REPORT

Quick scan alternatives to the fumigant Phosphine
Quick scan naar alternatieven voor het bestrijdingsmiddel fosfine

Review and analysis of alternatives for the use of the fumigant phosphine in the agro supply chain

Client: Ministry of Infrastructure & Watermanagement, the Netherlands

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Quick scan naar alternatieven voor het bestrijdingsmiddel fosfine

Subtitle: Review and analysis of alternatives for the use of the fumigant phosphine in the agro supply chain
Identificatie en analyse van alternatieven voor het gebruik van het bestrijdingsmiddel fosfine tegen ongedierte in de agro toeleveringsketen

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Executive Summary - UK

The reason for this quick scan

This report summarizes a preliminary scan on the alternatives to the use of the fumigant phosphine in the agro supply chain. Phosphine is used in this chain against vermin. This scan has been commissioned by the Ministry of Infrastructure and Water Management of the Netherlands and prepared by Royal HaskoningDHV (RHDHV), after an event of uncontrolled phosphine gas exposure in 2019, released from the cargo in a barge.

Approach to the quick scan

The scope of the scan goes beyond the identification of alternative substances replacing phosphine but also examines alternative methods to assure a safer fumigation process. All alternatives will be ranked according to their hierarchy of control (HoC), an approach applied in several chemical legislations when looking for safer alternatives. These are the following 5 levels of control:

- Level 1: Highest level of control by removing the hazardous substance and achieving the result without a chemical
- Level 2: Substitution: substitute the hazardous substance with a less hazardous substance
- Level 3: Engineering controls: technical measures that separate the worker from the hazard or control the hazard with other technical mitigation measures
- Level 4: Administrative controls: organizational and procedural improvements to increase safety
- Level 5: Personal Protective Equipment (PPE): lowest level of control

The quick scan consisted of the following steps:

- A literature review and scan of all available literature on alternative fumigation methods
- Five interviews with relevant stakeholders, selected from 15 possible candidates, in the Netherlands

Results

The following categories of fumigation methods have been identified in the literature, listed in Table I (see Annex I), as possible alternatives to phosphine gas against vermin and consolidated in the following categories, in Table II (see Annex II) :

- Fumigation based on a toxic effect (HoC: level 2)
- Fumigation based on asphyxiation (HoC: Level 2)
- Combined method toxic / asphyxiation (HoC: Level 2)
- Physical methods (HoC: level 1)
- Mechanical methods (HoC: level 1)
- Methods to improve the safety of phosphine use as fumigant (HoC: level 3, 4 and 5)

Regulatory

The use of fumigants in the EU are regulated under the Biocidal Product Regulation (BPR) and/or the Plant Protection Products Regulation (PPPR), depending on the scope of the use. There is no global mandatory regulatory framework for the use of fumigants in storage and transport of bulkcargo, only recommendations in the context of international organisations.

General conclusions

This quick scan for alternatives resulted in the identification of limited options that can be applied on the short term.

Sustainable alternatives based on asphyxiation with nitrogen or carbon dioxide are not sufficiently operational or registered for use in all modalities of transport and not cost competitive compared to the existing practices for overseas bulk transport. It can only be applied now as an alternative for phosphine in relatively small quantities of cargo in contained packaging (from big bags to containers) and high added

value food products (for instance nuts, coffee, fruit, etc). It is not feasible for most of the transport of agribulk by sea vessels, for cost and technical reasons.

The identified optional alternative fumigants, based on a toxic effect, do not seem to be sufficiently operational or registered for use in the supply chain of agribulk. Toxic alternative agents will also be toxic to humans and at the same time some are harmful for the environment (f.i. greenhouse gases).

For the foreseeable future fumigation with phosphine, according to RHDHV, will be expected to be the preference in combatting vermin worldwide for transport overseas. From a regulatory perspective the (safe) use of phosphine gas generated with phosphide pellets is regulated in Europe under the BPR (Biocidal Product Regulation) and PPPR (Plant Protection Product Regulation). Some improvement of safety measures can be made and are already in preparation by het College voor de toelating van gewasbeschermingsmiddelen en biociden (Ctgb).The route to impose measures via a mandatory global framework on transport (e.g. International Maritime Organization IMO conventions) to ensure and regulate safe use of phosphine gas is considered not feasible (no priority in global context).
The occasional mandatory use of phosphide tablets in some non-EU countries of origin before transport overseas, is an obstacle to phase out phosphine gas use. However, safer methods using phosphide pellets, can be implemented in the short term.

Resistance of vermin to phosphine has not been identified as an issue during the interviews but has been recorded as a risk in the literature. This may increase in the future and requires monitoring.

Short term recommendations
In the short term there are no available alternatives for fumigation of grains and animal feed materials, which could replace the use of phosphine at an effective and feasible scale in the supply chain.

To reduce the risk of the use of phosphine gas releasing agents, all efforts must be focused on safer use of phosphine with technical and organisational means. The report “Ketenanalyse gegaste lading ” (Annex 1 to the letter to the Dutch Parliament, April 4, 2022), proposes detailed measures to improve the safety of the use of it, from a technical point of view as well as from an organisational point of view (the latter includes the regulatory perspective).
The core conclusions are that effectiveness and safe use conditions of phosphine use can only be met if, after fumigation the stored product ready for transport is sufficiently ventilated and remaining pellets can be removed before transhipment at the destination. This can be achieved when the phosphide pellets are applied in sleeves or plates, which can be removed easily. Stricter communication procedures and registration before transhipment operations will significantly contribute to the removal of residual phosphide pellets before any other handling in the supply chain and therefor reduce the risks.

As the improvements cannot be enforced with a regulatory framework globally it is recommended that the large agri trading companies importing the agriproduct to the EU must impose the same conditions as mentioned above in the contracts for overseas bulk transport from non-EU countries. The use of loose pellets should be banned at a global level to lower the risks to an acceptable level.

Within the EU discussions are ongoing regarding a ban of fumigation with phosphide pellets, applied in any form (loose pellets and sleeves or plates) during transport. The time of transport between source and destination within the EU is too short for effective ventilation of the fumigated cargo.

Once the measures mentioned above have been realized, the effectiveness should be monitored Europe wide, as well as non-compliances and, worse, incidents. Based on the collected monitoring data further steps within the EU and globally can be considered.

Long term recommendations

The results of the above-mentioned monitoring should be evaluated periodically. If these do not lead to the required results and non-compliances continue to be recorded or worse, incidents still occur, other, more effective measures should be implemented.

These measures should aim at eliminating the use of phosphine in the supply chain, applying practical methods that can be easily implemented, higher in the Hierarchy of Control. The measures are most effective when looking at the whole supply chain holistically and applying an IPM (Integrated Pest Management) approach. Subsequent measures, following the Hierarchy of Control, could be possible:

- Highest level of control: Eliminating the need for the use of any substance: imposing a strict hygiene control and applying mechanical measures in the whole supply chain, based on a IPM approach. Assure a legislative framework within the EU, with additional contract conditions imposed by the global players in the global supply requiring and monitoring these measures worldwide. Start with dedicated food and feed supply chains with high added value and scale up to bulk products.
- Second level of control: Substitution of a toxic substance with a non-toxic substance: for example, using the asphyxiation effect of CO_2 or N_2; these substances have to be registered for application within the EU within the PPPR or BPR (the EU Regulatory framework) depending on the scope of the use.
- Second level of control: Substitution of a toxic substance with less toxic substance: for example, using a toxic fumigant (ethyl formate) combined with the asphyxiation effect of nitrogen or carbon dioxide; these substances and products have to be registered for application in the EU within the PPPR or BPR framework.
- Third combined with the fourth levels of control: improve the safety of the use of phosphine gas releasing agents, using sleeves or plates and the authorized instructions for use procedures. This can be implemented in the EU within the PPPR or BPR framework and globally through contract conditions and IMO recommendations.
- As there are no regulatory options applicable on the whole supply chain worldwide, contract conditions only can be imposed from source to end user and need to play a more important role in the effective application of IPM and alternatives to fumigation with phosphine gas releasing agents. To be effective these conditions should be geographically complementary and technically aligned with the EU regulatory framework. The large global food and feed traders need to play an important role in applying and monitoring these conditions from the non-EU source until the point it enters in the EU.
- As costs are an obstacle for these measures for bulk food and feed, application of the IPM principles with the high value products for human consumption separated from animal feed products can be a feasible start. After sharing the (positive) experience bulk food and feed products may follow.

Samenvatting - NL

De reden voor deze quick scan

Dit rapport vat een quick scan samen van de alternatieven voor het gebruik van het ontsmettingsmiddel fosfine in de agroketen (fumigatie). Fosfine wordt in deze keten gebruikt tegen ongedierte. Deze scan is in opdracht van het Ministerie van Infrastructuur en Waterstaat van Nederland opgesteld door Royal HaskoningDHV (RHDHV), na een gebeurtenis van ongecontroleerde blootstelling aan fosfinegas in 2019, vrijgekomen uit de lading in een binnenschip.

Aanpak van de quick scan

De reikwijdte van deze scan gaat verder dan enkel de identificatie van alternatieve stoffen die fosfine vervangen, maar onderzoekt ook alternatieve methoden om een veiliger fumigatieproces te garanderen. Alle alternatieven worden gerangschikt volgens hun hiërarchie van beheersing of “hierarchy of control” (HoC), een benadering die in verschillende (chemische) wetgeving wordt gebruikt bij het zoeken naar veiligere alternatieven. Dit zijn de 5 volgende niveaus van controle:

- Niveau 1: Hoogste niveau van beheersing door het verwijderen van de gevaarlijke stof en het bereiken van het resultaat zonder een chemische stof
- Niveau 2: Vervanging: vervang de gevaarlijke stof door een minder gevaarlijke stof
- Niveau 3: Technische beheersmaatregelen: technische maatregelen die de werknemer van het gevaar scheiden of het gevaar beheersen met andere technische beperkende maatregelen
- Niveau 4: Administratieve controles: organisatorische en procedurele verbeteringen om de veiligheid te verhogen
- Niveau 5: Persoonlijke Beschermingsmiddelen (PBM): laagste niveau van controle

Deze quick scan bestaat uit de volgende stappen:

- Een een scan van beschikbare literatuur over alternatieve fumigatiemethoden
- Vijf interviews met relevante stakeholders, geselecteerd uit 15 mogelijke kandidaten, in Nederland

Resultaten

De volgende categorieën fumigatiemethoden zijn in de literatuur geïdentificeerd, vermeld in tabel I (zie bijlage I), als mogelijke alternatieven voor fosfinegas tegen ongedierte en geconsolideerd in de volgende categorieën, in tabel II (zie bijlage II):

- Fumigatie op basis van een toxisch effect (HoC: niveau 2)
- Fumigatie op basis van verstikking (HoC: Level 2)
- Gecombineerde methode toxisch / verstikking (HoC: Level 2)
- Fysische methoden (HoC: niveau 1)
- Mechanische methoden (HoC: niveau 1)
- Methoden om de veiligheid van het gebruik van fosfine als ontsmettingsmiddel te verbeteren (HoC: niveau 3, 4 en 5)

Regelgeving

Het gebruik van ontsmettingsmiddelen in de EU is gereguleerd onder de Biociden verordening (BPR) en/of de Gewasbeschermingsmiddelen verordening (PPPR), afhankelijk van de omvang van het gebruik. Er is geen wereldwijd verplicht regelgevingskader voor het gebruik van ontsmettingsmiddelen bij de opslag en het vervoer van bulklading, alleen aanbevelingen in het kader van internationale organisaties.

Algemene conclusies
Deze quick scan naar alternatieven voor het gebruik van fosfinegas uit fosfidetabletten toegepast in voeding en diervoeder als ongediertebestrijding resulteerde in de identificatie van een beperkt aantal opties die op korte termijn kunnen worden toegepast.

Duurzame alternatieven op basis van verstikking met stikstof of kooldioxide zijn niet voldoende operationeel of toegelaten voor gebruik in alle vervoersmodaliteiten en niet prijsconcurrerend in vergelijking met de bestaande praktijken voor bulkvervoer overzee. Het kan nu alleen worden toegepast als alternatief voor fosfine in relatief kleine hoeveelheden lading in gesloten verpakkingen (van big bags tot containers) en in voedingsmiddelen met een hoge toegevoegde waarde (bijvoorbeeld noten, koffie, fruit, enz.).
De geïdentificeerde, mogelijke, alternatieve ontsmettingsmiddelen, gebaseerd op een toxisch effect, lijken onvoldoende operationeel of zijn niet toegelaten voor gebruik in de toeleveringsketen van agribulk. Giftige alternatieve middelen zullen ook giftig zijn voor de mens en daarnaast zijn sommige ook schadelijk voor het milieu (bijvoorbeeld broeikasgassen).

Voor de nabije toekomst zal fumigatie met fosfine volgens RHDHV naar verwachting de voorkeur hebben in de wereldwijde bestrijding van ongedierte voor transport overzee. Vanuit regulerings perspectief is het (veilige) gebruik van fosfinegas gegenereerd met fosfidetabletten in Europa gereguleerd onder de BPR (Biocidal Product Regulation) en PPPR (Plant Protection Product Regulation). Verbetering van veiligheidsmaatregelen kan worden aangebracht en is al in voorbereiding door het College voor de toelating van gewasbeschermingsmiddelen en biociden (Ctgb).

De route om maatregelen op te leggen via een verplicht mondiaal kader voor vervoer (bijv. het reguleren van veilig gebruik van fosfinegas) wordt niet haalbaar geacht (geen prioriteit in mondiale context). Het verplichte gebruik van fosfidetabletten in sommige niet-EU-landen van herkomst vóór transport naar het buitenland, vormt een obstakel om het gebruik van fosfinegas geleidelijk af te schaffen. Op korte termijn kunnen echter wel veiligere methoden met behulp van fosfidetabletten worden geïmplementeerd.

Resistentie van ongedierte tegen fosfine is tijdens de interviews niet als een probleem geïdentificeerd, maar is in de literatuur als een risico geregistreerd. Dit kan in de toekomst toenemen en vereist monitoring.

Aanbevelingen op korte termijn
Op korte termijn zijn er geen alternatieven beschikbaar voor het fumigeren van granen en diervoeders, die het gebruik van fosfine op een effectieve en haalbare schaal in de toeleveringsketen zouden kunnen vervangen.

Om risicoreductie van het gebruik van fosfinegas afgevende middelen te bereiken, moeten alle inspanningen gericht zijn op een veiliger gebruik van fosfine met technische en organisatorische middelen. Het rapport “Ketenanalyse gegaste lading” (bijlage 1 bij de brief aan de Tweede Kamer, 4 april 2022), stelt gedetailleerde maatregelen voor om de veiligheid van het gebruik ervan te verbeteren, zowel vanuit technisch oogpunt als vanuit organisatorisch oogpunt (de laatste inclusief aanpassing van regelgeving). De kern hiervan is dat aan de effectiviteit en veilige gebruiksvoorwaarden van fosfinegebruik alleen kan worden voldaan als na fumigatie het opgeslagen product voldoende geventileerd is en de resterende pellets kunnen worden verwijderd, voorafgaand aan verdere handelingen. Dit kan worden bereikt wanneer de fosfidepellets worden aangebracht in enveloppen of sokken, die gemakkelijk kunnen worden verwijderd. Strengere communicatieprocedures en registratie vóór verlading, zal significant kunnen bijdragen aan de verwijdering van achterblijvende fosfide pellets vóór elke verdere stap in de toeleveringsketen, wat tot een reductie van het risico zal leiden.

De verbeteringen kunnen niet wereldwijd worden afgedwongen met een regelgevend kader. Daarom wordt aanbevolen dat grote agrarische handelsbedrijven, die het agroproduct naar de EU importeren, dezelfde voorwaarden opleggen als hierboven genoemd. Het gebruik van losse fosfide pellets zou op mondiaal niveau moeten worden verboden om de risico's tot een aanvaardbaar niveau terug te brengen. Binnen de EU zijn discussies gaande over een verbod op fumigatie met fosfide pellets, in welke vorm dan ook (losse pellets én in enveloppen en sokken) tijdens transport. De transporttijden tussen bron en bestemming binnen de EU zijn te kort voor een effectieve fumigatie en voldoende ventilatie.

Zodra de bovengenoemde maatregelen zijn gerealiseerd, wordt aanbevolen de effectiviteit in heel Europa te monitoren, evenals niet nalevingen en, erger nog, incidenten. Op basis van deze verzamelde gegevens kunnen verdere stappen binnen de EU en wereldwijd worden overwogen.

Aanbevelingen op lange termijn

De resultaten van bovengenoemde monitoring zouden periodiek geëvalueerd moeten worden. Als deze niet tot de gewenste resultaten leiden en er worden niet-nalevingen geconstateerd of erger nog, er doen zich toch incidenten voor, dan zouden er andere, effectievere maatregelen genomen moeten worden.

Deze maatregelen moeten gericht zijn op het elimineren van het gebruik van fosfine in de toeleveringsketen, door praktische methoden toe te passen die gemakkelijk kunnen worden geïmplementeerd, hoger in de beheersing hiërarchie (HoC). De maatregelen zijn het meest effectief wanneer holistisch naar de hele toeleveringsketen wordt gekeken en een IPM-benadering (Integrated Pest Management) wordt toegepast.
De volgende aanvullende maatregelen, in navolging van de controlehiërarchie, zouden mogelijk kunnen zijn:

- Hoogste beheersingsniveau: het gebruik van welke stof dan ook overbodig maken: een strikte hygiëne opleggen en mechanische maatregelen toepassen in de hele toeleveringsketen, op basis van een IPM-benadering. Zorgen voor een wetgevend kader binnen de EU, met aanvullende contractvoorwaarden opgelegd door de wereldspelers in de wereldwijde toelevering, die deze maatregelen wereldwijd vereisen en controleren. Begin met voedsel- en diervoederketens met hoge toegevoegde waarde en schaal dit op naar (goedkopere) bulkproducten.
- Tweede beheersingsniveau: Vervanging van een giftige stof door een niet-toxische stof: bijvoorbeeld door gebruik te maken van de verstikkende werking van CO_2 of N_2; deze stoffen moeten worden geregistreerd voor toepassing binnen de EU binnen de PPPR of BPR (het EU-regelgevingskader), afhankelijk van het toepassingsgebied van het gebruik.
- Tweede beheersingsniveau: Vervanging van een giftige stof door een minder giftige stof: bijvoorbeeld gebruik van een toxisch ontsmettingsmiddel (ethylformiaat) gecombineerd met het verstikkende effect van stikstof of kooldioxide; deze stoffen en producten moeten worden geregistreerd voor toepassing in de EU binnen het PPPR- of BPR-kader.
- Derde gecombineerd met het vierde beheersingsniveau: verbetering van de veiligheid van het gebruik van fosfinegas afgevende middelen, met behulp van enveloppen of sokken, alsmede de geautoriseerde gebruiksprocedures. Dit kan in de EU worden geïmplementeerd binnen het PPPR- of BPR-kader en wereldwijd via contractvoorwaarden en IMO-aanbevelingen.
- Aangezien er geen regelgeving is die wereldwijd van toepassing kan zijn op de hele toeleveringsketen, kunnen enkel contractvoorwaarden worden opgelegd van bron tot eindgebruiker en moeten deze een belangrijkere rol spelen bij de effectieve toepassing van IPM en alternatieven voor begassing met fosfinegasafgevende middelen. Om doeltreffend te zijn, moeten deze voorwaarden geografisch complementair zijn en technisch afgestemd op het regelgevingskader van de EU. De grote wereldwijde handelaren in levensmiddelen en diervoeders moeten daarin een belangrijkere rol spelen bij het toepassen en controleren van deze voorwaarden vanaf de niet-EU-bron tot het moment waarop ze de EU binnenkomen. Aangezien

kosten een belemmering vormen voor bovengenoemde maatregelen voor bulkvoeding en diervoeder, kan toepassing van de IPM-principes met de hoogwaardige producten voor menselijke consumptie gescheiden van diervoederproducten een haalbare start zijn. Als er positieve ervaringen zijn opgedaan , dan kan deze aanpak worden uitgebreid naar bulk 'food en feed'

1 Introduction

This report

This report summarizes a preliminary scan on the alternatives to the use of the fumigant phosphine gas (released from phosphide pellets) in the agro supply chain, prepared by Royal HaskoningDHV and commissioned by the Ministry of Infrastructure and Water Management in the Netherlands. The scope of this scan was limited to the existing literature and the expert opinion collected during interviews.

Background information

Phosphine gas has been widely applied for decades as a fumigant in the transport and storage of animal feed and food within the agroindustry. Phosphine is used as insecticide or acaricide to protect storage goods like animal feed and feed ingredients, food and food ingredients. This comprises the phytosanitary treatment of grain silos, seeds, plant products, dry fruits, dates and many more products. It replaced the previously widely used methyl bromide, which was phased out under the Montreal Protocol (established to prevent the ozone layer depletion). Pellets of phosphide salts, e.g. aluminium phosphide, magnesium phosphide, calcium phosphide or zinc phosphide generate and release phosphine gas upon contact with moisture. These pellets are usually added to the agri products at the source before international transport and slowly release the phosphine gas throughout the cargo during transport.

Phosphine gas can lead to health effects to people when inhaled. In 2019 and in 2021 two serious incidents in the Netherlands occurred. The first incident took place in 2019 when a couple, the owners of the barge, was exposed to phosphine gas released from the cargo in a barge. The second incident occurred when high concentrations of phosphine were measured at the barge unloading area after the transfer from train to barges. The latter incident did not lead to health effects with the workers.
The Ministry of Infrastructure and Water Management initiated a study after the second incident in 2021. The scope of the report was to identify the vulnerabilities of present practices in the supply chain of food and feed and identify the opportunities to improve the safety of present practices (“Analysis on fumigated cargo with pesticides”, April 4, 2022). The final version was published during the preparation of this report. This report on possible alternatives to the fumigant phosphine is prepared as a commitment after the incident of 2019.

The objective

The primary objective of this quick scan is to identify possible alternatives for the use of phosphide pellets for fumigation of cargo grains during transport. The second objective is to analyse and compare the feasibility of alternatives based on the technical and regulatory conditions. Technical conditions are effectiveness, workability, as well as toxic effects for man and environment. Regulatory conditions in the use of these alternatives comprise the international regulatory framework(s) and agreements.

Regulatory background

The salts aluminium phosphide and magnesium phosphide could be used in the Netherlands to generate phosphine gas and are authorised under the framework of either the European Biocidal Product Regulation (BPR) or the Plant Protection Product Regulation (PPPR). There are 7 product authorisations for phosphine releasing agents under these two regulations in the Netherlands, 5 of which are allowed to be used for the fumigation of agri and other products.
There is no unified global regulation on the use of phosphine releasing agents in storage and transport of bulk, only recommendations may be taken in International Maritime Organisation (IMO) context and The European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN) , when it concerns inland waterways.

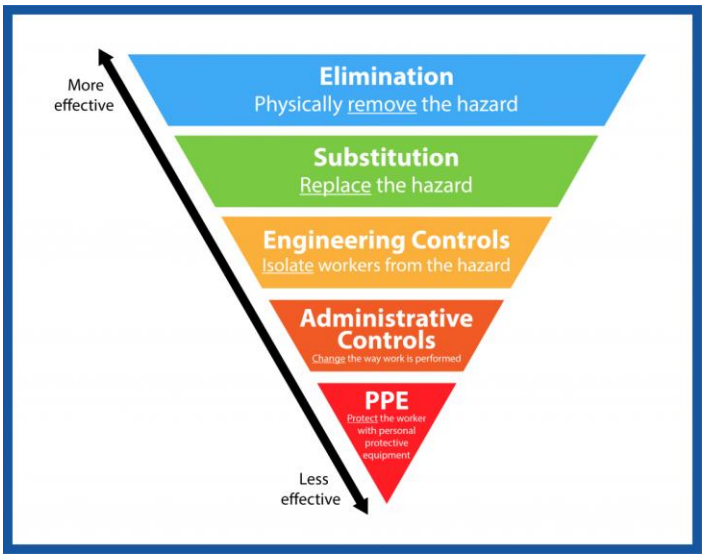
The table of content to the quick scan

Royal HaskoningDHV presents this quick scan of possible alternatives and its technical and regulatory feasibility in the following chapters:

2 Methodology quick scan alternatives to phosphine

2.1 Scope of work: scanning alternatives

The initial question: looking for alternatives to phosphine, suggests looking for alternative substances only, with lower health risks for workers and the environment. However, the core of the problem is the unsafe situation with the release of a toxic substance (being phosphine gas released from phosphide pellets). A replacement with another toxic substance does not make the alternative necessarily safer. Therefore, the scan will look for “safer” alternative methods (and not necessarily alternative substances) to apply phosphine generating agents in the agro-supply chain.
When looking for safer use of hazardous substances one must follow the Hierarchy of Control (HoC). The most effective and safe approach is to develop a method with the elimination of any hazardous substance, which is the highest level of control. Substitution with a less toxic substance is the next level of control. The complete HoC is summarized in the following figure:



Level 1: Elimination: highest level of control, removing the hazardous substance
Level 2: Substitution: substitute the hazardous substance with a less hazardous substance
Level 3: Engineering controls: technical measures that separate the worker from the hazard
Level 4: Administrative controls: organisational and procedural improvements to increase safety
Level 5: Personal Protective Equipment (PPE): lowest level of control

The principles of the HoC can be found in several EU legislations, based on the following safety sciences and / or practices:

- Process safety (as laid down in the EU Seveso directive 2012/18/EU)
- Industrial Hygiene (as laid down in the EU legislation on the protection of workers 2004/37/EG, the carcinogens and mutagens agents at work directive)
- The chemical legislation: REACH Regulation (EG Nr. 1272/2008) requirements in the Authorisation procedure when performing a AoA (Assessment of Alternatives)

How to fit in the Letter to the Dutch Parliament April 2022
The report “Analysis on fumigated cargo with pesticides” (April 4, 2022), identified vulnerabilities of present practices related to phosphine as fumigants and included recommendations identifying opportunities to improve the safety of present practices.

These recommendations include technical improvements in the use of phosphide pellets as well as steps to tighten the regulatory environment at national and European level and include recommendations in globally active organisations (for example IMO-International Maritime Organisation). All recommendations are categorized in the Hierarchy of Control:

- Engineering controls (3rd level of control)
- Administrative controls (4th level of control)

This letter to the parliament was published during the preparation of this quick scan. The results have been integrated into this report, in paragraph 4.8 Phosphine improved Methods.

2.2 Methodology and activities of this quick scan

This quick scan has been performed in the following steps:

1. Collection of data, including the regulatory conditions
2. Analysis
3. Reporting

2.3 Collection of other data

The collection of data on alternatives to the use of phosphine gas releasing products has been based on two sources:

- Literature review
- Interviews with stakeholders

2.3.1 Literature review

Based on mostly scientific publications from the last two decades and other publications (for example supplier information), primarily from Australia, the United States, the Netherlands and Belgium, an overview has been created on potential alternatives.
The methods were included in Table I in Annex 1. For each method the following information was extracted in the publication:

- Functionality and workability
- Logistics and supply chain availability
- Risks (acute and long term risks for workers, the general public and / or the environment (including impact on greenhouse effect), and possible biological resistance). Risks can be toxicological but also physical (such as fire or risk of asphyxiation)
- International conditions and agreements
- Fitness (based on costs)
- Applicability on means of storage and transport
- Hierarchy of Control of the measure (HoC from 1st to 5th level of control)

2.3.2 Interviews

After approaching 15 professionals, 5 were selected for interviews by telephone, based on their experience with phosphine. The following professionals were interviewed:

- Staff with practical experience in fumigation and alternatives working in transport trade, storage, testing and quality management.
- Governmental staff.

The interviewees were asked about their experience with phosphine and possible alternatives. This quick scan includes interviews with staff members of the following organisations:

1. Peterson Control Union (quality management and supply chain solutions for agribulk)
2. Bargeowner Ms Fox (phosphine incident the Netherlands 2019)
3. Ruvoma (pest control and gas measurements)
4. The Dutch Ministry of Infrastructure and Water Management
5. CTGB (Board for the Authorisation of Plant Protection Products and Biocides)

3 Results data collection

3.1 Results literature review

The review of the literature resulted in the identification of the following categories of fumigation methods, as possible alternatives to phosphine gas, that were consolidated in table I:

- Fumigation based on a toxic effect (HoC: level 2)
- Fumigation based on asphyxiation (HoC: Level 2)
- Combined method toxic / asphyxiation (HoC: Level 2)
- Physical methods (HoC: level 1)
- Mechanical methods (HoC: level 1)
- Methods to improve the safety of phosphine use as fumigant (HoC: level 3, 4 and 5)
- Combined methods applying Integrated Pest Management (HoC: starting with the highest level of control 1 and working down to level 5)

3.2 Results Interviews

The interviews were used to identify additional information on possible alternatives to phosphine gas and the safe(r) use of phosphine gas as fumigant.
The interviews did not result in the identification of additional alternatives, to the ones listed above (in detail listed in Table I, identified in the literature).
One interviewee reported on the practical experience in their operations with methods based on asphyxiation (with pure nitrogen, carbon dioxide or oxygen depleted air). Their practical experience was shared, including its limitations and possible further developments. No other experience with any of the other alternatives, listed in Table I, was shared during the interviews. It appears, according to the interviews, that phosphine gas releasing phosphide pellets are not applied in the Netherlands for fumigation of grains and animal feed for transport, despite the existing authorisations for specific purposes (storage) and other applications such as for imported timber. In case of the imported timber, phosphide pellets are applied during storage in the Netherlands, if it is infested with insects.

4 The Regulatory context and other conditions

4.1 Overview applicable rules, regulations and conditions

This text on existing regulatory context is based on the interviews and the “Ketenanalyse gegaste lading ” (Annex 1 to the letter to the Dutch Parliament, April 4, 2022).
The following, most relevant, regulations and conditions, for this quick scan, on the use of fumigants in agriproduct transport,are detailed in this chapter:

- Chemical Product legislation (EU and National): BPR (Biocidal Product Regulation) and PPPR (Plant Protection Products Regulation)
- International agreements and legislation (Transport legislation and international conventions)
- Contractual agreements in the supply chain
- Local (Harbour or Municipal) decrees

Other applicable legislation and conditions are:

- Labour legislation (EU and National): European Directives and the Dutch Labour law and decree
- Food safety Legislation (EU and National)
- Legislation in the country of origin (outside of the EU)
- GAFTA (Global trade association for in agricultural commodities and spices) rules on fumigation

4.1.1 Chemical Product legislation (EU and national)

The Biocidal Product Regulation ((EC) nr. 528/2012) and the Plant Protection Products Regulation ((EC) nr. 1107/2009) have a direct effect in the EU Member States. The Netherlands has additional requirements implemented in the national law (Wet gewasbeschermingsmiddelen en biociden - Wgb) which is applicable to products under both European laws.
The Plant Protection Products Regulation (PPPR) regulates the marketing and use of Plant Protection Products (PPPs) in Europe. These products are used to protect crops and plant products and agricultural commodities that have not been physically treated for further use. In the EU, the assessment of PPPs falls under the EFSA authority.
The Biocidal Product Regulation (BPR) regulates the marketing and use of biocidal products (BPs) in Europe. Biocidal products have many uses including the protection of treated agricultural product. ECHA is the EU authority coordinating the assessment of biocides.
There are five phosphine gas releasing products authorised for fumigation of agri and other products in the Netherlands, four under the PPPR and one under the BPR. They are all based on aluminium phosphide or magnesium phosphide releasing phosphine. Products authorised under the BPR are categorized in specific Product Types (PT).

Name product	Regulation	Validity authorisation	Scope
Quickphos PT, 15194 N	PPPR	≤ 31 Aug 2024	Professional use as insecticide during storage. Mole and water vole controlling agent by means of fumigation.
PHOSTOXIN BAG, 15783 N	PPPR	≤ 31 Aug 2024	Professional use as insecticide and mite controlling agent by means of fumigation.
Degesch plates, Degesch Strip NL-0008366-0000	BPR	≤ 31 January 2023	PT 18 - Insecticides, acaricides and products for the control of other arthropods. Professional use to control insects in stored products in gas-tight enclosures.
Degesch Strip 15845 N	PPPR	≤ 31 Aug 2024	Professional use. Insecticide and acaricide by means of fumigation.
Degesch Plate 15767 N	PPPR	≤ 31 Aug 2024	Professional use. Insecticide and acaricide by means of fumigation.

In getting bioactive substances to the EU market, approval of these active substances is mandatory within one of the two Regulations. Active substances first need to have an EU approval before products can be authorised in member states. The process of preparing a new active substance dossier and its EU evaluation takes several years (e.g., 6-10 years). Once the active substance has been approved, a national product authorisation is required, which could take several years to complete the process. Therefore, identifying a new alternative to phosphine and bringing it to the market would be a long(er) term solution only, should there be no existing registration of that suitable alternative.

Should there be indications (e.g., identified during enforcement in The Netherlands) of unacceptable risks of authorised products, authorities or member states can change the registration based on art. 48 BPR or art. or 44 PPPR. Stricter requirements and measures for application or even a ban of the substance could be the consequence, should the risk mitigation measures be insufficient.

4.1.2 International agreements and transport legislation

IMO

The International Maritime Organization (IMO) sets global standards for the safety, security, and environmental performance of international shipping in guidelines. National governments are responsible for the implementation of IMO rules into local legislation and the enforcement. With the acceptance of the IMO convention a government agrees to implement an IMO rule into national legislation.

The IMO regulatory framework contains conventions, codes and guidelines. Conventions and codes can become mandatory after national implementation. Guidelines which create a standard, are not mandatory, but can be seen as a recommendation. The International Maritime Dangerous Goods (IMDG) Code, was developed in the IMO context as an international code for the maritime transport of dangerous goods in packaged form, in order to enhance and harmonize the safe carriage of dangerous goods and to prevent pollution to the environment. It includes rules for fumigated cargo in loading units, but not in bulk.

An IMO recommendation requires agreement among its 175 member states and is therefore difficult to agree upon.

To get all IMO members to accept a (mandatory) code on the correct use of phosphide in bulk cargo is considered not feasible, only a recommendation is considered feasible.

European agreements and transport regulations
The regulations on transport of hazardous substances by road (ADR), rail (RID) or inland waters (ADN) includes safety requirements for fumigated cargo limited to loading units. There are no safety requirements for bulk load. As identified in the “Ketenanalyse gegaste lading ” (Annex 1 to the letter to the Dutch Parliament, April 4, 2022), safety requirements are being discussed and will be included in the ADN.

4.1.3 Contractual agreements in the supply chain

The international Grain and Feed Trade Organisation (GAFTA) provides rules and regulations applicable to all members (1900 members in 100 countries) and supports members through contracts and arbitration. The GAFTA also published a fumigation standard. This standard is intended to improve the level of competence and understanding about pest control and fumigants. GAFTA rules are not mandatory but can be contractually agreed upon.

The recommendations and / or fumigation standards that GAFTA and IMO have published can be used in the supply chain. If the parties in the market that trade between producers and end users globally include these technical measures in their contracts, the agreed measures and procedures become mandatory and will increase the safety of the use of the applied fumigant (being phosphine releasing phosphide pellets). Contract conditions have the advantage of being applied between parties globally, also in the absence of a regulatory framework. Disadvantage is that the contracting parties need to set up their own monitoring and / or enforcement mechanisms, as there is not a governmental authority overlooking contract conditions.

4.1.4 Local (Harbour or Municipal) decrees in the Netherlands

Local harbours or municipal authorities can require precautionary measures to be applied on sea vessels with food or feed from (non) EU countries arriving in European ports. After the incidents with phosphine gas, the municipalities of Rotterdam (including Schiedam, Vlaardingen, Dordrecht, Papendrecht and Zwijndrecht) adopted on November 30, 2020 additional rules for incoming sea vessels loaded with food and grain fumigated with phosphine, amending article 4.7 of the existing Harbour decree Rotterdam 2020. The municipality of Amsterdam adopted the same additional rules on November 26, 2020. It is effective in the harbours of all mentioned municipalities since January 1, 2021.
This amendment includes mandatory procedures for sampling of the cargo, removal of residues, ventilation of the cargo, before transhipment from sea vessels to inland navigation vessels, when a vessel with a fumigated bulk load arrives. The ventilation of the cargo includes a binding procedure for a mandatory transfer to an unmanned barge, before transfer to another modality of transport, if phosphine gas is still present and loose phosphide pills are used. A gassing conductor is in the lead during the whole process. This will increase the safety during transhipment in the receiving port and will have a significant cost increasing effect too. It is assumed that this cost increase will drive contract partners to a more preventive approach to combatting vermin in the country of origin and a more sufficient ventilation procedure during transport, which will ultimately result in a positive effect on the whole supply chain and less required safety measures and lower costs in the Dutch harbours.

5 Evaluation of alternatives

5.1 Introduction

Based on the literature review and the interviews with stakeholders, potential future alternatives were analysed and grouped in this chapter.
The interviews gave limited information to validate aspects of other alternatives, identified in the literature and listed in Table I.

5.2 Phosphine existing situation

From a source shipped from outside the EU to the EU
According to the interviews most shiploads of food and animal feed, which are shipped from overseas to Western-Europe (including the Netherlands), are fumigated with phosphine gas. The countries of origin are for example Brazil, India, USA, Ukraine and Russia.
Phosphide pellets or tablets (often aluminium or magnesium phosphide or in some cases zinc phosphide and calcium phosphide) are in most cases brought as loose pellets into the bulk product. The amount is based on a standard ratio (x pellets per ton). In contact with the present moisture the pellets generate the toxic gas phosphine.
A well-executed fumigation process in a sea vessel takes a prescribed number of days for gassing followed by a prescribed numbers of days for ventilation. According to regulatory information the gas and ventilation procedure takes at least 3 to 8 days. However, a longer period of up to ten days for fumigation and ventilation each was mentioned in an interview. This required longer period could not be validated. Intercontinental shipping (from Brazil or India to Europe) offers sufficient time for gassing and ventilation during transport. For shorter transport times extra ventilation before handling cargo is required, to ensure a safe situation. Upon arrival in a port in the Netherlands a certified company measures the level of phosphine before any transhipment to other modes of transport (on board of the sea vessel). The maximum acceptable phosphine level is 0.01 ppm. The obligations in other ports in the EU have not been reviewed.

From a country shipped within the EU
For EU transport (waterways, road and rail) for food and grain phosphine incidents have occurred on transport connections between Eastern European countries (for instance Poland, Romania and Hungary) and Western Europe (Germany, France, Netherlands, Austria and Belgium).
This should be covered and enforced with EU legislation (BPR and PPPR). Within the EU discussions are ongoing regarding a ban of fumigation with phosphide pellets, applied in any form (loose pellets and sleeves or plates) during transport. The time of transport between source and destination within the EU is too short for effective effective ventilation of the fumigated cargo.

5.3 Fumigants based on a toxic effect

Methods
The following alternative fumigants, based on a toxic effect, were identified in the literature:

- Carbonyl sulfide (Cosmic)
- Carbon disulfide
- Ethanedinitrile (Sterigas)
- Sulfuryl Fluoride (ProFume, Vikane)
- Ethyl formate (+ CO2 / N2), (Vapormate)
- Ozone
- Entomopathogenic fungi (EPF)

The fumigants and the literature sources are all included in Table I.

Carbonyl sulfide (CAS no. 463-58-1.) Though effective within a shorter period than phosphine fumigation, it had some colouring and odour effects on the products. This colouring and odour potential makes it less suitable for consumption of the products.
Carbonyl sulfide has no registrations within REACH or authorisations under PPPR or BPR and therefore products are not commercially available. It is thus not an alternative for phosphine fumigation on the short term.
Carbon disulfide (CAS no. 75-15-0). The fumigant is not carcinogenic and has no adverse effect on the environment. The major advantage of carbon disulfide is its minor effect on seed germination. However, residues of carbon disulfide persist in treated commodities for a longer period than that of other fumigants. Some of the limitations of the fumigant include high flammability, the need for a longer exposure period, persistence in treated commodity, lack of residue limits of Codex Alimentarius and high human toxicity. This substance is registered under REACH, but not under BPR or PPPR, and it is thus not an alternative for phosphine fumigation on the short term.
Ethanedinitrile (CAS no. 460-19-5; Cyanogen, Sterigas) is applied for timber only, is highly toxic for the environment (and more toxic than methylbromide) and not available for feed and food.
Ethane dinitrile has a REACH registration, but no authorisation as biocide or plant protection product registration. Preparations for a BPR authorisation active substance dossier have been indicated in 2021. In conclusion, this substance is not a short-term alternative.
Sulphuryl fluoride (CAS no. 2699-79-8) is a commercially available fumigant which has no effect on product quality. Effective fumigation requires more sulphuryl fluoride than methyl bromide (which is not used anymore)., Sulfuryl fluoride currently does hold biocidal registrations in EU for PT08 (Product Type wood preservative; 2 authorisations in the Netherlands for Profume and Vikane, professional use only) as well as PT18 (Product Type insecticide, but no authorisation in the Netherlands). It also holds registrations as a plant protection product for a fumigant insecticide (for the Netherlands: Profume, 13358 N, professional use only). Sulphuryl fluoride has a very strong greenhouse potency.

These four toxic fumigants have a similar to worse human health toxicity profile compared to phosphine gas and will require comparable or enhanced measures to ensure safe use for workers. Apart from sulfuryl fluoride, the substances do not have European approval as active substance in plant protection products (PPP) and biocidal products (BP) and are not included in the review programmes for PPP's or BP's. In addition, sulfuryl fluoride has a strong greenhouse potency.
All of them are unsuitable as short- or long-term alternatives for phosphine gas.

Ethyl formate
The only toxic fumigant that compared favourably to the other alternative fumigants with regards to human health and environmental hazards is ethyl formate (CAS no.: 109-94-4) combined with nitrogen (or carbon dioxide). It can be applied in shipping containers loaded with general freight. As it is combined with a gas that can lead to asphyxiation (nitrogen or CO_2), the gas can only function in a closed mode of transport or storage and not in large quantities that are transported in bulk. A disadvantage is the higher price compared to phosphine use, which will not lead to market acceptance for high volume bulk transport of low value commodities. If this innovative method will get market acceptance, the unit price will still remain higher than fumigants with a toxic effect only, as it requires measures to enable the asphyxiation effect. The substance has a REACH registration but no biocidal or plant protection registration and is not part of these review programmes. This would therefore only be a viable alternative, when authorised under BPR or PPPR and if the practical applicability (bulk transport) can be improved for products of high value transported in containers and stored in closed silos. Currently the efficacy information is only based on the producer who is pushing for market acceptance and not independently validated.

Ozone has been considered as an alternative fumigant. Ozone is part of the assessment program for biocidal active substances for PT02, 04, 05 and PT11 (disinfectant and preservative uses only). Currently, a consultation process is ongoing towards approval of ozonated water as active, basic substance under the PPPR. The latter concerns consideration as substance, not predominantly used as plant protection product, but this registration may be of value for plant protection. However, its oxidising properties (it reacts with many materials such as metals), rapid degradation and incapability to penetrate barriers (insect eggs are resistant) makes it unsuitable as an alternative. Therefor the economic interest in applying for approval may be limited.

Entomopathogenic fungi (EPF)
One article looked at advances in biocontrol of stored grain using strains of entomopathogenic fungi (EPF). These fungi have the potential to kill insects and could have the capability to be a useful biological tool as vermin control. The method is in a very early stage, without any reported practical results.

Hierarchy of Control and experience
All the above considered alternatives can be categorized as a level 2 measure (substitution) in the hierarchy of control: replacing a toxic substance with another substance. An improvement can only be achieved if the alternative substance is as effective, but less toxic for humans and with less risks for workers and the environment and thus requiring less mitigation measures . The above substances do not qualify as improvements, with ethyl formate as exception with a lower toxicity. However this alternative is only effective combined with a gas that can lead to asphyxiation.
None of the interviewees had experience with one of the above-mentioned alternative fumigants.

5.4 Fumigants based on an asphyxiation effect (N_2 and CO_2)

Methods
In the literature the following methods, based on asphyxiation of vermin, were identified:

- Application of pure nitrogen or carbon dioxide sourced from gas suppliers
- In situ (on site) generation of oxygen depleted air (consisting of a high concentration of nitrogen [> 80%] and depletion of oxygen [< 21%])

The characteristics of those fumigants are all included in Table I.

Evaluation
The method is based on asphyxiation with a gas, using pure nitrogen or carbon dioxide, supplied by gas suppliers or oxygen depleted air generated on site with air separation units .
The on site depleted air will contain a mixture of mainly nitrogen (80%) , carbon dioxide and depleted oxygen (< 21%).
The storage or transport must be sufficiently airtight to enable the gas to create a low oxygen concentration during a longer period (10 days and more) to be effective. On site generation also requires high voltage current. It can be applied in storage, but not easily in (sea) transport for several reasons: applicability and costs. On site generation on a sea going vessel would require high voltage current, which is not feasible during longer transatlantic voyages on vessels. The ship and cargo on a sea vessel is not designed to realize over- or under storage pressure. Overall, these procedures to create depleted oxygen conditions are much more expensive than the application of phosphine released from phosphide pellets, and therefore it is currently only applied on high value products.
Should the ship enable sealed transport (in closed containers or in separated parts of the ship), and there is availability of an asphyxiation gas, then phosphine can be substituted in oversea transport for agriproducts. As this requires a complete technical transition for sea transport, it is not considered a short-term alternative.

Regulatory
Carbon dioxide and nitrogen need to be registered under the regulations of the BPR or PPPR to be allowed as alternatives in case they are used as a biocide or a plant protection product.
Carbon dioxide is currently in a transition process in the Netherlands (triggered by the Regeling uitzondering bestrijdingsmiddelen-RUB), towards full registration under current requirements. The active substance evaluation for biocidal active substances allows carbon dioxide to be used in PT (Product Type) 15 (avicide) and PT18 (insecticide and acaricide) under the BPR.
As a plant protection product CO_2 is allowed to be used as an insecticide for fumigation in storage of plants and plant products.
Nitrogen produced in situ (through separation from ambient air) is regarded as a specific active substance and is not approved as a biocidal active substance or substance for plant protection and therefore can currently not be used in Europe as PPP or BP.

Interviews
The company Peterson Control Union operates an on-site unit generating oxygen depleted air and is thus a proponent of the method. It also claims it is cost effective for high value products in storage and transport. There are various storage options where this can be applied: in silos and in warehouses with a lining coverage and an on-site unit generating oxygen depleted outside air, being blown under the lining. Another option could be a sealed container for transport, but no examples were shared during the interviews. The procedure takes at least 10 days to be effective.

The feasibility of these alternatives is also based on the availability of large quantities of nitrogen and carbon dioxide available in storage or power current to run air separation equipment and an air-tight sealed storage or transport modality. Absence of this equipment within the whole food and feed supply chain in storage and transport do not make this a viable option on the short term. A transition towards a long-term solution for non-toxic fumigation would require a complete aligned supply chain working towards this goal.
The investments in these methods demonstrate that Peterson apparently sees business opportunities and anticipates on a transition towards wider applicability of these methods on the long term.

Hierarchy of Control
This method can be categorized as a level 2 measure (substitution) in the hierarchy of control: replacing a toxic substance with another substance. An improvement is that the method is based on another principle (asphyxiation) which kills vermin and has other occupational risks for professional staff (like the risks in confined spaces with depleted oxygen) but no risks for the environment. Though asphyxiation in confined spaces is an existing occupational risk too, the technical and procedural mitigation measures can be managed within the working sphere on the vessel.

5.5 Physical methods (temperature or radiation)

Methods
In the literature the following physical methods were identified:

- Heating
- Radiation

Evaluation
The methods are effective (heating may slightly impact the quality of the grain), but both methods, according to the interviewees, cannot be applied for large quantities (bulk transport) and are significantly more expensive than phosphine use (6 times for heating). The specific costs per ton have not been reported in the literature or interviews.

During interviews it appeared that when a product is heated to 90 degrees Celsius it eliminates all vermin. This practice is performed higher up in the supply chain (in the Netherlands) for smaller quantities, before supplied to the final clients who will use the product (feed or further packaging as food). The main purpose is Salmonella prevention, with elimination of vermin as a side effect. Apparently, the value of the end product justifies this use of this more expensive method to address vermin.

In some countries like for instance Vietnam there are good results reported by using radiation (microwave). This is physically only feasible in small amounts of cargo and high value products (costs are up to 8 times more expensive than traditional toxic fumigants).

Regulatory
Physical methods do not require authorisation under the PPPR or BPR as the methods do not use any chemicals. These Regulations have a scope limited to a chemical substance that is in use as Plant Protection Product or Biocidal Product.
Occupational Health and Safety legislation are applicable and an employer's responsibility.

Hierarchy of Control
This method can be categorized as a level 1 measure (elimination) in the hierarchy of control: eliminating a toxic substance with application of another method without the use of substances. It is an improvement that the method is based on another principle that kills vermin and has less occupational risks for professional staff (although still occupational risks exist).

5.6 Mechanical methods

Methods
The following mechanical methods are applied in the supply chain:

- Sieving
- Blowing (for example in a centrifuge)

Evaluation
In the literature these methods have not been identified as stand-alone technology. However, interviews indicated that the application of good housekeeping, including these mechanical methods, in the source or exporting country, would reduce the need of fumigants before transport in a sea vessel to Europe.
These methods are applied in the Netherlands, only as a last step (for example after heating) before reaching the end client in order to supply a completely clean product, free of remains of vermin.

Applicability and logistics
The use of mechanical methods combined with good housekeeping in the source country of the production is an effective solution, to reduce the need of fumigant during transport overseas. The challenge is the implementation and control in the country of origin. It adds an extra processing step for the producer, which will increase his price compared to competitors.

Regulatory
Mechanical methods do not require authorisation under the PPPR or BPR as the methods do not use any chemicals. These regulations have a scope limited to a chemical substance that is in use as Plant Protection Product or Biocidal Product.
Occupational Health and Safety legislation are applicable and an employer's responsibility.

Hierarchy of Control
This method can be categorized as a level 1 measure in the hierarchy of control: eliminating a toxic substance with application of another method without the use of substances at all. An improvement is that the method is based on another principle that kills vermin and has less or other occupational risks for professional staff (although still occupational risks exist on site, for example machine safety measures).

5.7 Integrated Pest Management (IPM) as a concept

What is IPM?
Integrated Pest Management (IPM) is a developed approach in academia, to reduce grower's reliance on chemical crop protection or biocidal agents. It is a sustainable and broad-based approach that integrates practices for the prevention and control of pests and diseases in crops, the use of non-chemical alternatives and only uses chemical agents if no alternatives exist.
IPM is based on the principles of quality control and setting a strategy for the whole supply chain which can significantly reduce the need for chemical agents. More details are included on the website of the University of Wageningen: (Integrated Pest Management (IPM) - WUR).
An example is the IPM-Rodents program which starts with prevention through good housekeeping and construction of physical barriers against rodents to reach the product. A second barrier is the use of traps. As a last resort the use of a rodenticide, a chemical agent against rodents can be applied.

Application and feasibility
The literature was not specific on the possible substitution of the use of phosphine gas as fumigation agent with the application of an IPM approach throughout the supply chain. The interviewees too, did not identify any equivalent experience with this concept. However, it was mentioned that good housekeeping at the source would reduce the need of fumigants later in the supply chain in several interviews, without referring to IPM.
Prevention at the source including good housekeeping is definitively the first important step of IPM and can help to reduce the need of toxic fumigants. As a second step, measures not requiring any chemical agents can be explored on its applicability throughout the specific supply chain in scope, before turning to chemical agents. The selection of chemical agents too, as a third step, can be tiered, starting with non-toxic methods (for example Nitrogen) to combinations (ethyl formate) and as a last step the "traditional" toxic fumigants.
IPM requires a comprehensive plan on implementation, control and monitoring of the whole lifecycle of the agriproduct along the supply chain from producer to end user. RHDHV considers this an excellent conceptual model for a specific targeted supply chain, as an alternative or to reduce the use of chemical agents if monitoring and full control of the method is realized. However, to implement it at a global level for a commodity food or feed product in the whole sector, is, according to RHDHV, at this moment, not considered feasible.

Hierarchy of Control
This method starts with an approach categorized in the highest level of the hierarchy of control: eliminating a toxic substance (thus level 1).
To ensure correct implementation it requires from source to end use solid organisational measures and administrative controls to ensure consistent application.

5.8 Improved methods of the use of Phosphine as fumigation gas

Recommended improvements based on the incidents in 2019 and 2021
An investigation was launched after the incident in 2021 and led to the report "analysis on fumigated cargo with pesticides" (April 4, 2022).

The report analyses the incident and includes the following recommendations for improved management of the use of phosphine:

- **Information in the supply chain:**
  Measures to include mandatory communication in the legal authorisation of the use of phosphide pellets and a recommendation to fill gaps between transport and occupational safety legislation.
- **Improvements in the conditions of (EU) approval of the use of phosphine:**
  Prohibition of loose phosphide tablets and removal requirements of unused tablets in transport.
- **Improvements in protocols:**
  Improve existing occupational health and safety protocols for cargo fumigated with pesticides by Harbour Authorities and social partners.
- **Improvement in coordinated enforcement and incident recording:**
  Coordination of international inspection services and establishment of an incident register.

Stakeholders that were interviewed during this quick scan confirmed the following recommendations:

- Ban the use of loose phosphide pellets during transport.
- Recommend the use of phosphide pellets in sleeves or plates, that can be removed before transhipment on the final destination.
- Improve the communication in the supply chain if phosphide pellets have been applied.
- Promote clean handling and good housekeeping in the source countries.
- Eliminate the need for the use of phosphide on the long term.
- Include these recommendations in actual legislation or international rules and recommendations

European Legislation and IMO (International Maritime Organisation)

During the interviews it appeared that phosphine incidents are not considered a top priority all over the world. In the countries overseas where grains and animal feed originate from, phosphide pellets are often used as a precautionary measure without assessing the actual need for them. Combined with the relatively low efforts and costs, these are the reasons for the widespread use.
Once all the above-mentioned recommendations have been correctly implemented in Europe, the main risk will arise from overseas non-EU shipments, as the EU Commission has no regulatory power outside of its area.

The IMO rules and guidelines for sea vessels include some general rules for the handling of the cargo and fumigation. The fumigation rules and guidelines are laid down in specific GAFTA procedures. There is no mandatory international framework to enforce these procedures on the use of phosphine.
Within Europe the BPR and PPPR can be used to impose safe use or phase out of the use of loose phosphide pellets.

Contract conditions

The remaining tool to impose specific fumigation methods are contract conditions between grain and food traders (for example compliance to the GAFTA fumigation rules). From the interviews and the above-mentioned report, the important players are (food and feed) traders. These, mostly global, companies are the main importers of grains and animal feed to the EU and supply the national end users.
The Dutch Grain Traders have added a clause “gassed loads” to their conditions which impose a mandatory communication in the transport chain. An important improvement for the safety in the supply chain is that these conditions include the obligation to communicate in transport documents that a cargo is treated with a gaseous toxic fumigant like phosphide.

Resistance
In the literature biological resistance of vermin to phosphine has been recorded. The consequence is that the agent becomes less effective over time. It was indeed acknowledged during the interviews that is theoretically possible, but it was not reported that it was already the case.

Hierarchy of Control
These improved methods to increase the safety of phosphine use can be categorized as level 3 and 4 measures in the hierarchy of control: engineering and administrative (procedural) controls.
Air sampling is a logical element of these controls. When air samples have to be taken in a cargo that may be fumigated with phosphine, the use of personal PPE, the lowest level of control, are required as a preventive measure.

5.9 The evaluation of phosphine and alternatives

Introduction to table II: evaluation of alternatives
The literature review and the interviews generated a long list of possible (theoretical) alternatives for phosphine. The interviews identified only limited practical experience with some of these alternatives. The main practical experience with alternatives were methods based on oxygen depletion. However, this method is not suitable for overseas transport and most other transport in bulk unless it is in closed storage and transport units for high value products (taking the costs aspect into account).
Heating followed with mechanical methods (sieving or blowing) is also applied in the supply chain, but at the end of the supply chain (before sale to the final client). These methods are generally too expensive and unsuitable for large quantities.
Table II is a visual overview of the alternatives for phosphine identified in this report and some of its basic conditions such as functionality, risks, and costs. The information is primarily based on literature, however information from interviews and RHDHV expert judgement were applied when compiling the information. The assessment criteria and differences between the methods are given below.

Functionality
Most toxic fumigants identified as possible alternatives to phosphide to combat vermin can be effective to some extent, if correctly applied. Some methods have a reported impact on the product (which makes them less functional) or literature reported conflicting results. Non-toxic methods can be effective too, however have more scope or cost limitations.
The technical and legal conditions for safe application and the opportunities to manage these conditions, throughout the whole supply chain (in all modalities of storage and transport), are a more limiting aspect of vermin control methods than the functionality as such. If one of the technical conditions in the chain cannot be met, the safe and effective vermin management with that method is compromised.

Logistics and supply chain
All methods based on asphyxiation require investments in equipment and sealed modules to be effective and these are for low value commodities not available for transport modalities in bulk. It is still unknown whether asphyxiation could be applied in bulk sea transport, as a technical review how to modify a sea vessel to make this possible, has not been identified.
Non-toxic methods based on physical or mechanical methods or the principle of IPM, need sufficient monitoring and control in the whole supply chain to ensure correct implementation. Especially IPM applied to agri-bulk is in an embryonic phase and not ready for full implementation in the supply chains in the worldwide markets.
The actual use of phosphide pellets is easy, whether they are applied in loose tablets or in sleeves or plates.

The ample availability of phosphide tablets worldwide and accessibility at low costs, in addition with the easy application and effectiveness makes phosphide the standard premium used product for fumigation of grains and animal feeds worldwide. Most interviewees acknowledged that there is no other better product to do the job and that there are no suitable alternatives for the same costs. An important additional reason is that generated phosphine gas from phosphide pellets, leaves no toxic residue in the product, If correctly ventilated. The end product is safe for consumption.

Most interviewees did not consider it necessary to ban the use of phosphine generating pellets, as the application of phosphine generating phosphide pellets in sleeves or plates, can improve the safety sufficiently.
At the same time the European regulators' efforts are aimed towards a package of measures to reduce the use of phosphide, to stimulate safer use of phosphide and ultimately to ban phosphide use during transport in EU.

Risks
Some of the optional alternative fumigants reviewed in this quick scan have a toxicity hazard to humans and would also require mitigation measures to ensure safe use. Some alternative fumigants have, additional to the human health hazard, environmental hazards, (for example a greenhouse potential) and are therefore not a feasible alternative for phosphide.
All nontoxic options for phosphine substitution, such as suffocating gasses, heating, or mechanical methods, have the benefit of lower occupational risks that are easier to manage compared to the toxic risks of phosphine gas releasing phosphide pellets.

The current situation of the application of loose phosphide pellets has significant exposure risks to humans, because of remaining pellets that cannot be removed before handling the fumigated cargo. The risks can be reduced substantially when the phosphide pellets are applied in sleeves or plates, which can be removed easily. Stricter communication procedures and registration before transshipment operations will significantly contribute to the removal of residual phosphide pellets before any other handling in the supply chain and reduce the risks.
The use of loose pellets must be banned at a global level to lower the risk to an acceptable level.
Within the EU discussions are ongoing on a ban of fumigation with phosphide pellets during transport, applied in any form (loose pellets ánd sleeves or plates). The time between source and destination within the EU are too short for effective ventilation of the fumigated cargo.

Applicability and Scope
Toxic fumigants can be applied in many modes of transport and storage, however no toxic fumigant has an EU approval for the broad scope of bulk transport and storage.
Asphyxiation is most successful in storage and in closed smaller packaging and sealed containers but cannot be applied in bulk transport for inland water or sea transport and rail and road transport at this moment.
Nontoxic and mechanical methods are only applied by secondary (smaller volume) distributors at this moment, before final packaging.

Costs

The alternatives based on asphyxiation and physical methods are expensive, compared to the use of phosphide. The costs of non-toxic, mechanical methods including good housekeeping do not require major investments but require a high level of control to monitor correct implementation throughout the whole supply chain. More specific information on costs of the latter could not be generated.

The costs of using phosphine releasing phosphide pellets is relatively low in the country of origin. However, the costs to reduce the risks (separate transfer upon reception of the cargo to ensure sufficient ventilation) in the receiving port are a financial burden for the clients (and not for those who send the cargo in the country of origin).
The use of phosphide pellets in sleeves or plates in the source country is (of course) more expensive than loose pellets for the vendor. The handling costs of the removal of the sleeves with remaining pellets are also cost increasing, compared to loose pellets. In general it can be assumed that a measure higher in the supply chain, has a preventive effect throughout the whole supply chain and reduces the mitigation costs in later steps in that chain. However, a comparison of the costs throughout the whole supply chain between the two approaches (loose pellets versus sleeves), has not been made.

The challenge of the actual situation is that the costs savings (of using loose pellets) are in most cases up in the supply chain (outside in the EU), and the cost increase to ensure safe handling in a later phase in the supply chain (in the EU)
As this cannot be regulated within one regulatory framework globally, contract agreements between the parties in the supply chain offer the sole opportunity to impose safer methods throughout the whole supply chain.

6 Conclusions and recommendations

This quick scan for alternatives to the use of phosphine gas from phosphide pellets applied in food and feed as vermin management resulted in the identification of limited options that can be applied on the short term.
Sustainable alternatives based on asphyxiation with nitrogen or carbon dioxide are not sufficiently operational or registerd for use in all modalities of transport and not cost competitive compared to the existing practices for overseas bulk transport. It can only be applied now as an alternative for phosphine in relatively small quantities of cargo in contained packaging (from big bags to containers) and high added value food products (for instance nuts, coffee, fruit, etc). It is not feasible for most of the transport of agribulk by sea vessels, for cost and technical reasons.

The identified optional alternative fumigants, based on a toxic effect, do not seem to be sufficiently operational or registered for use in the supply chain of agribulk. Toxic alternative agents will also be toxic to humans and at the same time some are harmful for the environment (e.g. greenhouse gases).

For the foreseeable future fumigation with phosphine, according to RHDHV, will be expected to be the preference in combatting vermin worldwide for transport overseas. From a regulatory perspective the (safe) use of phosphine gas generated with phosphide pellets is regulated in Europe under the BPR (Biocidal Product Regulation) and PPPR (Plant Protection Product Regulation). Some improvement of safety measures can be made and are already in preparation by het College voor de toelating van gewasbeschermingsmiddelen en biociden (Ctgb).The route to impose measures via a mandatory global framework on transport (e.g. International Maritime Organization IMO conventions) to ensure and regulate safe use of phosphine gas is considered not feasible (no priority in global context).
The occasional mandatory use of phosphide tablets in some non-EU countries of origin before transport overseas, is an obstacle to phase out phosphine gas use. However, safer methods using phosphide pellets, can be implemented in the short term.

Resistance of vermin to phosphine has not been identified as an issue during the interviews but has been recorded as a risk in the literature. This may increase in the future and requires monitoring.

Short term recommendations
In the short term there are no available alternatives for fumigation of grains and animal feed materials, which could replace the use of phosphine at an effective and feasible scale in the supply chain.

To reduce the risk of the use of phosphine gas releasing agents, all efforts must be focused on safer use of phosphine with technical and organisational means. The report “Ketenanalyse gegaste lading ” (Annex 1 to the letter to the Dutch Parliament, April 4, 2022), proposes detailed measures to improve the safety of the use of it, from a technical point of view as well as from an organisational point of view (the latter includes the regulatory perspective).
The core conclusions are that effectiveness and safe use conditions of phosphine use can only be met if, after fumigation the stored product ready for transport is sufficiently ventilated and remaining pellets can be removed before transhipment at the destination. This can be achieved when the phosphide pellets are applied in sleeves or plates, which can be removed easily. Stricter communication procedures and registration before transshipment operations will significantly contribute to the removal of residual phosphide pellets before any other handling in the supply chain and reduce the risks.
As the improvements cannot be enforced with a regulatory framework globally it is recommended that the large agri trading companies importing the agriproduct to the EU must impose the same conditions as mentioned above in the contracts for overseas bulk transport from non-EU countries. The use of loose pellets should be banned at a global level to lower the risks to an acceptable level.

Within the EU discussions are ongoing regarding a ban of fumigation with phosphide pellets, applied in any form (loose pellets and sleeves or plates) during transport. The time of transport between source and destination within the EU is too short for effective effective ventilation of the fumigated cargo..

Once the measures mentioned above have been realized, the effectiveness should be monitored Europe wide, as well as non-compliances and, worse, incidents. Based on the collected monitoring data further steps within the EU and globally must be defined.

Long term recommendations

The results of the above-mentioned monitoring should be evaluated periodically. If these do not lead to the required results and non-compliances continue to be recorded or worse, incidents still occur, other, more effective measures should be implemented.

These measures should aim at eliminating the use of phosphine in the supply chain, applying practical methods that can be easily implemented, higher in the Hierarchy of Control. The measures are most effective when looking at the whole supply chain holistically and applying an IPM (Integrated Pest Management) approach. Subsequent measures, following the Hierarchy of Control, could be possible:

- Highest level of control: Eliminating the need for the use of any substance: imposing a strict hygiene control and applying mechanical measures in the whole supply chain, based on a IPM approach. Assure a legislative framework within the EU, with additional contract conditions imposed by the global players in the global supply requiring and monitoring these measures worldwide. Start with dedicated food and feed supply chains with high added value and scale up to bulk products.
- Second level of control: Substitution of a toxic substance with a non-toxic substance: for example, using the asphyxiation effect of CO_2 or N_2; these substances have to be registered for application within the EU within the PPPR or BPR (the EU Regulatory framework) depending on the scope of the use.
- Second level of control: Substitution of a toxic substance with less toxic substance: for example, using a toxic fumigant (ethyl formate) combined with the asphyxiation effect of nitrogen or carbon dioxide; these substances and products have to be registered for application in the EU within the PPPR or BPR framework.
- Third combined with the fourth levels of control: improve the safety of the use of phosphine gas releasing agents, using sleeves or plates and the authorized instructions for use procedures. This can be implemented in the EU within the PPPR or BPR framework and globally through contract conditions and IMO recommendations.
- As there are no regulatory options applicable on the whole supply chain worldwide, contract conditions only can be imposed from source to end user and need to play a more important role in the effective application of IPM and alternatives to fumigation with phosphine gas releasing agents. To be effective these conditions should be geographically complementary and technically aligned with the EU regulatory framework. The large global food and feed traders need to play an important role in applying and monitoring these conditions from the non-EU source until the point it enters in the EU.
- As costs are an obstacle for these measures for bulk food and feed, application of the IPM principles with the high value products for human consumption separated from animal feed products can be a feasible start. After sharing the (positive) experience bulk food and feed products may follow.

Acronyms

ADN	The European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways
ADR	The Agreement concerning the International Carriage of Dangerous Goods by Road
BP	Biocidal Product
BPR	Biocidal Product Regulation
CtgB	College voor de toelating van gewasbeschermingsmiddelen en biociden
EU	European Union
HoC	Hierarchy of Control
IMDG	International Maritime Dangerous Goods Code
IMO	International Maritime Organization
IPM	Integrated Pest Management
PPE	Personal Protective Equipment
PPP	Plant Protection Products
PPPR	Plant Protection Products Regulation
RHDHV	Royal HaskoningDHV

Annex

1. Table I. Identified literature on possible alternatives to fumigation

Royal HaskoningDHV

Annex I
Table I

Number	Phosphine and Alternative for phosphine Fumigant/technique	Logistics and supply chain Easy to produce (locally), raw materials available	Easy packaging, transport and store	Availability ready to market (maturity of the technique)	Functionality / workability Efficient and easy of use application	Effectiveness to kill klander or other vermin	Impact required mitigation measures to ensure safe use on workability	Risks Workers	Environment	General public	Biological resistance	International Conditions (regulatory and agreements) Allowed due to international obligations and legislation	Implementable due to international circumstances and cooperationbetweenstates	Fitness Affordability based on life cycle cost in 5 years*	HoC	Means of storage/transport		Literature	Comment
1	**phosphine pills**	++	+	++	++	++	-	-	-	++	-	++	+	+	NA	Deepsea (Ocean)	Y	CNB (2020)	Although phosphine has genotoxic effects to humans and increasing environmental and workspace restrictions (Bond, 1984), phosphine is still widely available as a registered fumigant around the world but requires very long exposure periods (Bond, 1984, Xin et al., 2008). (Coetzee (2020))
1a	**Rationale**		corrosive to metals. Pills in a container.		Pills can start emmiting gas at unwanted times and cannot be removed from commodity.	In order to kill grain pests at all stages of their life cycle (egg, larva, pupa, adult), including pests with strong resistance, phosphine gas concentration, levels need to reach and be maintained at 300 parts per million (ppm) for seven days (when grain is above 25°C) or 200ppm for 10 days (between 15–25°C).	Protocols, procedures, monitoring and PPE required: Not able to remove pills from the commodity is a risk.	High acute toxicity via inhalation. EU: LTEL: 0.1 ppm. STEL: 0.2 ppm. Flammable in hot and humid conditions.	Very toxic to aquatic life		Issue in Australia in grain storage. Lethargy (too high % fumigant) not dead and still proliferate. This is known as Phosphine resistance.				Shortsea (in between regional ports)	Y	Phostoxin-Tablet-Pellet-manual	
																Rail	Y	CLM (2001) Insectvrij zonder Methylbromide	
																Truck	?	https://en.wikipedia.org/wiki/Phosphine	
																Binnenvaart (barge)	N	Emery et al. (2011) Lessons learned from phosphine resistance monitoring in Australia	
																Silo	Y	GRDC (2011) A Grains Industry Guide	
																Bigbag	?	Solvay (2021) Cylinderized Phosphine Fumigation	
																Container	Y		
2	**Phosphine bagchain/blanket**	++	+	++	++	++	-	-	-	++	-	++	+	+	3	Deepsea (Ocean)	Y	CNB (2020)	
3a	**Rationale**		corrosive to metals.Bagchain/blanket bag chain/blanket in a box.		Can be removed from commodity.	In order to kill grain pests at all stages of their life cycle (egg, larva, pupa, adult), including pests with strong resistance, phosphine gas concentration, levels need to reach and be maintained at 300 parts per million (ppm) for seven days (when grain is above 25°C) or 200ppm for 10 days (between 15–25°C).	Protocols, procedures, monitoring and PPE required: Able to remove sleeves from the commodity.	High acute toxicity via inhalation. EU: LTEL: 0.1 ppm. STEL: 0.2 ppm.	Very toxic to aquatic life		Issue in Australia in grain storage. Lethargy (too high % fumigant) not dead and still proliferate. This is known as Phosphine resistance.				Shortsea (in between regional ports)	Y	Phostoxin-Tablet-Pellet-manual	
																Rail	Y	CLM (2001) Insectvrij zonder Methylbromide	
																Truck	?	https://en.wikipedia.org/wiki/Phosphine	
																Binnenvaart (barge)	N	Emery et al. (2011) Lessons learned from	
																Silo	Y	GRDC (2011) A Grains Industry Guide	
																Bigbag	?		
																Container	Y		
3	**Cylinderized Phosphine (ECO2FUME ® and VAPORPH3OS®)**	++	+	++	+	++	-	-	-	++	-	++	+	+	3	Deepsea (Ocean)	?	Solvay (2021) Cylinderized Phosphine	
3a	**Rationale**		corrosive to metals. Pure Phosphine PH3 gas in reusable tanks.		More efficient application than pills, airtight conditions; gas concentration can be controlled preventing narcosis instead of death.	In order to kill grain pests at all stages of their life cycle (egg, larva, pupa, adult), including pests with strong resistance, phosphine gas concentration, levels need to reach and be maintained at 300 parts per million (ppm) for seven days (when grain is above 25°C) or 200ppm for	Protocols, procedures, monitoring and PPE required: Applied as gas.	High acute toxicity via inhalation. EU: LTEL: 0.1 ppm. STEL: 0.2 ppm.	Very toxic to aquatic life		Issue in Australia in grain storage. Lethargy (too high % fumigant) not dead and still proliferate. This is known as Phosphine resistance.				Shortsea (in between regional ports)	?	GRDC (2011) A Grains Industry Guide	
																Rail	?		
																Truck	?		
																Binnenvaart (barge)	?		
																Silo	Y		
																Bigbag	?		
																Container	?		
4	**Phosfine fumigation box**	++	+	++	+	++	-	-	-	++	-	++	+	+	3	Deepsea (Ocean)	?	Kotzur (2021) Fumigation box	
4a			corrosive to metals. Installation on site.		More efficient application than pills, airtight conditions; gas concentration can be controlled preventing narcosis instead of death.	In order to kill grain pests at all stages of their life cycle (egg, larva, pupa, adult), including pests with strong resistance, phosphine gas concentration, levels need to reach and be maintained at 300 parts per million (ppm) for seven days (when grain is above 25°C) or 200ppm for	Protocols, procedures, monitoring and PPE required: Applied as gas. Silo: ground level fumitation + safer than headspace fumigation.	High acute toxicity via inhalation. EU: LTEL: 0.1 ppm. STEL: 0.2 ppm.	Very toxic to aquatic life		Issue in Australia in grain storage. Lethargy (too high % fumigant) not dead and still proliferate. This is known as Phosphine resistance.				Shortsea (in between regional ports)	?	Solvay (2021) Cylinderized Phosphine	
																Rail	?		
																Truck	?		
																Binnenvaart (barge)	?		
																Silo	Y		
																Bigbag	?		
																Container	?		
5	**Carbonyl sulfide (Cosmic)**	?	+	--	+	-	-	-	-	-	?	?	?	?	2a	Deepsea (Ocean)	?	Somiahnadar Rajendran (2001) Alternatives to methyl bromide as fumigants for stored food commodities. Pesticide Outlook – Fumigants. DOI: 10.1039/b110950c	Research work on carbonyl sulfide in Australia, Germany and the USA reveal that egg stage is highly tolerant to the fumigant, the effective exposure period is half that of phosphine and it is effective against insects and mites at ≥5°C. Carbonyl sulfide is naturally present at low levels in food grains, vegetables (Brassica spp.) and cheese.
5a	**Rationale**		As a gas in cilinders.	Not on the market as fumigant. Treated product off-odour and off colour. Vs No effects.	32 g/m3 for 24 h	Egg stage is highly tolerant to the fumigant. Vs COS kills all life stages of all test insects Conflicting.	The occupational risks presented by COS as a fumigant of bulk grain are significant, these are, as they have been for a considerable time for phosphine and methyl bromide, manageable by good occupational safety practices.	TLV-TWA 10 ppm. High acute toxicity via inhalation. In terms of classical regulatory toxicology studies, the available database for COS is deficient in many aspects. IPZS: Very toxic to aquatic life.	In terms of classical regulatory toxicology studies, the available database for COS is deficient in many aspects. Breakdown product: H2S.	Consideration may need to be given to scrubbing of ventilated COS and its breakdown product hydrogen sulfide, at the completion of fumigation to minimise worker and bystander exposure.		No indication was found in literature and internet searches that carbonyl sulphide was consequently registered anywhere in the world as a fumigant.				Shortsea (in between regional ports)	?	Armstrong et al (2014)	Reports from Australia indicate that the fumigant does not affect the quality of wheat, sorption is less and germination is not affected following exposure to dosages ranging from 12 to 125 g m−3 for 24 h. However, investigations on carbonyl sulfide carried out in China showed contradictory results. Xianchang et al. (1999) reported that carbonyl sulfide affects germination of cereals except sorghum and barley and imparts off-odour following treatment at 50 to 500 g m−3 for 7 days. Bread made from wheat that was fumigated at 50-200 g m−3 (and aerated for 180 days) was tainted. Milled rice after treatment of paddy rice with carbonyl sulfide at the above dosages had undesirable odour. Change in colour was also observed in fumigated soybean. Zettler et al. (1999) also noticed off-odour during the first 24 h of aeration in walnuts that were fumigated with carbonyl sulfide at 24-56 g m-3 for 24 h. It is suggested that hydrogen sulfide present in the product sample, as an impurity, is partly responsible for the
																Rail	?	CLM (2001) Insectvrij zonder Methylbromide	
																Truck	?	Bartholomeus (2005)	
																Binnenvaart (barge)	?	Ryan (2006) Cosmic and Sterigas	
																Silo	Y		
																Biobag	?		
																Container	?		
6	**Ethanedinitrile (Sterigas)**	++	+	-	+	+	-	-	-	-	?	?	?	?	2a	Deepsea (Ocean)	Y	Ryan (2006) Cosmic and Sterigas	We know the following about EDN (EPA NZ (2018) edn_faqs): 1. EDN is not an ozone-depleting gas nor is it a greenhouse gas. 2. EDN is not significantly more toxic to humans than methyl bromide. 3. Exposure to EDN is not cumulative. 4. EDN is more volatile than methyl bromide; and, 5. Decomposes more readily in the environment. 6. EDN degrades to form ammonia and carbon dioxide. The Food and Agriculture Organisation of the United Nations considers that following fumigation any residual cyanide in fumigated food stuffs would be at very low levels and will present no hazard to human consumers. In 1996, CSIRO (along with Inventors/Applicants O'Brien I., Desmarchelier, F. J. M., and Ren, Y.) patented ethanedinitrile
6a	**Rationale**	EDN is currently manufactured exclusively by Drasiovka, a family-owned company based in the Czech Republic. Drasiovka purchased the sole rights to EDN from Linde AG at the end of 2014, followed by a significant investment to develop EDN into a commercially and	As a gas in cilinders. Flammable gas; non-flammable mixture of EDN in liquid CO2.	Implemented for timber but not for grain.	Maintain airtight seal to achieve the dose/ grains and time. Devitalise grains and weed seeds + sterilise pathogens: - 115 g/m3 for 5 d exposure.	EDN showed high toxicity to all immature and adult stages tested and in this respect is more toxic than methyl bromide and sulfuryl fluoride	Protocols, procedures, monitoring and PPE required: Applied as gas. Breakdown: hydrogen cyanide. re-entry into the buffer zone should not be undertaken until levels of ethanedinitrile and/or hydrogen cyanide are below 1 ppm.	TLV-TWA 10 ppm. Toxic if inhaled. Breakdown: hydrogen cyanide. Fatal inhaled: TWA 0.9 ppm.	Very toxic to aquatic life + with long lasting effects.			SEVESO E1	There is an emergency allowance for timber. No data for grain in EU.			Shortsea (in between regional ports)	Y	Armstrong et al (2014)	
																Rail	Y	Ducom (2006)	
																Truck	?	Ratendran (2007)	
																Binnenvaart (barge)	?	Australian government (2013) PUBLIC RELEASE SUMMARY on the Evaluation of ETN-sterigas	
																Silo	Y	EPA NZ (2018) edn_faqs	
																Biobag	?	EPA (2018) EDN-Science-Memorandum	
																Container	?		
7	**Ethyl formate (+ CO2 VAPORMATE or + N2)**	++	+	++	++	++	++	++	++	++	+	?	?	+	2a	Deepsea (Ocean)	Y	Coetzee et al. (2021) Ethyl formate + nitrogen fumigant: a new, safe, and environmentally friendly option for treating a 20 ft shipping container loaded with cereal freight	This study has proven that ethyl formate + nitrogen fumigation technology in shipping containers, stationary or in-transit on road and at sea, is effective, safe, comparatively inexpensive and environmentally friendly. This technology will present industry with a faster, easier and safer way to fumigate commodities in shipping containers and at the same time saving millions of dollars by reducing labour costs and a significant decrease in total supply chain time from loading to unloading.(Coetzee 2020)
7a	**Rationale**	Commercially available	As a gas in cilinders. Flammable gas; non-flammable mixture with CO2 or N2.	Commercially available	No residues on the products. Equilibrium of ethyl formate was achieved in containers within 30 minutes after application.	All tested adult insects (100%) were killed within 2-3 hours.	effective and also safe with no detectable risk to the public, crew members on the barge or workers. After an aeration period of 15 minutes, ethyl formate can be eliminated below the TLV level of 100ppm. Levels of ethyl formate at workspace during application, fumigation and aeration were far below TLV of 100ppm. It was concluded that after a short aeration process, there was no risk to personnel entering the containers to unload.	GRAS, food additive. Breakdown to formic acid and ethanol. + non-flammable ethyl formate + nitrogen fumigant TVL-TWA 100ppm			Toxicity of volatile formate esters to insects is much higher than related alkyl esters, due to hydrolysis of the formate esters to form formic acid and its inhibition of cytochrome c oxidase. From our knowledge of the mechanism of action, the development of insect resistance to ethyl formate is predicted to be slow.		Commercial formulations, such as VAPORMATE® may be expensive in comparison with methyl bromide or phosphine for durables. In transit fumigation is costly. This technology will present industry with a faster, easier and safer way to fumigate commodities in shipping containers and at the same time saving millions of dollars by reducing labour costs and a significant decrease in total supply chain time from loading to unloading.		Shortsea (in between regional ports)	Y	Coetzee et al (2020) In-transit fumigation of shipping	VAPORMATE® is an eco-friendly, safe, non-residual fumigant. You can use it to protect your post-harvest produce, packaged and stored foods and processing equipment. It is already approved for a long – and growing – list of fruits, vegetables and grains. The active ingredient of VAPORMATE is ethyl formate – an agent that simply degrades to naturally occurring substances. Benefits at a Glance •Environmentally friendly solution •Fast-acting for greater productivity •Easy to dose and apply •Effective with a wide range of insects, fruit, vegetables and grains •Extensive consulting, installation, safety training and support services. Ethyl formate is a naturally occurring volatile present in the environment air, milk, cheese, wheat, beer, and many fresh products.[14] It is rapidly hydrolyzed to ethanol and formic acid which are also biogenic compounds.[10] Ethyl formate is generally regarded as safe (GRAS) as a food additive[23] and is used as a flavoring agent with no evidence that it is hazardous to the public.[24] The work safety related TLV is 100 ppm, which is the maximum concentration that a person is allowed to be exposed to daily for a working lifetime. The TLV of ethyl formate is much higher than those of the chemical fumigants, methyl bromide (4 ppm),
																Rail	Y	CLM (2001) Insectvrij zonder Methylbromide	
																Truck	Y	Armstrong et al (2014)	
																Binnenvaart (barge)	Y	Ducom (2006)	
																Silo	?	Ratendran (2007)	
																Bigbag	?	Coetzee (2020) Exploration of ethyl formate + nitrogen as a fumigant. Thesis	
																Container	Y	Coetzee et al (2019) commercial trial evaluating the noval use of ethyl formate for in-transit fumigation of shipping containers Guide on use and safety vapormate: 9731_Vapormate_Application_guide_ST_tcm17-589873.pdf (linde-gas.com) https://www.linde-gas.com/en/products_and_supply/fumigants/vapormate/index.html	
8	**Ozone**	+	-	--	-	-	?	+	++	++	NA	?	?	-	2b	Deepsea (Ocean)	N	Rajendran (2001) Alternatives to methyl bromide as fumigants for stored food commodities	Ozone has a number of important characteristics that make it a poor choice as an alternative fumigant: - powerfull oxidising agent; reacts with many materials - does not penetrate barriers easily; eggs are resistant - degrades rapidly so continuous replacemet needed
8a	**Rationale**	Ozone can be generated on location by subjecting air to an electric arc converting oxygen to ozone. This gas containing ozone can be then pumped through a grain	Corrosive to metals and degrades equipment such as rubber seals, and electrical equipment at unacceptable rates.In situ generation, no need to store and dispose of	Not on the market as fumigant. Laboratory studies.	No residues on the products or effects or grain quality. It needs to be continually generated and also poses engineering challenges for distributing it throughout	Kills adults of several pest species present in grain. Does not penetate barriers and eggs are resistant,	GRAS.TLV-TWA 0.1 ppm.	No adverse effect.	Very reactive, no bystander exposure.				Corrosive to metals and degrades equipment such as rubber seals, and electrical equipment at unacceptable rate.			Shortsea (in between regional ports)	N	Armstrong et al (2014)	
																Rail	N	Bonjour (2011) Efficacy of Ozone Fumigation	
																Truck	N		
																Binnenvaart (barge)	N		
																Silo	Y		
																Biobag	N		
																Container	Y		
9	**IPM – integrated Pest Management**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2a	Deepsea (Ocean)	?	https://www.wur.nl/en/Dossiers/file/Integrated-Pest-Management-IPM.htm	Integrated Pest Management (IPM) - WUR
9a	**Rationale**															Shortsea (in between regional ports)	?		Integrated Pest Management (IPM) is a sustainable and broad-based approach that integrates practices for the economic prevention and control of pests and diseases in crops. Natural enemies can be effective, and pesticides (chemical substances for controlling pests) are only used when alternative options do not produce the required result. There are fewer problems with natural crop protection agents because of the presence of residues from pesticides. There is also less resistance to natural agents. Integrated crop protection is not a "one stop shop" solution but more a sustainable and broad-based approach that integrates eight practices for the economic prevention and control of pests and diseases in crops.
																Rail	?		
																Truck	?		
																Binnenvaart (barge)	?		
																Silo	?		
																Biobag	?		
																Container	?		
10	**Entomopathogenic fungi (EPF)**	?	?	?	?	?	?	?	?	?	?	?	?	?	1	Deepsea (Ocean)	?	Batta (2016) entomopathogenic fungi	The recent advances in biocontrol of stored-grain insects using formulated and unformulated strains of entomopathogenic fungi (EPF) are reviewed and discussed. Several liquid and dry formulations of EPF strains were developed and used against these insects. However, a literature search revealed lack of any commercially registered product of these formulations. Therefore, in order to achieve an effective control of these insects, the following potential areas of future research have been identified and discussed: (i) screening for new effective strains of EPF, in addition to new effective formulations, (ii) applying the most effective strains and formulations selected in the previous step under storage conditions, (iii) optimising the proportions of ingredients in the selected formulations and (iv) integrating the products of the most effective formulations, after registration and commercialisation, in the
10a	**Rationale**															Shortsea (in between regional ports)	?		
																Rail	?		
																Truck	?		
																Binnenvaart (barge)	?		
																Silo	?		
																Biobag	?		
																Container	?		
11	**Sulfuryl Fluoride (ProFume, Vikane)**	++	++	++	++	++	-	-	--	-	+	++	++	?	2a	Deepsea (Ocean)	?	Postharvest fumigant I ProFume.com - Profume	ProFume® Sulfuryl fluoride is also a greenhouse gas – 4800 times the potency of carbon dioxide or equivalent – and stays in the atmosphere for 36 years.
11a	**Rationale**		As a gas in cilinders.	Commercially available	Chamber fumigations can be completed in 12 hours or less. No effect on product quality. A key issue in the need to use more sulphuryl fluoride than methyl bromide to achieve an effective fumigation (Adam et al. 2010) is sulphuryl fluoride's lack of efficacy against insect	Controls all life stages of insects. Greater tolerance off the eggs.	Protocols, procedures, monitoring and PPE required: Applied as gas.	TLV-TWA: 5 ppm. Toxic if inhaled. Fluoride is thought to be the actual active component.	Greenhouse gas. 4800 times the potency of carbon dioxide or equivalent – and stays in the atmosphere for 36 years.	USA: due to fluoride health effect children: teeth and bones. https://www.epa.gov/sites/default/files/2016-10/documents/hydrogen-fluoride.pdf	No resistance of the insects. Risk is that the eggs surviving may lead to resistance ultimately.	Registered in 19 countries as fumigant.				Shortsea (in between regional ports)	?	Tom Phillins (2017) Phosphine Fumigation of Grain	Ultimately, sulphuryl fluoride, with all its negative issues presents the only possible second choice after ethanedinitrile for further study as a methyl bromide alternative. However, sulphuryl fluoride should be considered for further research only if the authors' first choice, thanedinitrile (refer to 4.5.3, page 39), is rejected as an option based on a technological and economic study.
																Rail	?	Rebecca Thyer (2009) Nitrogen explored as fumigant option. Ground Cover	
																Truck	Y	EURL-SRM (2018) Analytical Observations Report	
																Binnenvaart (barge)	?	CLM (2001) Insectvrij zonder Methylbromide	
																Silo	Y	Armstrong et al (2014)	Sulphuryl fluoride was reported to be an "ideal" fumigant for structures against termites (Stewart 1956) and commodity insect pests (Kenaga 1957) because it is toxic to insects under all temperature and exposure conditions, non-flammable, non-explosive, easily dispersed, essentially non-reactive with a wide range of metals, fabrics, leather and paper goods, wood, plastics, and rubber
																Bigbag	?	Rajendran (2001) Alternatives to methyl bromide as fumigants for stored food commodities	
																Container	Y	Profume-App-Manual-DP_0817_NEW	
12	**Controlled atmosohere /N2/CO2)**	++	--	+	-	-	?	++	++	++	NA	-	?	+	2b	Deepsea (Ocean)	Y	CATT – Ruvoma.nl	"It is safe to use, environmentally friendly and its only operating cost is electricity. It also produces no residues, with the atmosphere returning to normal as soon as the PSA machine is turned off." "The running cost is not expensive – at about 25 cents per tonne of grain" "nitrogen's environmentally friendly attributes might allow nitrogen-treated grain to be marketed as 'green grain'. "producing enough pure nitrogen gas has been a limiting factor." Low-oxygen atmosphere generated on-site from air through pressure-swing absorption and subsequent filtration through a carbon
12a	**Rationale**	PSA nitrogen generators	in situ generation	Nitrogen is already in use at many of Australia's bulk handlers, including CBH, ABB and GrainCorp. For example, Graincorp's Newcastle terminal has been using nitrogen to treat exported grains for some years,	Long treatment needed, 10 days or more. No residue or reaction with the product.	Very low oxygen conc. Needed (<2%), sub-lethal effects occur.			Produces no residues, with the atmosphere returning to normal as soon as the machine is turned off.		Until more is known about the mode of action of controlled atmospheres in causing insect death and the occurrence of sub-lethal effects that can be predicted and detected, it is unlikely that controlled atmospheres will be acceptable as		Initial costs are high. The running cost is not expensive – at about 25 cents per tonne of grain			Shortsea (in between regional ports)	Y	Rebecca Thyer (2009) Nitrogen explored as fumig	
																Rail	?	Yongling Ren et al. (2012) CRC50147. Alternatives to Phosphine	
																Truck	?	Tom Phillips (2017) Phosphine Fumigation of Grain	
																Binnenvaart (barge)	Y	Rajendran (2001) Alternatives to methyl bromide as fumigants for stored food commodities. Pesticide Outlook – Fumigants. DOI: 10.1039/b110950c	
																Silo	Y	CLM (2001) Insectvrij zonder Methylbromide	
13	**CO2 + high pressure**	?	?	?	+	-	?	NA	NA	NA	NA	?	?	+	2b	Deepsea (Ocean)	?	Armstrong et al (2014)	The primarybenefit from using the carbon dioxide combined with high pressure was that the treatment timewas short, generally 15-60 minutes. However, there are time-related issues with loading the carbon dioxide required to reach the desired pressure (Kutbay et al. 2011) SiberHegner (dierveoder industrie voor kleine huisdieren) is sinds 1996 bezig met het ontwikkelen van een techniek om zowel de producten, de grondstoffen als de pellets insectvrij te maken. Bij een temperatuur van ongeveer 25oC wordt, afhankelijk van het materiaal een CO2-druk van 17-20 bar toegediend. Ook deze techniek is erg kennisintensief voor behandeling van de verschillen in product en te bestrijden plaag. Een volledig proces duurt 6 uur. SiberHegner heeft faciliteiten voor behandeling van zowel verpakt
13a	**Rationale**				No residue or reaction with the product. Perfect sealing required.	Slow reaction > 2 weeks						In NL: CO2 is on the "Regeling Uitzondering Bestrijdingsmiddelenwet"		Initial costs are high. The running cost is not expensive.		Shortsea (in between regional ports)	?	CLM (2001) Insectvrij zonder Methylbromide	
																Rail	?		
																Truck	?		
																Binnenvaart (barge)	?		
																Silo	Y		
																Biobag	N		
																Container	Y		
14	**Irradiation**	?	?	?	?	?	?	?	?	?	?	?	?	?	1	Deepsea (Ocean)	?	Armstrong et al (2014)	Whether irradiation could be used as a treatment against is doubtful because of the costs of providing enough irradiator capacity. Whether other factors, such as energy costs, are prohibitive to the use of irradiation must be considered. Straling is een techniek die erg interessant kan zijn voor behandeling van granen, leesproducten en enkele soorten fruit en vruchtgroenten. Gegevens t.a.v. andere typen exportmaterialen zijn niet beschikbaar. De kosten liggen 2,5-8 x hoger dan die van methylbromide. De initiële kosten voor de ontwikkeling van apparatuur en installaties zijn hier niet in meegenomen. Enkele toepassing van straling zijn geaccepteerd als quarantaine behandeling in de VS.
14a	**Rationale**															Shortsea (in between regional ports)	?	CLM (2001) Insectvrij zonder Methylbromide	
																Rail	?		
																Truck	?		
																Binnenvaart (barge)	?		
																Silo	?		
																Biobag	?		
																Container	?		
15	**Heat**	?	?	?	-	?	?	NA	NA	NA	NA	?	?	-	1	Deepsea (Ocean)	?	Mourier (2000) Control of insects and mites in grain using a high temperature/short time (HTST) technique	One of the major reasons is the lack of perceived need because the current system is working well at an acceptable cost. The heat disinfestation systems used in the past were not well adopted because of their high capital and operating costs as compared to chemical methods. Dust handling and management capability, heat recovery, cooling techniques, and post treatment protection have also been serious problems. Until these are overcome the well established methods and beliefs about disinfestation cannot be challenged successfully. Complete control of grain mites and adult S. granarius in wheat was obtained with an inlet temperature of 300–350°C and an average residence time in the drum of 6 s. More than 99% mortality was obtained for all stages of S. granarius with an inlet temperature of 300–350°C and an average exposure period of 40 s. For control of P. truncatus in maize, an inlet temperature of
15a	**Rationale**				A total heat treatment can be between 1-25 days. Grain quality can be affected.									It can be 6.5x the cost of Mebr treatment.		Shortsea (in between regional ports)	?	CLM (2001) Insectvrij zonder Methylbromide	
																Rail	?	Rashid Qasrani and Jonathan banks (2000) The prospects for heat disinfection of grain	
																Truck	?		
																Binnenvaart (barge)	?		
																Silo	?		
																Biobag	?		
																Container	?		
16	**Carbon disulphide**	?	?	?	?	?	?	?	?	?	?	?	?	?	2a	Deepsea (Ocean)	?	Rajendran (2001) Alternatives to methyl bromide as fumigants for stored food commodities. Pesticide Outlook – Fumigants. DOI: 10.1039/b110950c	The fumigant is not carcinogenic and has no adverse effect on the environment. The major advantage of carbon disulfide is its small effect on seed germination. However, residues of carbon disulfide persist in treated commodities for a longer period than that of other fumigants (Haritos et al., 1999). Some of the limitations of the fumigant include high flammability, longer exposure period, persistence in treated commodity, lack of residue limits of Codex Alimentarius and high human toxicity. Carbon disulphide is commonly formulated in mixtures with nonflammable ingredients for fumigating grain. Previously, CS2 was used extensively in fumigation chambers for the treatment of plant products, such as dried beans and peas. Although still used to some extent for this purpose, it has been largely replaced by methyl bromide, which is nonflammable and more easily volatilized
16a	**Rationale**															Shortsea (in between regional ports)	?	Carbon disulphide FaO (1984)	
																Rail	?		
																Truck	?		
																Binnenvaart (barge)	?		
																Silo	?		
																Biobag	?		
																Container	?		
17	**Physical separation (eg at the source) of oxygen from the air**																	Interview Peterson	

Based on the information in the articles above, a comparative (qualitative) ranking was applied for the conditions and characteristics of the alternatives. The following ranking is applied in Table I in Annex I:	
+ +	better
+	slightly positive / better
0	neutral
-	slightly negative / worse
- -	worse

Annex

2. Table II. Consolidated results of alternatives to fumigation

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Annex II
Table II

Principle of the method	Specific Method	Functionality	Risks to Humans	Risks to the Environment	International Conditions (incl. regulatory and agreements)	Scope (transport and storage)	Costs	Hierarchy of Control
Toxic effect	Phosphine existing situation	++	--	+	++ / -	++	++	-
Toxic effect	Carbonyl sulfide	+ (conflicting results in literature)	--	- (toxic to aquatic life)	-	+/- (storage only)	?	2
Toxic effect	Carbon disulfide	+/ - (high flammability)	+	+	-	?	?	2
Toxic effect	Ethane dinitrile	+ (timber only)	--	-- (highly toxic)	-	--	?	2
Toxic effect	Sulphuryl fluoride	++	--	-- (very strong greenhouse potency)	+ (some applications; not food and feed)	+	?	2
Toxic effect	Ozone	+/ -	+	++	+ / - (as disinfectant and preservative)	?	?	2
Toxic effect	Entomopathogenic fungi	+	+	++	- (in research phase)	?	?	2
Toxic effect	Phosphine improved methods	++	+ / O	+	+ / -	++	+	3, 4 and 5
Combined method (slightly toxic and asphyxiation)	Ethyl Formate and Nitrogen (Vapormate®)	+	O / -	++	O	O	-?	2
Asphyxiation effect	N_2 / CO2 / oxygen depleted air	++	O	++	+ / - / O	O	--	2
Physical methods	Heating	++	O	O (energy use)	++	-	--	1
Physical methods	Radiation	++	O	++	++	O	--	1
Mechanical methods	Sieving / Blowing / Rotating	++	O	+	++	-	-	1

	Functionality (If conditions are met)	Risks to Humans	Risks to the Environment	International Conditions (incl. regulatory and agreements)	Scope (transport and storage)	Costs
--	very low	very high	very high	cannot be approved	very limited	very high
-	low	high	high	not approved	limited	high
O	neutral	neutral	neutral	No approval required	neutral	neutral
+	good	low	low	in process	broad	low
++	very good	very low	very low	approved	very broad (all modalities)	very low