do not provide sufficient weed control on their own and require co-application of pre and post-emergent herbicides such as isoxaben at the time of planting, followed by bi-weekly applications of post-emergent herbicides phenmedipham and fluazifop. In future, herbicides will likely become an important component of pest management strategies in Australian strawberry nurseries (Mattner *et al*., 2017).

In addition, significant progress has been made with substrate production of strawberry runners, decreasing costs and increasing the yields (Braet *et al.*, 2017; Boonen *et al.*, 2017; Goodchild *et al*., 2018 *et al.*, 2017; Lieten, 2017; Massetani *et al.*, 2017; Murthy *et al.*, 2017; Robinson Boyer, 2016; Smith *et al.*, 2017; Taghavi *et al.*, 2018). Substrate production entails producing plants in structures, without soil, with close control of environmental conditions such as light, temperature, humidity, and nutrient solutions. Japan, South Korea and Taiwan are leading countries of a recent version of soilless technology known as "plant factory", which is successfully used for strawberry transplant production (Park *et al*., 2018; Kozai *et al.*, 2016),

Soilless production of strawberry fruit is already in place in Australia (Fresh fruit portal, 2017; Hortidaily portal, 2018; Costa group holdings portal, 2018; Dornauf, 2018; Smith, 2017; Neal *et al.*, 2017; Milinkovic *et al*., 2017; Mattner *et al*, 2017).

6.4.4. Alternatives for strawberry runner production in Canada

Dazomet, MS, MK and Pic are registered at the federal level in Canada, however, the government of Prince Edward Island does not allow the use of these fumigants even for the purposes of trialing/testing, due to concerns of potential groundwater contamination.

Nursery production on substrates has been used in Canada for many years, mainly for production of tree seedlings (AgriFood Canada, 2003), and this has generated a wealth of knowledge and experience with this technique. A good amount of research has been conducted on soilless production of strawberry fruit and runners (Naasz *et al.*, 2009; Depardieu *et al.*, 2016, 2017, 2018). A recent research project was started in 2017 looking for more sustainable systems, including the Raised BEdTrough System (RABETS) originally developed in California (MAPAQ, 2017).

Quebec, the third largest producer of strawberry runners in North America after California and Florida, supplies 50% of Canada’s total production. Soilless production is well developed; strawberry plants are produced under high tunnels in quality soilless substrate (Les fraises de l’ile d’Orléans, 2018). Substrates are typically based on peat and/or coir, or perlite. More than half of the Canadian strawberry nurseries already produce plug plants and unrooted tips on substrate- filled trays, (Mallen and Bradt , 2016; Taghavi *et al*., 2017; AMA 2018).

6.5 Other issues

6. 5.1 Barrier films

For many years MBTOC has underlined the benefits of using barrier films (VIF, TIF) when applying soil fumigants, as they allow for lower dosage rates, thus reducing emissions whilst increasing effectiveness of fumigants. Many decisions taken under the Montreal Protocol require and encourage MB emission reduction, and for many years research has shown the benefits of barrier films in reducing MB application rates. Barrier films are mandatory or at the very least strongly encouraged for use with all fumigants in various countries (TEAP, 2017; 2018).

A trial conducted by Thalavaisundaram *et al.*, (2015) showed that sealing the soil with VIF improved the efficacy of ethanedinitrile (EDN) for soil disinfestation in runner production, as compared with LDPE. VIF also significantly improved weed control and increased runner yields compared with LDPE.

In addition, totally impermeable film (TIF) can contribute to control of *Cyperus* (nutsedge), one of the most damaging weeds and often controlled with MB in the past. TIF inhibits yellow and purple nutsedge even in the absence of a fumigant, and can be used successfully in combination with some pre-emergence herbicides or fumigants such as Paladin Pic-21 (DMDS) (Boyd and MacRae, 2018).

6. 5.2 Methyl bromide alternatives and sustainable soil fumigation

As previously reported, soil fumigation is a widespread practice to control soil borne pathogens of many crops e.g. tomatoes, carrots, tobacco, strawberries, cucurbits. After the phasing out of MB, many old and new chemical alternatives including 1,3-D, MITC generators (MS, MK and dazomet), Pic, MI (methyl iodide) and DMDS have been developed and are commercially used. However, stringent environmental regulations largely affect the continued availability of these products all over the world (EU, 2016; UN, 2015ab).

In many countries around the world, the range of chemical alternatives available for plant protection has been dramatically reduced after being re-evaluated, due to a high toxicity risk to humans and the environment (phytotoxicity, pollution of underground water, pesticide residues). In Europe for example, only MS/MP and dazomet are presently authorized, but limited to one application every third year on the same field. Pic was withdrawn in June 2013 and 1,3-D in 2009, although several Member States granted periods of 120-day authorizations for emergency uses. Recently the European Commission in co-operation with EFSA and all 27 Member States has concluded a review of all existing active substances (EU, 2016).

General health issues reported in reference to fumigants are summarised in Table 6-17 (EU, 2016)

TABLE 6-17: GENERAL HEALTH ISSUES ASSOCIATED TO SOILS FUMIGANTS

Fumigant	Health issues
Methyl bromide	Mutagenic potential Highly toxic Brain, kidney, respiratory toxicant IARC Group 3 carcinogen
1,3 D	Highly toxic Mutagenic potential Possible urinary, liver and kidney toxicant
Dazomet	Skin and eye irritant
Metham sodium	Possible liver and urinary tract toxicant USEPA - probable human carcinogen
DMDS	Toxic by ingestion Inhalation may cause nausea, headache and dizziness
SF	Prolonged exposure may cause pulmonary edema, nausea and abdominal pain Possible kidney, CNS, blood and bone toxicant

6.6. References

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7

Chapter 7. Alternatives to Methyl Bromide for Structures and Commodities

7.1. Introduction

Methyl bromide (MB) was mentioned for postharvest pest control for the first time by Mr. Le Goupil in 1932. It rapidly became established as a fumigant of choice for whole site fumigation of grain mills and of bag stacks of grain, particularly in USA and the continent of Africa. Phosphine was also being adopted at this time for postharvest insect control in various bagged and bulk dry foodstuffs.

Methyl bromide was recognized as an Ozone Depleting Substance under the Copenhagen Amendment (1992). Over the next three decades alternatives for almost all previous controlled uses of methyl bromide have been identified, developed and put into practice, replacing MB use for pest control in structures and commodities (SC).

MBTOC has reported extensively on MB alternatives for SC in its past Assessment Reports (2011, 2015) and these reports provide thorough information on the subject. This chapter thus focuses on the last critical uses remaining since 2014, whilst providing an overview of alternatives adopted for the different previous uses.

7.2. Historic perspective on alternatives adopted for key SC uses of the past

During the initial MB phase-out years, the main alternatives used for its replacement were other available and registered fumigants, principally phosphine,; Controlled atmosphere treatments using low oxygen systems with carbon dioxide and nitrogen were used to a limited extent. In some situations, intensive use of contact insecticides like pirimiphos-methyl, dichlorvos, pyrethroids (e.g. deltamethrin, permethrin, cyfluthrin, natural pyrthrins) (Arthur, *et al*, 2014; Campbell, *et al*., 2017) and natural or synthetic pyrethrins Other insecticidal or at least repellent extracts of plants were also considered (and still are) as potential replacements for MB and are subject to continuing research.

In ensuing years, registration of new and rediscovered fumigants for use on dry (durable) foodstuffs occurred (e.g. sulfuryl fluoride, propylene oxide, iodomethane, carbonyl sulphide and ethane dinitrile (cyanogen)). In addition, adoption of nonchemical (physical) measures like heat (including the heat production by combustion of carbon containing sources, electrical heat, irradiation with gamma ray or electromagnetic waves, infra-red, high frequency), cold and percussion (entoleter) usually as part of an Integrated Pest Management (IPM) system has occurred for pest control in SC.

The combination of these alternatives together with applications of macro- and microbiological antagonists, various traps, intensive cleaning (sanitation) and other measures were also introduced within IPM schemes for structures and commodities.

Sulfuryl fluoride (SF) became a prominent in-kind MB alternative in some regions following its registration in various countries, particularly for disinfestation of empty structures like flour mills, churches and other historic and cultural buildings.

European countries were able to completely phase out MB in SC in 2005 with only a few requests for Critical Use Exemptions (CUE); the last nomination was made for 2008 use, followed by a complete ban for all uses and production (including for QPS) in 2010.

Table 7-1 shows the relatively low volume critical use exemptions for MB remaining in 2018. These relate to a single Party, the Republic of South Africa (RSA) and are for treatment of some grain mills and for some houses (dwellings and churches) infested by wood-destroying pests, particularly drywood termites. The nominations were made given that equally effective and economically feasible alternatives are not yet available. However, SF has recently been registered in RSA, and MBTOC is confident that this remaining use will soon be replaced by this fumigant, complemented by heat treatments.

In all other Parties of the Montreal Protocol, MB use for pest control in SC has completely been phased out and replaced with alternatives. Table 7-1 shows examples of key alternatives to MB implemented around the world for pest control in structures and commodities.

TABLE 7.1: HISTORICAL KEY USES OF MB, PEST ORGANISMS AND PRESENT REPLACING ALTERNATIVES

Former Key use of MB in SC	Typical pests	Alternatives now in place[a]
Grain and flour mills	Pyralid moths, *Tribolium* spp, *Cryptolestes* spp. *Oryzaephilus* surinamensis	SF, heat, biological antagonists like parasitoid wasps, intensive cleaning, contact insecticides, mass trapping, cold
Historic and cultural buildings (including churches)	Wood-destroying pests (e.g. *Anobium punctatum*, *Hylotrupes bajulus*, *Lyctus brunneus*	SF, CO_2, HCN
Cereal grain and similar commodities in bag stacks	Cosmopolitan grain insect pests (e.g. *Sitophilus* spp., *Tribolium* spp, Pyralid moths)	phosphine, hermetic storage, parasitoid wasps (example: *Lariophagus distinguendus)*, deltamethrin or other contact insecticides, diatomaceous earth
Cereal grain and similar commodities in bulk	Cosmopolitan grain pests (e.g. *Oryzaephilus surinamensis*, *Rhyzopertha dominica*, *Sitophilus spp. Sitotroga*)	Phosphine, contact insecticides, cooling, controlled atmospheres and hermetic storage, SF
Nuts	Pyralid mothss, *Oryzaephilus*	SF, phosphine, trapping
Dried fruit	Pyralid moths, *Carpophilus* spp.	SF, phosphine, trapping
Spices	Pyralid moths, Stegobium and c	Irradiation, phosphine, cold, carbon dioxide under high pressure
Houses and other structures with wooden components	*Wood destroying pests including Anobium*, *Hylotrupes*, *Lyctus*, Drywood termites	SF, heat, insecticide treatments
Artefacts (e.g. books, art works with wooden frames, basketwork, carpets, furs, skulls)	General pests including clothes moths, dermestid beetles, wood borers, *Lepisma saccarinae*	nitrogen, carbon dioxide, heat, cold

a May be used singly or in rational combination according to situation treated

7.3. Alternatives for food processing structures and durable commodities (controlled uses, non-QPS)

Researchers around the world continue to conduct research aimed at identifying and adopting alternatives to MB for controlling pests causing problems in the structures and commodities sectors (Ducom, 2012). However, as of 2015, all postharvest uses of MB had been phased out in non-A5 Parties and no CUNs have been submitted since.

The main in-kind alternatives to the disinfestation of flourmills and food processing premises are sulfuryl fluoride (including combinations of SF and heat or phosphine (Opit, *et al*., 2016) and heat (as full site or spot heat treatments). HCH is also available for full site fumigation in some countries.

Increasingly, control of structural pests in some food processing situations is obtained without full site fumigation through a more vigorous application of various IPM approaches., sometimes including localised use of fumigants (e.g. ethyl formate). Other pest control operators report success using phosphine alone (Rogers, *et al*., 2014; Ryan and Nicholson, 2014; Tütüncü, *et al*., 2014) or a combination of heat, phosphine and carbon dioxide, but note these measures need to be in place to protect susceptible equipment from corrosion by phosphine.

Treatment of commodities with sulfuryl fluoride has also expanded in the USA. SF is in use for disinfestations of museums (structures) against insect pests in Japan. SF is now extensively used for disinfestation of bulk grain in parts of Australia, where resistance to phosphine in some insect pests makes phosphine use ineffective (Jagadeesan and Nayak, 2017; Xinyi, *et al*., 2017).

Phosphine fumigation has been established as the leading treatment of infested durable commodities. In Japan, Soma, *et al.,* (2018) developed aluminium phosphide generators for treating infested grain in silo bins. The generators were exposed to the free air space above the grain and recirculating air accelerated the even distribution of the gas. The decomposed generators could be removed from the bins without residue build-up in the grain. This technique was then adopted in Germany, USA and Australia.

In Germany, historically, the so called Cartox-system was used to fumigate grain in concrete silo bins by recirculating ethylene oxide and carbon dioxide. Cook, (1980) patented the recirculation of phosphine in grain silos to speed up the disinfestation. Reichmuth, (1983) used Detia Bag Blankets - exposed into the airspace of grain silos - to treat the grain with phosphine by recirculating the gas/air mixture. The blankets were removed after treatment without residue build-up on the grain (Reichmuth, 1991, 1994).

Although phosphine has remained the fumigant of choice to replace MB in many postharvest treatments, some problems with its use need attention, in particular the potential development of resistant pests (Cato, *et al*., 2017; Gautam, *et al*., 2017; Jagadeesan, *et al*., 2014; Konemann, *et al*., 2017; Rafter, *et al*., 2017; Sağlam, *et al*., 2015; Venkidusamy, *et al*., 2018).

Carmi, *et al.* (1994) used carbon dioxide from the top to speed up the even distribution of the gas throughout the grain in silos. In Australia, Winks, (1993) developed the phosphine fumigation further by continuously purging a low concentration phosphine/air mixture using a phosphine containing steel cylinder (see also Ryan and Nicholson, 2014).

Empty structure fumigation against insect pests can effectively be carried out with HCN (Steijskal, *et al*., 2017).

7.4. Regulatory considerations

Many commercial companies, researchers and governments have undertaken significant efforts to conduct research, apply for registration, and make alternatives available to users. However, the registration of chemicals for pest control, including MB, is under continuous review in many countries and the number of registered active compounds has been reduced in many countries due to the revision of their negative effects on human health and the environment.

Additional registration issues arise when treatments are needed 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 the Republic of South Africa (RSA), until recently, no fumigant alternatives to methyl bromide were registered for mills and houses. However, as previously mentioned, registration of sulfuryl fluoride has been released in January 2018 and the registration process for EDN is under way.

7.5. Update on methyl bromide alternatives research

Around the world, substantial research has been pursued in the effort to find suitable alternatives to MB for the remaining commodity and structural treatments. These include studies on alternative fumigants (Işikber, *et al*., 2015; Subramanyam, *et al*., 2014), on controlled atmospheres with elevated temperaturse or raised pressure, on microwaves, radio frequency (Uraichuen, *et al*., 2014) or ionizing radiation, or heat. Carbon dioxide and ethyl formate are also considered alternative chemicals for SC disinfestation (Bansal, *et al*., 2015; Kim, *et al*., 2015; Hamdi, *et al*., 2015; Ling, *et al*., 2016; Abdelgaleil, *et al*., 2016).

7.5.1. Alternatives to methyl bromide for high moisture dates

Pest infestations in the field often lead to serious postharvest problems in dates. Historically, dates have been disinfested prior to storage with ethyl formate, ethylene dibromide or ethylene oxide, and also MB, since the latter forces a large proportion of larvae and adults inside the dates to emerge from the fruit after which they die. This is essential to meet some religious and food quality requirements.

The specific situation of high moisture dates, at one point indicated as critical in A5 countries producing dates is now considered resolved. Phosphine fumigation, supplied by tablet formulations or a phosphine generator has largely replaced postharvest MB fumigation in Algeria, Tunisia, Egypt, Jordan, UAE, KSA and other countries. Further, treatment with radiofrequency is proposed for this purpose (Pegna, *et al*., 2017). Berrebeuh, *et al.* (2017) presented a very comprehensive description of post-harvest date processing parameters. In Israel, heat disinfestation by means of solar dryers has been successfully implemented to replace MB fumigation without negative effect on the organoleptic date properties (Navarro and Navarro, 2015).

7.5.2. Dry cure pork – one of the last critical MB uses for infested commodities

Natural pork products are susceptible to pest infestation, partially because of the lengthy storage time required for flavour development. Although pest control was achieved without MB in all other countries producing cured ham products, particular conditions present in the USA made this use very difficult to replace. The last exemption for this use was granted for 2016. Extensive research led to complete replacement of MB in this sector (Phillips et *al*., 2015).

Initial reductions in methyl bromide consumption were achieved through improvements in fumigation practice, reduced curing time and reduced frequency of fumigation. Key pests involved were the red-legged ham beetle (*Necrobia rufipes*) and the ham mite (*Tyrophagus putrescentiae*), which was particularly difficult to control to levels required in order to meet US food hygiene standards (nil tolerance on inspection). At present, a multi-university, multi-state research program is ongoing, focused on improving processing sanitation, IPM and pest control through a variety of possible fumigants and physical processes. Steam cleaning, use of approved disinfectants with acaricidal properties, dips and coatings to protect hams in storage, are used as elements of an integrated approach to replace MB (Phillips, *et al*., 2017).

7.5.3. Summary of alternatives for mills

Disinfestation of mills, empty or with residual grain and/or flour presented the biggest challenge for the quick phase out of MB in SC worldwide. Disinfestation of structures, often single premises of more than 100,000 m³ in capacity, often required huge amounts of MB to achieve rapid and thorough pest control including all developing stages of insects and mites, rodents, fungi (e.g. *Aspergillus* spp. and *Penicillium* spp., typical postharvest and storage fungi and molds) and nematodes (e.g. in infested hay).

After its introduction, the highly toxic and efficacious MB fumigant replaced other products quickly. After 1945, millions of m³ of flour mills - that had been treated earlier with hydrogen cyanide - were disinfested with MB.

Presently, flour mills in many countries around the world, such as the Philippines, Malaysia, Indonesia, the United States and the European Union, use IPM as an alternative to MB fumigation. Deep cleaning, together with residual spraying and misting are used for controlling insect pests. Pheromone traps are used for early detection of new grain pest infestations. In countries like the Philippines, Thailand, Singapore and Malaysia where phosphine is the only viable fumigant available, initiatives are under way to register sulfuryl fluoride (SF), which will expand the very limited pest management options available. In the United States, cold air is applied over the top of grain bins to reduce the re-infestation potential during storage, as most infestations occur near the top of the silos or grain storage bins.

SF was well known for pest control against wood boring pests long before becoming an option for mill disinfestation, developed in the USA in the 1990s by tits registration holder Dow Agrosciences. Researchers from many countries took part in this process, showing the efficacy of SF under various climatic conditions against various pest insects and mites, both in laboratory and field trials. Residue formation was also studied, showing that this compound had limited properties as a commodity treatment. For example, its weak efficacy against some insects eggs required high dosages preferably at high temperatures (above 25 °C). Nevertheless, this compound, where registered, is a key replacement for MB for the treatment of mills and other structures.

In the United States, Europe and others, use of heat to control insect pests in structures was actively investigated (Beckett, *et al*., 2007). This technique was well known and in use for controlling wood destroying insects in wooden parts of attics, so in many countries the expertise and technical gear was available and was easily adapted for the disinfestation of empty structures like flour mills. Cost wise, heat is more expensive than MB (about 2 $ instead of 1 $ per m³) but is still an effective method, which became more interesting as the price of MB increased. Limitations of this technique include sensitivity of wooden and plastic parts of buildings to water loss, slow heating of crevices in concrete surfaces where insects may hide, and energy consumption including its relation to global warming. Still, this method has potential and is often applied locally to infested machinery or parts of buildings. Infrared irradiation and other electromagnetic means can be used to produce heat.

The combination of thorough cleaning, use of contact insecticides or massive release of parasitic wasps as pest antagonists has become a mainstay of pest control for structures such as flour mills. Most often, all commodities within the mills, (i.e. raw grain or flour in bulk, in silos or packed), are removed in advance, as they can be possible sources of re-infestation (or as a matrix for residue formation if SF is used) and to ensure that wasps have good access to the remaining pests. Other fumigants such as hydrogen cyanide, have been reintroduced into the market to some degree.

Full site MB fumigation of flour mills has been discontinued in all countries except RSA. Where full site treatment is conducted, periodic applications with heat or alternative other fumigants, mainly SF (Drinkall, *et al*., 1996, 2003; Ducom, *et al*., 2003; Reichmuth, *et al*., 2003) and hydrogen cyanide (Rambeau, 2001) are conducted. Alternative targeted approaches may in some circumstances provide adequate insect infestation control (Belda, *et al*., 2011).

Schuh, *et al*., (2008) described in detail the combined use of SF and heat in a big mill in Germany. By applying the fumigant at elevated temperatures, a significant reduction of SF emission was possible since the increased metabolic rate of the pest insects and all their stages including eggs allowed full control with fairly low ct products of the fumigant. The computer program FUMIGUIDE - supplied by the registrant - contains the lethality data for various insects and stages for the temperature range between 20°C and 40°C, enabling the fumigator to adjust the dosage to the target temperature within the treated premise.

MBTOC considers that full site heat treatments may be similar in cost to MB use, with moderate capital investment requirements. Heat treatments may also be used to treat particular machines, difficult to treat by other methods.

In general, effective pest control in mills requires a combination of measures including localised heat treatment, fumigation with hydrogen cyanide (recently registered in Europe (Stejskal, *et al.*, 2017)) , phosphine or sulfuryl fluoride, as local registration and circumstances permit, plus various insect control measures applied as an IPM system. Pest control intervention may be guided by appropriate pest monitoring.

Changing from an established system of periodic routine MB treatment requires time to trial, refine and implement; changes to the mill and machinery structure may be needed to remove pest harbourage as part of the IPM system; MBTOC has accounted for this when assessing CUN. IPM measures, cleaning and sanitation, as well as spraying of insecticides, full site heat disinfestation of mills smaller than 10,000 m^3 and localised heat treatment of infested machinery in larger mills, should lead to a reduced requirement or even elimination of full site fumigations.

Careful inspection of imported grain is essential; if insects are intercepted separate phosphine fumigation should be conducted prior to introducing this grain into the mills and the milling process in gastight silo bins. Early detection of insect infestations in grain can be difficult, especially for immature stages of a number of pests that develop and feed inside the grain kernels, easily evading visual analysis in food industries. Are a number of diagnostic techniques are available for detecting hidden pest infestations, for example the insect fragment test, near-infrared spectroscopy, ELISA and X-ray image analysis (Hagstrum and Subramanyam, 2014; Hubert et al. Stejskal, 2009; Trematerra, 2013. Unfortunately, they carry some limitations in terms of sensitivity and cost-time compromise (Neethirajan et al., 2007; Perez-Mendoza et al., 2005). Recently, a new molecular approach based on a multiplex PCR has been developed and is commercially available for the detection and identification of most important primary pests of grain (Sola et al., 2018).

If fumigations are not sufficiently effective, survivors will multiply quickly reaching high numbers. Results may be improved with appropriate sealing, which can be checked and improved with a gas-loss test prior to fumigation (MBTOC 2002, 2006, 2010, 2014, 1990; Reichmuth, 1990). Full-site mill treatments with heat, sulfuryl fluoride or phosphine are most commonly considered as alternatives to MB treatment to control insect pests worldwide. These measures may not be feasible where sulfuryl fluoride is not registered, where phosphine needs long and costly downtime and may damage sensitive electronic items by corrosion, or where imported equipment is needed to carry out the heating is only available at high capital costs. HCN has been reconsidered as a MB alternative and newly registered for this purpose in countries in Europe (Stejskal, *et al*., 2017).

Disinfestation of parts of the building by local use of contact insecticides, biological antagonists and intensive cleaning as elements of integrated pest management is in use where other measures may not be feasible. Entoleters are put in place at the end of the chain of milling grain to obtain and/or ensure insect free products prior to loading the flour into trucks. Alternative integrated systems are practiced in many countries (Bell, 2014).

Heat treatment may be similar in cost to MB, with moderate capital investment requirements (Hofmeir, 2018; Thermonox; Kroll, 2018). Heat treatments may also be used to treat particular machines difficult to fully clean by other methods.

7.5.4. Summary of alternatives for houses

As described previously, use of SF (where registered) and/or heat are the main adopted alternatives for destroying structural pests in houses around the world. The method of choice will strongly depend on the specific pests present. For example, certain termites can be controlled easily with fairly low doses of SF that kill the egg-laying queens. In many countries termites do not occur and wood boring beetles are the target for control, requiring other conditions for effective control. In the United States, termites and carpenter ants are usually controlled using baits containing a slow acting insecticide (abamectin, boric acid, fipronil, or propoxur), which must be replenished as they deplete and may take a long time to work effectively. If the nest is exposed, it can be treated directly with an insecticide (bifenthrin, cyfluthrin, cypermethrin, deltamethrin, lambada cyhalothrin, or permethrin), often formulated as foams or dusts. If baits are not used, insects in the nest must be exposed to insecticide directly. In addition, it is important to remove possible outdoor sources of infestation (decaying wood such as old stumps, logs or lumber piles).

Under certain conditions, phosphine may be an efficient alternative to MB, especially when sensitive objects to corrosion like copper containing computers, switches, and other electric and electronic devices can be removed prior to the treatment. For termite control, killing of the queens can be achieved with fairly low concentration x time products (ct) of SF, in the range of 500 g h/m^3 (20 g/m^3 for 25 h), if the exposure occurs under gas tight sheets and well-sealed houses. These conditions are commonly known to control drywood termites (Stewart, 1957, Osbrink, *et al.*, 1987). Fumigation with hydrogen cyanide (Rambeau, *et al*., 2001) and even inert atmospheres, like nitrogen and carbon dioxide with low residual content of oxygen, are effectively used under corresponding conditions (Lewis and Haverty, 1996; Reichmuth, 2007). Strang (2014) described in detail the use of heat against pests in cultural property.

Control of wood boring insects with heat, even in heavily infested houses within highly infested areas, has been common practice for many years around the world (Hammond, 2015). Phosphine without added heat, is unlikely to be feasible due to its slower action, with fully effective treatments against wood boring pests taking several days.

In RSA, five target pests are mentioned in the critical use nomination: *Cryptotermes brevis*, the West Indian drywood termite; *Hylotrupes bajalus,* the European house borer, and the small wood and furniture beetles, *Anobium punctatum*, *Lyctus brunneus* and *Nicobium castaneum*. Lethal ct levels against these pests differ significantly and are also dependent of temperature in the structure.

For controlling low infestations of drywood termites, infestations of other wood destroying insects, particularly *Hylotrupes bajulus* (wood boring beetles), or multiple infestations of drywood termite (with or without *Hylotrupes bajulus*) SF is mainly used (MBTOC Assessment reports 1998, 2002, 2006, 2010, 2014), but also heat. Drywood termite infestations can typically be treated using the 'search-and-destroy' system, where access is possible. In this process, the nests are located acoustically, electronically or with detector dogs and eliminated by injecting insecticides. Baiting is not normally used as unlike subterranean termites, drywood termite nest in walls and ceilings and do not touch the soil. Established infestations of *Hylotrupes bajulus*, and other wood boring insects, in structural timber are likely to require full-site treatments. Alternatives to MB include heat treatments at moderately elevated temperatures around 56°C (Dreger, 2007; Lewis and Haverty, 1996). MBTOC found two suppliers of heat producing machines that are also prepared to demonstrate the technique (Hofmeir, 2018; Thermonox; Kroll, 2018). The web links also contain technical details and prices.

In RSA, wood destroying insects were found attacking various wooden structures, mainly in houses and residential units (2,560 facilities and houses, mainly brick, mortar and iron structures with wooden frames) located along coastal areas and partly inland. These buildings typically had volumes of 600 m^3 to 850 m^3, but some were much larger. About 75% require complete structure fumigations for about 1,152,000 m^3 and 25% partial fumigations (individual rooms, individual flats, calculated with about 1/5 of a 600 m^3-structure) for 384,000 m^3 leading to 41.47 tonnes plus 3.53 tonnes, or a total of 45 tonnes of MB used. About 200 structures are fumigated per month. Five target pests are cited in the nomination: *Cryptotermes brevis*, the West Indian drywood termite; *Hylotrupes bajalus*, the European house borer, and the small wood and furniture beetles, *Anobium punctatum, Lyctus brunneus* and *Nicobium castaneum*.

For SF use, the computer program (FUMIGUIDE, provided by the registrant) will determine the necessary dosage for full control of the specific pest species in the future. Treatments are carried out either on entire houses under PVC 450 µm tarpaulin or on gas-tight sealed parts of structures. Heat treatment, a technique used under similar circumstances in many countries, was regarded by the Party as not feasible due to the high investment associated with importing heating units and excessive running costs compared with MB treatment, as well as poor access of the heat into some parts of the roof spaces. Heat treatment for control of wood boring pests is also not acceptable for obtaining a "Free of Insects Certificate", required for a sale agreement to proceed. This certificate is only produced after inspection from pertinent authorities.

Registration of sulfuryl fluoride (SF), is now complete in RSA and fumigation with this product is possible for both houses and mills included in the CUNs. As expected, some time is needed to set up supply and training systems, so the 2018 registration is likely be followed by about another two years of preparation for the fumigating companies to fully enter with SF into the practice of fumigation. The phase in of SF of about 30% could happen in 2019, leading to a significant reduction of the use of MB for this sector within the next years.

In the case of wood boring insect pests, control of the egg stage will require higher ct products than those used to control termites since controlling the queens is enough to wipe out the termite infestation. Even with fairly low ct products in the range of 500 g h/m^3 (20 g/m^3 for 25 h), exposure under sheeted and well-sealed houses will lead to complete control. Such treatments are known to control drywood termites since many years (Stewart, 1957; Osbrink, *et al.,* 1987).

7.5.5. Aircraft disinfestation

The company Advance Fumigation and Pest Control Limited provides Aircraft Disinfestation services primarily at London Heathrow and Gatwick airports and by arrangement at other regional airports.

Because of the increase in bed bug infestations on board aircrafts, the company Heat Go has, in conjunction with Global Aviation Pest Solutions (GA-PS) pioneered a method of thermal disinfestation where by hot air is carefully introduced into the aircraft cabin, then dissipated equally throughout the infested zone of the cabin. The cabin temperature is constantly monitored to ensure that at no time during the treatment could the temperature reach a critical threshold. This procedure has been approved by Boeing (non-technical objection NTO has been issued for all fleet types) and recently Airbus Industry have issued a Technical Adaptation (TA) applicable to A330 and A340 fleet types. This company has undertaken 25 aircraft heat disinfestation treatments over the last three years with no damage or deleterious effect to any aircraft cabin, furnishings or equipment.

7.6. Special review on controlling pest eggs with sulfuryl fluoride

SF fumigation has been adopted by several Parties as the main MB alternative for some major postharvest and structural uses. The lack of full effectiveness of SF against eggs of pests is mentioned in the literature (Flingelli, *et al*., 2012; Buckley and Thoms, 2012) and was an issue in several critical use nominations. MBTOC collated available data on the fumigation of eggs of stored product insects and especially those occurring in rice and flourmills, the situations of particular concern where SF is a potential or actual methyl bromide replacement (MBTOC, 2015; TEAP, 2011) Summaries of published mortality data and lethal responses of eggs of 28 economically important insects and mites following fumigation with sulfuryl fluoride at 20°C are presented. Pest species are sorted into groups that are probably, possibly or unlikely to be controlled at 1,500 g h m^{-3} at 26.7°C (80° F) and 24 h exposure. This ct-product is the maximum rate that is allowed under the registration of SF as a pesticide ('label' rate) for control of all developmental stages of stored product pest, such as specified in the 'Fumiguide', a proprietary guide to the use of SF as a postharvest and structural fumigant. Due to the limited effect towards eggs, the guaranteed control of this developing stage is often exempted from the label. In practice, the additional elevation of the temperature within the infested area or addition of another toxicant may ensure also the complete control of this stage.

7.7. Other alternatives

Research on the use of propylene oxide (PPO) and carbon dioxide (Gautam, *et al.,* 2014), PPO with carbon dioxide and SF (Jimenez, *et al*., 2014) and PPO with ethyl formate (Wolmarans, *et al*., 2017) as alternatives to methyl bromide continues, and these chemicals are being adopted in several countries. Other chemical options include methyl iodide, phosphine (Ertürk, *et al*., 2018), fumigation under hermetic vacuum (Kumar, *et al*., 2017), phosphine under low pressure (Athanassiou, *et al*., 2016; Şen, *et al*., 2015), hydrogen cyanide (HCN) (Stejskal, *et al*., 2017), methyl isothiocyanate (MITC) (Ducom, 1994) and carbon dioxide (CO_2), ethanedinitrile (EDN) (Thalavaisundaram and McConville, 2017), ozone (Grisales, *et al*., 2017; Hansen, *et al*., 2014; Işikber, *et al*., 2015; Pandiselvam, *et al*., 2017; Subramanyam, *et al*., 2014), hermetic storage (Murdock and Baributsa, 2014; Navarro and Navarro, 2014; Prasantha, *et al*., 2014), hermetic storage and heat (Bruin, *et al*., 2014), nitrogen and heat (Athanassiou, *et al*., 2016), nitric oxide (Liu, *et al*., 2017), chlorine dioxide (Han, *et al*., 2016; Xinyi, *et al*., 2017), carbonyl sulfide (COS), as well as monoterpenoids (*Sağlam*, et al., 2013).

Adoption of Controlled Atmospheres (CA) and Modified Atmospheres (MA) as a means to control pests in stored commodities continues to increase. CA and MA treatments offer large commercial and small packing houses, even farmers, effective postharvest pest control options useful for most durable commodities (and even non-food commodities such as museum and historical artefacts), under a very wide range of circumstances, without using chemical fumigants. The CA treatment is based on creating a low-oxygen environment within a structure causing death of pests.

Use of irradiation as a phytosanitary treatment has increased with an undetermined part of this volume directly replacing methyl bromide fumigation (Mansour, 2016). Also, radio frequency is discussed for the treatment of infested dates (Pegna, *et al*., 2017).

Plenty of scientific activities to search for alternatives to MB are dedicated towards essential oils and extracts of various species of plants and their leaves, branches and fruits as possible insecticides or repellents (Alkan, *et al*., 2018; Babarinde, *et al*., 2017). Campolo, *et al.*, 2014; Ertürk, *et al*., 2017b, Nenaah, 2014; Oboh, *et al.*, 2017) and diatomaceous earths (Ertürk, *et al*., 2017a; Sağlam, *et al*., 2017)

In Europe - especially in Germany - and in the US, parasitic wasps and predators now comprise a significant part of pest management programs for facilities and stored products. Biological control is applied worldwide during pre-harvest for arthropod pest management in a number of commercial crops. In comparison, biological control is not yet considered an option during the post-harvest processing chain, except in few examples in some countries. In Europe - especially in Germany - and in the US, parasitic wasps and predators now comprise a significant part of pest management programs for facilities and stored products. However, the increase of resistance of many pest species towards insecticides, the reduction in the number of active registered compounds and, the adverse impacts on the environment are also relevant reasons to develop alternatives to the use of toxic compounds for stored products pest control (Riudavets, 2018). Heat, cold and essential oils (Guo, *et al*., 2016), are further options being researched and for which adoption has occurred around the world.

7.8. Integrated Pest Management

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. A reduction in use of pest control chemicals in food processing, and using less toxic chemicals is a goal of most IPM practitioners. Modern strategies concentrate on approaches where the infestation itself is limited at an early stage to prevent later mass growth and necessities for acute and immediate control.

Kostyukovsky, *et al.* (2016) propose to implement especially ecofriendly volatile extracts of plants into this concept. Biological control addresses the need of finding ways to attack the first intruders into a storage system and/or release biological antagonists like parasitic wasps to control stages of insect pests at a low level detected by traps with pheromone baits.

7.9. References

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8

Chapter 8. Economic Issues

8.1. Introduction

In the case of most CUNs relatively simple partial budget analyses are sufficient to establish economic (in)feasibility.

Australian and Canadian Parties may shift the emphasis in their respective nominations to the issue of economic infeasibility. MBTOC also anticipates that it may be asked to comment on the type(s) of economic evaluation that will be required with QPS uses of methyl bromide. This will include analysis of:

- The costs of eradication of exotic or invasive species of plants or pests
- The economic costs of exposure to exotic or invasive species of plants or pests
- The costs of trade distortions created by non-tariff barriers.

8.2. Economic feasibility of alternatives to MB

No CUN has to date relied on an argument of economic infeasibility to motivate the use of methyl bromide. Despite this, during CUN evaluations MBTOC tries to assess the financial feasibility of alternatives (Decision IX/6) with the information provided in the CUN because an alternative may be considered technically feasible, but may not be economically feasible. MBTOC then reports on the economic arguments put forward in the CUN.

Measurement of the economic implications of the use of methyl bromide or an alternative can in most cases be done satisfactorily by means of partial budgeting (e.g. Mattner *et al.*, 2017; Rysin *et al.*, 2015) (with sensitivity analysis if required – cf Wolverton, 2014). This has the advantage of simplicity. However, because prices can change stochastically, it may become necessary to use more stable estimates of supply and demand in a partial equilibrium analysis, or even to conduct a general equilibrium analysis where a change in the market under consideration has knock-on effects on other markets (e.g. Miller and Mann, 2017).

Likewise, conventional economic analysis only considers the 'visible' differences in outcome as a result of the use of methyl bromide or it's alternatives. For example, a partial budget analysis only measures changes in the user's revenue, while the benefits to society of less ozone depletion are ignored. Again, it is possible to include these benefits and costs with techniques such as 'willingness to pay' (e.g. Pappalardo, *et al*., 2017) or other means of shadow pricing (Carroll, *et al.*, 2017).

However, all of these analyses can become complicated, and require a lot of data, hence the simplest techniques should be used where feasible. This is also reflected in the literature, which is dominated by partial budgeting exercises.

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Annex 1

Annex 1. Methyl Bromide Technical Options Committee - Committee Structure

MBTOC structure as at 31 December 2018

Co chairs

Ian Porter	La Trobe University Australia
Marta Pizano	Consultant Colombia

Subcommittee chairs, chapter lead authors for this Assessment

- **Chapter 1 -** Executive summary
- **Chapter 2 -** Introduction to the assessment - lead author, *Marta Pizano.*
- **Chapter 3 -** Methyl Bromide production and consumption (controlled uses) - lead author, *Marta Pizano.*
- **Chapter 4 -** Methyl Bromide emissions. Lead authors *Ian Porter, Jonathan Banks*
- **Chapter 5 –** Quarantine and Pre-shipment - *Marta Pizano, Ian Porter, Ken Glassey*
- **Chapter 6 -**Alternatives to Methyl Bromide for soil treatment – lead authors *Mohamed Besri*, *Ian Porter*
- **Chapter 7 -** Alternatives for Treatment of Post-Harvest Commodities and Structures –*Christoph Reichmuth*.

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. Disclosures of Interest (DOI) are posted at the Ozone Secretariat website and are updated as necessary, once a year at minimum. They can be accessed at http://ozone.unep.org/science/assessment/teap

Table A-1 below contains the lists of MBTOC members at December 31st, 2018.

TABLE A-1: MBTOC MEMBERS AS AT DECEMBER 31ST, 2018

Chairs		**Affiliation**	**Country**
1. Ms. Marta Pizano	F	Consultant, Hortitecnia Ltda.	Colombia, A5
2. Dr. Ian Porter	M	La Trobe University	Australia, Non-A5
Members		**Affiliation**	**Country**
3. Dr. Aocheng Cao	M	Institute of Plant Protection, Chinese Academy ofr Agricultural Sciences	China, A 5
4. Dr. Jonathan Banks	M	Consultant	Australia, Non-A5
5. Prof. Mohamed Besri	M	Dept. of Plant Pathology, Institut Agronomique et Vétérinaire Hassan II	Morocco, A5
6. Mr. Fred Bergwerff	M	ECO2, Netherlands	Netherlands, Non-A5
7. Sait Erturk	M	Ministry of Agriculture	Turkey, A-5
8. Mr. Ken Glassey	M	Senior Advisor Operational Standards Biosecurity New Zealand, Ministry of Agriculture and Forestry Wellington	New Zealand Non- A5
9. Mr. Alfredo Gonzalez	M	Fumigator	Philippines, A5
10. Dr Rosalind James	F	United States Department of Agriculture	USA, Non-A5
11. Mr. Takashi Misumi	M	Quarantine Disinfestation Technology Section, Ministry of Agriculture, Forestry and Fisheries MAFF	Japan, Non A5
12. Prof. Christoph Reichmuth	M	Professor, Humboldt University Berlin. Retired from JKI Germany	Germany, Non-A5
13. Mr. Jordi Riudavets	M	IRTA-Department of Plant Protection.	Spain, Non-A5
14. Mr. Akio Tateya	M	Technical Adviser, Japan Fumigation Technology Association	Japan, non-A5
15. Mr. Alejandro Valeiro	M	National Project Coordinator, National Institute for Agriculture and Technology, Tucumán	Argentina, A 5
16. Prof. Nick Vink	M	University of Stellenbosch, Department of Agricultural Economics	South Africa, A 5
TOTALS	16		F= 2 M = 14 A5= 7 non A5 = 9