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 has been shown to control soil-borne pathogens and weeds as effectively as MB/Pic without causing crop phytotoxicity.
- Recent research shows that MI/Pic eradicates *M. phaseolina* in infested crowns buried in the soil, and that iodine species do not accumulate to harmful levels in soil treated with MI/Pic.
- A new chemical company is registering MI in Australia. Decision by APVMA on approval for use in strawberry industry expected in first half of 2021.

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.
- Current trials are evaluating improved methods for applying barrier films with 1,3-D/Pic, and different timings of application on pathogen control. Results will be available in October 2020.
- 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.
- Current trials are evaluating co-application of Pic with higher rates of EDN for pathogen control. Results will be available in October 2020.
- 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.
- Not technically feasible because these combinations do not control soil-borne pathogens as effectively as MB/Pic.
- 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.
- EDN must be applied under TIF to comply with the product label. Trials show these films cannot yet be joined under the conditions at Toolangi using hot-glue systems.
- Current trials are evaluating the application of EDN at greater depths with a new rig (Figure 1a) and higher application rates. Results will be available in October 2020.
- 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.
- Co-application of EDN and Pic is showing promise but is not technically feasible because it does not control pathogens as effectively as MB/Pic at greater soil depths.
- It is not clear whether co-application of these products will require a separate registration for commercial use.
- EDN + Pic must be applied under TIF to comply with the product label. Trials show these films cannot be joined under the conditions at Toolangi using hot-glue systems.
- Current trials are evaluating the application of EDN + Pic at greater depths with a new rig (Figure 1a) and higher application rates. Results will be available in October 2020.
- 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.
- Arkema are no longer pursuing registration of DMDS and DMDS/Pic in Australia. Not available to runner growers.

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.
- 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.

Propylene oxide (PPO)

- Not registered for use in soils in Australia.
- Plans were in place to import PPO and PPO/Pic into Australia for trials in the runner industry in 2016/17. However, instability of formulations of PPO in-cylinder prevented this importation. The registrant is conducting studies to improve the
stability of PPO in-cylinder before this fumigant can be imported into and trialled in Australia.

- Not registered and not available to Victorian runner growers. Registration applications for PPO and PPO/Pic could only be prepared when two years of efficacy trials are completed.
- Very long way from potential registration, 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 have commenced but there is no commitment from the chemical company to pursue registration in Australia.
- 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).
- 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* (Appendix I). 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 does not provide adequate control of soil-borne pathogens compared with MB/Pic.
**Microwave**

- Not currently technically feasible due to inadequate control of soil-borne pathogens compared with MB/Pic, particularly at greater depths. Research is underway to improve the effectiveness of microwave treatment by using longer exposure times and different 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).
- A new company (GroWave) is now leading the development of microwave and has prioritised its commercialisation in the runner industry at Toolangi.
- Current trials are evaluating longer wavelengths and exposure times of microwave on soil heating and control of pathogens. Results will be available in October 2020.
- Not currently available to runner growers because no commercial rigs are available.

**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.
- 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 economically viable (Stanghellini, 2017).

**Emission Reduction Strategies**

**Lower Dose Methyl Bromide**

- On-going research does not support bioequivalency and registration of rates below 25 g MB.m$^{-2}$ (see AUS02 CUN15).
- Current trials are evaluating lower rates of MB/Pic under TIF. Results will be available in October 2020.
- 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).

- Gluing (including hot-glue) methods for TIF have not proven adequate under the conditions at Toolangi. New trials will evaluate the use of perforated LDPE edges for gluing TIF.

- 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.
Figure 1. (a) New rig for applying fumigants at greater depths (see inset) in trials in the strawberry runner industry in 2019/20. (b) Former rig for applying fumigants in trials in the runner industry in 2018/19 featuring duck-foot tyres (inset). This rig did not prove robust at applying fumigants at greater depths and required modification (see above).