The status of key substitutes to MB and emission reduction strategies are summarised below, and further detailed in the main document.

Fumigant Substitutes

Methyl iodide

- Key component of industry's plan to transition away from MB/Pic.
- Technically feasible for use in the Victorian runner industry because it controls soil-borne pathogens and weeds as effectively as MB/Pic without causing crop phytotoxicity.
- Saluterra Pty Ltd is seeking registration of MI in Australia. A decision by APVMA on approval for use in the strawberry industry is scheduled by 17 July 2022.

1,3-D/Pic Products

- Formulations containing 100:0, 65:35, 40:60, and 20:80 mixtures of 1,3-D/Pic are registered for use in soils in Australia.
- Not technically feasible due to inadequate pathogen control at greater soil depths, higher incidences of soil-borne disease in runner crops and subsequent fruit crops, and crop phytotoxicity (Table 2 & Appendix 1.7).
- Not approved for use by VSICA because formulations of 1,3-D/Pic are less effective in controlling pathogens than MB/Pic. Their use would result in a complete loss to growers because runners are unmarketable.

Chloropicrin (Pic)

- Registered for use in soils in Australia.
- Not technically feasible because it does not control pathogens and weeds as effectively as MB/Pic and reduces runner yields and subsequent fruit yields (Table 2).
- Not approved for use by VSICA. Its use would result in a complete loss to growers because runners are unmarketable.

Pic or 1,3-D co-applied with methyl isothiocyanate (MITC) generators

- The MITC-generators, dazomet, metham sodium and metham potassium, are registered for use in soil in Australia.
- A metham spading rig was imported into Australia from Europe in 2013 for application of MITC in trials, but has proved an ineffective application method on clay soils at Toolangi, Victoria.
- Not technically feasible because application of MITC (as spade injected metham sodium or incorporated dazomet) on its own or co-applied with Pic and 1,3-D/Pic caused significant phytotoxicity in runner crops, and does not control soil-borne pathogens as effectively as MB/Pic.

- Not approved for use by VSICA. Its use would result in a complete loss to growers because runners are unmarketable.

Pic or 1,3-D/Pic co-applied with herbicides

- The integrated use of the pre-emergent herbicide isoxaben and the post-emergent herbicides phenmedipham and fluazifop-p with Pic or 1,3-D/Pic (20:80) can improve weed control without causing phytotoxicity to runner crops (Appendix 1.7).
- Not technically feasible because these combinations do not control soil-borne pathogens as effectively as MB/Pic, and may result in lower berry yields in the subsequent fruit crop (Table 2 & Appendix 1.7)
- Chemical companies have decided not to proceed with registration of isoxaben and phenmedipham in runner crops for commercial reasons.
- Fluazifop-p is registered for strawberry, but does not provide adequate weed control unless integrated with the use of phenmedipham and isoxaben.
- Not approved for use by VSICA. Its use would result in a complete loss to growers because runners are unmarketable.

Ethanedinitrile (EDN)

- Registered for use in soils in Australia.
- Showing promise, but not yet technically feasible because of inadequate pathogen control compared with MB/Pic, particularly at greater soil depths.
- Current trials showed that broad acre application of EDN under TIF using hot glue systems did not control pathogens to adequate levels (Appendix 2.7)
- Previous evidence from trials at Toolangi (see AUS02 CUN23) and published research shows that EDN may cause ammonium toxicity in some crops (Stevens et al., 2020b), and this may explain why EDN treatment causes considerably lower runner yields than MB/Pic.
- The registrant has made the commercial decision to target the use of EDN for turf crops that are not affected by ammonium toxicity and that only require pest control at shallow depths (Stevens et al., 2020a; 2021), and not strawberry runner crops at Toolangi.
- Not approved for use by VSICA. Its use would result in a complete loss to growers because runners are unmarketable.

EDN + Pic

- These products are individually registered for use in soils in Australia.
- Recent trials show that co-application of EDN and Pic does not improve control of pathogens at greater depths compared with EDN alone (see Table 2 & AUS02 CUN23).

- It is not clear whether co-application of these products will require a separate registration for commercial use.
- EDN may cause ammonium toxicity in strawberry crops (see above).
- Not approved for use by VSICA. Its use would result in a complete loss to growers because runners are unmarketable.

Dimethyl Disulphide (DMDS)

- Not registered for use in Australia.
- DMDS and DMDS/Pic were imported into Australia in 2014 for trial purposes.
- Not technically feasible due to inadequate pathogen and weed control compared with MB/Pic, particularly at greater soil depths (Table 2).
- The registrants have recommenced registration process for this substitute based on recent data showing efficacy against *M. phaseolina* (Appendix 3.7)
- Not available to runner growers. Registration may take a considerable time because DMDS is a new pesticide chemistry in Australia.

Recaptured Methyl Bromide from Quarantine Applications

- Research has examined the amendment of soils with carbon waste containing recaptured QPS MB as an alternative to soil disinfestation with non-QPS MB.
- Recaptured QPS MB on carbon has provided unreliable control of pathogens and weeds due to its inconsistent content of MB (Table 2).
- Registration of this by-product is required because the properties of recaptured MB on activated carbon must be reviewed compared with the known properties of virgin MB.
- Long way from commercial availability because there is no current commitment from chemical companies to improve the consistency of formulation to support registration.
- Not registered and not available to runner growers.

Allyl isothiocyanate (AITC) and AITC/Pic

- Dominus® (AITC) and Ally® (AITC/Pic) were imported into Australia in 2018 for trials.
- Trials are completed, but there is no commitment from the chemical company to pursue registration in Australia. The products were withdrawn from registration in the USA.
- Not registered and not available to Victorian runner growers.

Non-Fumigant Alternatives

Soil-less Systems

- Already adopted for commercial production of Nucleus, Foundation and Mother stock runners in the multiplication scheme (first, second and third generations, respectively).
- Partial budget analysis shows that soil-less systems (plug plants) are currently not economically feasible (more than twice as costly as bare-rooted runners grown in MB/Pic-treated soil) for production of the last generation of runners (Certified stock) (see Part E 16). Outdoor systems for production of tips do not improve the economics of plug plants compared with protected systems because runner yields are too low (88% lower runner yields, Milinkovic et al., 2017).
- Not technically feasible for Certified stock because the subsequent fruit yields from runners produced in soil-less systems are mostly lower than those from bare-rooted runners produced in MB/Pic-treated soil (Part C 8g).
- Commercial substrate from accredited sources can contain pathogens of strawberry, including *M. phaseolina* (see AUS02 CUN20). Plug plants produced in untreated substrate are not approved for Certification.

Biofumigation

- Not technically feasible due to inadequate weed and pathogen control.
- Biofumigant crops do not release the same concentration of isothiocyanates into soil as commercial fumigants. Consequently, biofumigants have not resulted in the same level of pathogen and weed control as commercial fumigants (Mattner et al., 2008).
- Integration of biofumigant crops with substitute fumigants can contribute to control of soil-borne pathogens (AUS02 CUN23), but not to levels equivalent MB/Pic.
- Fully adopted by runner growers at Toolangi, as a complimentary treatment to soil fumigation with MB/Pic.

Microwave

- Not currently technically feasible due to inadequate control of soil-borne pathogens compared with MB/Pic, particularly at greater depths (Table 2 & Appendix 4.7). Research is underway to improve the effectiveness of microwave treatment by using longer wavelengths to target soil treatment at greater depths.
- Analysis shows that microwave is economically viable if technical issues can be overcome.
- Recently completed research shows that microwave has a beneficial impact on soil biology for crop growth (Khan et al., 2019; Khan et al., 2020).
- A new company (GroWave Pty Ltd) is now leading the development of microwave and has prioritised its commercialisation in the runner industry at Toolangi.
- Not currently available to runner growers because no commercial rigs are available and research to date does not support consistent efficacy.

Anaerobic Soil Disinfestation

- Pot trials with this method have commenced, but so far have delivered inconsistent pathogen control.
- Long way from commercial trials due to difficulties with implementation on steep slopes, which occur in the Victorian runner industry.

Steam

- Very difficult to implement for soil disinfestation in clay soils containing rocks and steep slopes at Toolangi for production of the certified generation of runners.
- Preliminary trials with a small prototype unit showed that steam did not control pathogens and weeds at Toolangi compared with untreated soils (Table 2).
- Not economically viable compared with MB/Pic and microwave treatment of soil.
- Study tours have been conducted to view steam units in Europe and California, but these are currently not commercially viable (Stanghellini, 2017).

Emission Reduction Strategies

Lower Dose Methyl Bromide

- On-going research since 2013 does not support bio-equivalency and registration of rates below 25 g $MB.m^{-2}$ (Table 2 & Appendix 6.7).
- Rates below 25 g $MB.m^{-2}$ not registered and not available to Victorian runner growers.

Rotation of MB with Alternative Fumigants

- Not currently technically feasible because of lower pathogen control and failure to control volunteer strawberries (see AUS02 CUN18 for details).

Impermeable Barrier Films

- Previous trials demonstrated that impermeable barrier films do not retain MB for longer periods in the high organic soils at Toolangi than standard LDPE films (AUS02 CUN16).
- Currently, impermeable barrier films do not offer a reliable mechanism for reducing application rates of MB because they do not remain in place for long enough in the runner industry (due to high winds).
- Traditional gluing methods for TIF have not proven adequate under the conditions at Toolangi.
- Recent trials showed that the hot-glue system for joining TIF sheets was not adequate (Appendix 2.7).
- Rates below 25 g $MB.m^{-2}$ are not registered and not available to Victorian runner growers under impermeable barrier films or standard LDPE films.