

**ANALYSIS OF ALTERNATIVES**  
and  
**SOCIO-ECONOMIC ANALYSIS**

**Legal name of applicants:** Dometic GmbH  
Dometic Hűtőgépgyártó és Kereskedelmi Zrt.

**Submitted by:** Dometic GmbH

**Substance:** Sodium chromate, EC 231-889-5, CAS 7775-11-3

**Use title:** The use of sodium chromate as an anticorrosion agent of the carbon steel cooling system in absorption refrigerators up to 0.75% by weight ( $\text{Cr}^{6+}$ ) in the cooling solution.

**Use number:** 1

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**LIST OF ABBREVIATIONS**

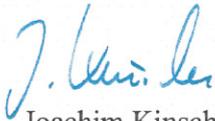
AM	Aftermarket
Annex XIV	Chemicals requiring authorisation under REACH
AoA	Analysis of Alternatives
APAC	Region: Australia and New Zealand, China, Japan and South East Asia
Cr <sup>6+</sup> , Cr(VI)	hexavalent chromium
CSR	Chemicals Safety Report
ECHA	European Chemicals Agency
EEA	European Economic Area
ELV	Directive on End-of Life Vehicle (2000/53/EC)
EMEA	Region: Europe, the Middle East and Africa
ES	Exposure scenario
IRR	Internal Rate of Return
Na <sub>2</sub> CrO <sub>4</sub>	Sodium chromate
NGO	Non-governmental organisation
NH <sub>3</sub>	Ammonia
NOAEL	No observed adverse effect level
NPV	Net Present Value
OEM	Original Equipment Manufacturers
REACH	Registration, evaluation, authorisation (and restriction) of chemicals
RMM	Risk Management Measures
RoHS	Restriction of Hazardous Substances Directive (2002/95/EC)
RV	Recreational Vehicle
SEA	Socio-Economic Analysis

**DECLARATION**

We, Dometic GmbH, request that the information blanked out in the “public version” of the Analysis of Alternatives and Socio-economic analysis is not disclosed. We hereby declare that, to the best of our knowledge as of today (18.5.2015) the information is not publicly available, and in accordance with the due measures of protection that we have implemented, a member of the public should not be able to obtain access to this information without our consent or that of the third party whose commercial interests are at stake.

Signature:

Date,Place:

  
Joachim Kinscher  
Geschäftsführer

2015-05-18, Siegen

## 1. SUMMARY

Dometic was established in the aftermath of the invention of absorption refrigeration in 1922. Sodium chromate is used in absorption refrigerators as a corrosion inhibitor. Starting in the 1930s, Dometic has conducted a lot of research to find a replacement for the use of sodium chromate in their products. In addition to studies conducted in-house, some studies have been conducted in partnership with universities and external research facilities. Decades of research have produced one possible alternative, inhibitor 7. Validation of the functionality of the alternative is still ongoing. Thus, Dometic will not have a technically feasible alternative by the sunset date.

Although inhibitor 7 shows promising results, it is an inferior corrosion inhibitor compared to sodium chromate. Therefore, additional design and engineering solutions are needed before the corrosion inhibition will be at the same level as it is with sodium chromate. In addition, inhibitor 7's ability to protect the cooling unit from corrosion is reduced at high temperatures (>180°C). For products with high boiler temperature, the final design solutions are still being sought. After these technical difficulties are solved, field studies will start as soon as possible. Testing of the products is laborious as units need to run for several years before they can be inspected. It is also necessary to test whether the new inhibitor provide products with an equivalent product lifetime as those produced currently with sodium chromate as inhibitor. Products equipped with inhibitor 7 would be introduced to the market gradually from 2018 onward, starting with products with the lowest boiler temperature, and subsequently to those that require a higher boiler temperature. The phase out of sodium chromate is planned to be completed in 2029.

As the non-use scenario Dometic would build up a new production facility for producing sodium chromate containing products in Zhuhai, China; this production facility would be in use from the sunset date until the sodium chromate phase out is complete. Due to the new factory, there would be investment cost, and cost for transporting the units back to Europe for sales, which are estimated to be 36,307,447 €. In addition, Dometic may lose a maximum of 55 jobs in its European factories; there is a real threat that the company's competitiveness would suffer; and market share would be lost as a consequence. On the other hand, the risks of continued use of sodium chromate are demonstrated to be at a level of low concern in the CSR, and the remaining human health risk is quantified to be 15,712 € to 33,724 €. Therefore, the analysis shows that the benefits of continued use of sodium chromate by Dometic outweigh the risks to human health.

As demonstrated in the AoA, there are no technically feasible alternatives by the sunset date and the phase out of sodium chromate will be completed in 2029. Dometic is highly committed to replacing sodium chromate in refrigeration products, which is evidenced by the roadmap for substitution.

In addition to

REACH, other regulations also motivate and oblige Dometic to replace sodium chromate, most notably ELV and RoHS regulations. In conclusion, Dometic is applying for authorisation with a 12-year review period.

## 2. AIMS AND SCOPE OF THE ANALYSIS

### 2.1. Background

Dometic Group (Dometic) was founded to focus on the absorption refrigeration technology, which was invented in 1922. The advantages of absorption cooling technology are silent and vibration-free operations, flexibility regarding the energy source, longer product life and reliability. This was the starting point for Dometic Group's journey of marrying comfort with mobility. At the moment Dometic serves six different business areas with various complementary products beyond absorption refrigeration. Most notable and relevant for the application for authorisation is the Recreational Vehicle (RV) business area that covers more than 50 % of total sales for Dometic. Dometic has over 6000 employees and 17 manufacturing plants worldwide. In the absorption refrigeration technology Dometic uses sodium chromate as a corrosion inhibitor of the carbon steel cooling system. There are two manufacturing plants in Europe that use sodium chromate. One is in Siegen (Germany) and the other is in Jászberény (Hungary). The products affected are Minibars, RV refrigerators and medical cold equipment.

### 2.2. Aim of the analysis

Dometic uses sodium chromate ( $\text{Na}_2\text{CrO}_4$ ; EC 231-889-5; CAS 7775-11-3<sup>1</sup>) as an anticorrosion agent of the carbon steel cooling system in absorption refrigerators up to 0.75 % by weight ( $\text{Cr}^{6+}$ ) in the cooling solution. Sodium chromate was included in the Annex XIV list because it's classified as Carcinogenic (category 1B), Mutagenic (category 1B) and Toxic for reproduction (category 1B). It is not considered a threshold substance, and consequently the adequate control of risks arising from the applied for use of the substance cannot be demonstrated in accordance with Annex I, section 6.4 of Regulation (EC) No 1907/2006.

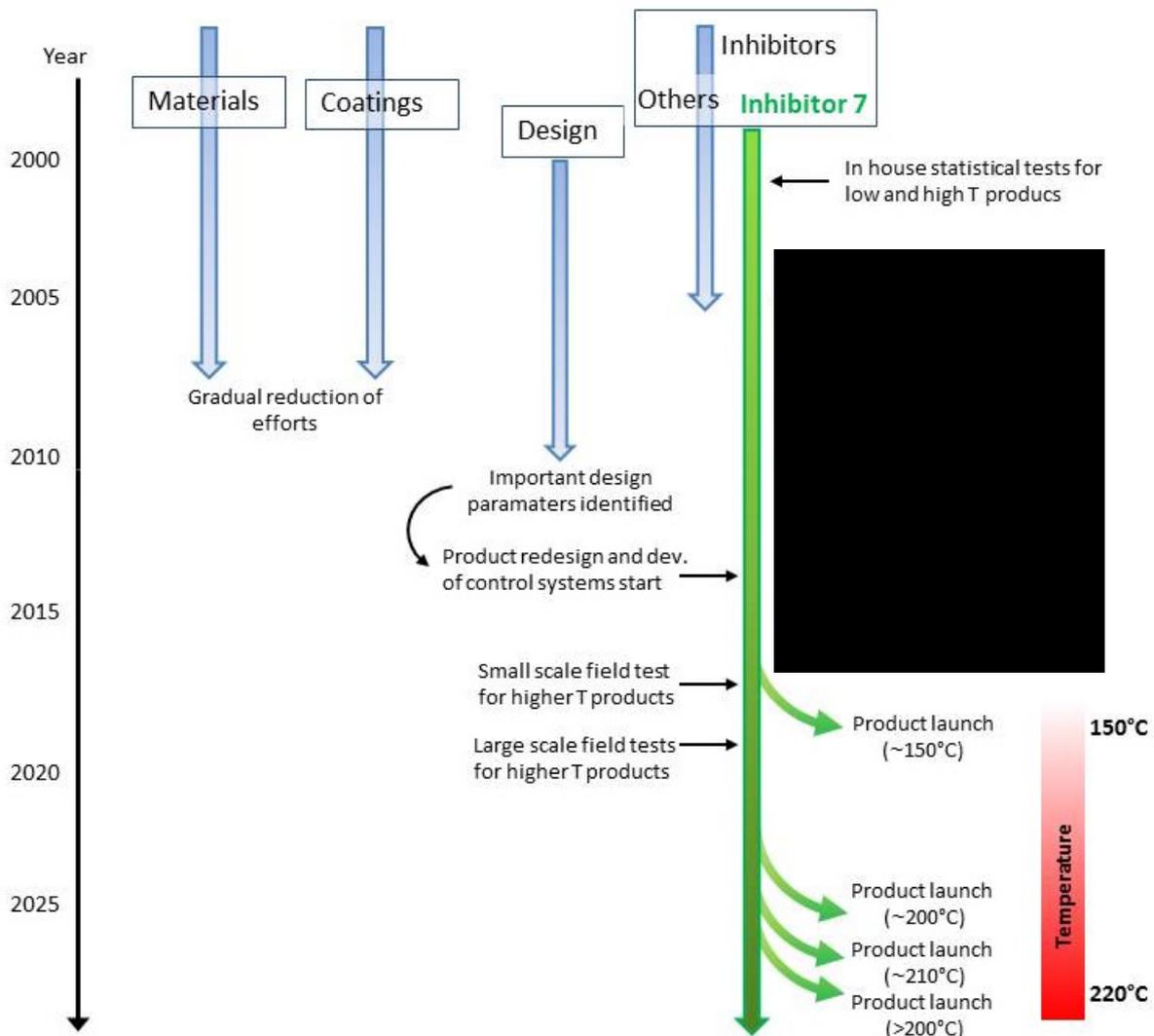
The aim of this analysis is to demonstrate that there are no suitable alternative substances or technologies for the applied for use. In addition, it is to be assessed whether the socio-economic benefits of the continued use of sodium chromate outweigh the risks to human health.

### 2.3. Substitution strategy

Right from the foundation of Dometic, R&D activities have been initiated to elucidate an alternative to sodium chromate as a corrosion inhibitor in its cooling units. The amount of work and resources invested into the research has been increasing as time has passed. It is

estimated that in the last 20 years 7 M€ have been invested into the research. Dometic has also partnered with external research facilities and universities in order to find the replacement. As presented in Figure 1 below, among the tested alternatives there have been various corrosion inhibitors, coatings, substrate materials and design parameters. More than 40 different alternatives were tested altogether. As a result of considerable research efforts one possible alternative was identified: a new corrosion inhibitor called inhibitor 7. The functionality of the new inhibitor is still under testing. Dometic will introduce inhibitor 7 into its products when the technical feasibility has been confirmed and they can guarantee that the new products will perform equally well as the ones using sodium chromate. It is estimated that the first products equipped with the new inhibitor will be launched to the market in 2018. Sodium chromate will then be gradually phased out from all Dometic absorption refrigeration products. The roadmap for substitution is presented in table format in Appendix 1. The content of the phase out plan with all its steps and decision points is also depicted in the sections below.

Figure 1. Activities to phase out sodium chromate



### 2.3.1. List of actions and timetables

#### Studies to validate inhibitor 7 function

Dometic utilises a battery of studies when evaluating alternatives for sodium chromate. The tests can be categorised into two groups: laboratory investigations and service life evaluations. Both of these categories compose a number of tests. Laboratory investigations are performed to have a more theoretical understanding of each alternatives capability to prevent corrosion. However, since the absorption system is a closed circulating system with high temperature and pressure it is very difficult to completely draw conclusions without very extensive real-life testing. The most valuable tests have been performed using various solutions in actual refrigerators by filling the cooling units with the refrigerant solution together with the inhibitor under investigation. The cooling units have then been operated continuously over long periods of time. At regular intervals some units were stopped and cut open, and the interior surfaces have been examined. The laboratory investigations and service life evaluations are explained in more detail in Appendix 2 Methods to evaluate alternatives.

After testing various alternatives to sodium chromate, only one inhibitor was found to have promising results. This inhibitor, named inhibitor 7, was found to be able to protect the carbon steel tubing from corrosion after 3 years of continuous circulation and it was consequently selected for further testing. The tests to validate inhibitor 7 function were first done in stand-alone cooling units. It was noticed that the new inhibitor protects the cooling unit from corrosion in low boiler temperatures (<180°C).

The experiment is still ongoing but the preliminary results were so encouraging that Dometic has decided to release those products into the market when all the necessary steps are complete.

In higher temperatures (>180°C), corrosion protection with inhibitor 7 did not function satisfactorily. Currently, the validation studies of inhibitor 7 function in higher boiler temperatures are ongoing. Products with higher boiler temperatures are mostly (but not exclusively) included in the RV and medical box product groups. Coincidentally these products are used in a harsher environment than products with lower operating temperature. They are exposed to considerable variation in outside temperature, vibration and they are on discontinuously. This has generated some technical problems that have to be solved before field trials can start. These difficulties are discussed further in the section below. A small scale field study is planned to start in 2017 with a controlled population of 50 units. After the first year Dometic would decide whether to proceed with large scale field studies. The reason for that is that Dometic believes it is very important to start the large scale field trials as soon as possible.

Redesign of products and production equipment

Since inhibitor 7 is a technically different inhibitor than sodium chromate, products have to be redesigned to achieve equivalent performance. The engineering of new products was started already in 2014 and finalized for some products. However, the introduction of inhibitor 7 to products with higher boiler temperature is more problematic, as the whole cooling unit has to be redesigned. High boiler temperature generate other problems however, e.g. products can over-heat. [REDACTED]

The new inhibitor has properties that demand a filling station to be used for filling the cooling units with the refrigerant. Therefore a new production line with the new filling station needs to be built at the Jászberény and Siegen factories. It is also noteworthy that products with different boiler temperature need different production equipment (bigger units have higher boiler temperature). Therefore, the construction of new production equipment in the two sites is dependent on the product portfolio mix between the factories. [REDACTED]

Decision points and phase out schedule

If the results from the field trials and statistical tests are positive, Dometic will firstly introduce products with the new inhibitor to the market, starting in 2018. At this stage, the products that could be launched would be the ones with the lowest boiler temperature, approximately 150°C. The phase out would then continue gradually to products operating under more difficult conditions and higher boiler temperatures. [REDACTED]

[REDACTED] If all goes well, Dometic could introduce products with high boiler temperatures to the market from 2025 on. The phase out of sodium chromate would be finalized in 2029, when all products would be using inhibitor 7 as the corrosion inhibitor.

**2.3.2. Monitoring the implementation of the substitution strategy**

The use of Cr(VI) is also regulated in other legislations in addition to REACH (EC 1907/2006). For example, the Restriction of Hazardous Substances Directive 2002/95/EC (RoHS) regulates the restriction of the use of certain hazardous substances in electrical and electronic equipment. This directive applies to the minibar products of Dometic. In order to use sodium chromate in minibars Dometic has applied for an exemption under the RoHS

directive for a period of 3 years, until 2019. The roadmap for substitution is also attached to the exemption application and it is therefore reviewed and updated every time a new extension for the exemption is applied for. It also adds pressure to replace sodium chromate in Dometic minibar products. Another legislation, the **Directive on End-of Life Vehicle 2000/53/EC (ELV)**, applies to Dometic's RV products. Dometic has also applied for an exemption for this legislation regarding their RV products; therefore the phase out plan of RV products is followed up and reviewed frequently. ELV also adds pressure to replace sodium chromate in RV products much in the same way as RoHS does it for the minibars.

Dometic is committed to replace sodium chromate and the following measures have been taken to ensure the timeline will be adhered to:

1. Dometic has hired an external consultant to manage the phase out plan
2. The project team has regular meetings where current progress is elaborated and possible problems are identified and solved
3. The build-up of the new production with the filling stations required by inhibitor 7 is contracted to an external contractor as a turnkey contract
4. Dometic board of directors is receiving updates of the phase out plan twice a year

#### **2.4. Temporal scope**

The temporal scope for the socio-economic analysis is set as:

1. Sunset date till 2029, which is the last product roll-out year after which time sodium chromate use will cease, for the economic, social and wider economic impacts.
2. The same time period is set for human health impacts, because Cr(VI) will reduce rather quickly to Cr(III) in the environment. Cr in the +3 oxidation state is not considered carcinogenic, mutagenic or reproductive toxin. Therefore it can be estimated that the human health impacts will stop when the use of sodium chromate ceases. **In addition, as described in the CSR and section 3.1.3 below, most of the chromate is reduced to Cr(III) during the product lifetime and there is no release of Cr(VI) during the product service life.**

#### **2.5. Geographic scope and relevant supply chain**

As stated above, Cr(VI) is reduced rather quickly to Cr(III) in the environment and Cr(III) is not carcinogenic, mutagenic or reproductive toxic. Therefore the diffusion of Cr(VI) is likely to be limited to a few kilometres from the point of release, which is the plant location.

It is a fact that the refrigerators are used Europe wide. However, as described later in section 4.4, as the non-use scenario Dometic would manufacture the products using sodium chromate in China. This basically means, assuming the market demand will remain the same in the non-use scenario, equal amounts of refrigerator units would be transported back to Europe. So the article service lives of sodium chromate in the in-use scenario and the non-use scenario would be the same and the net impact would be zero. In addition, CSR has already assessed that there is no release of Cr(VI) during the article service life. Therefore the

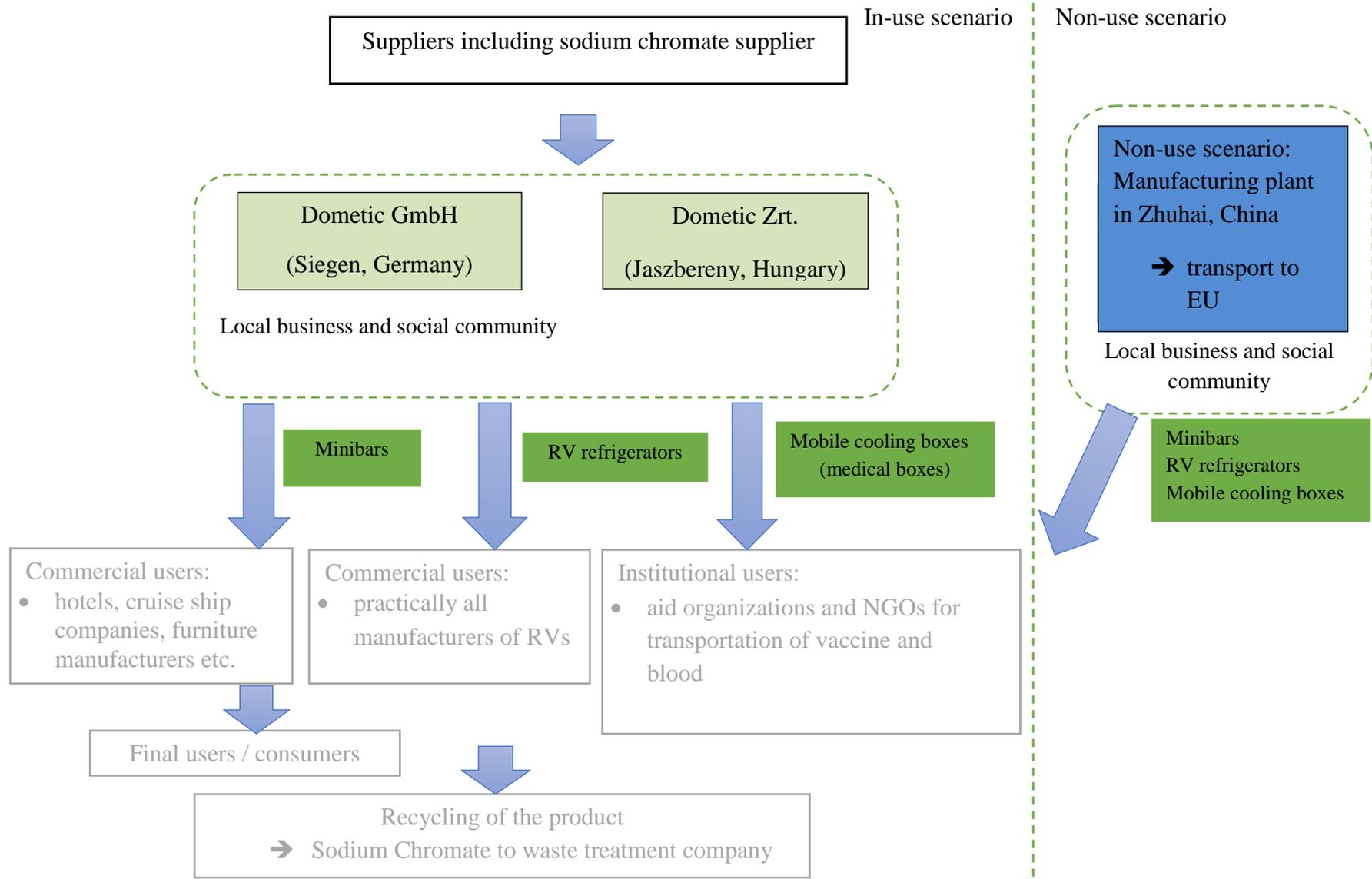
analysis of the impact of the use of sodium chromate from the manufacturing stage only shall be sufficient.

Economically and socially the impacts of the non-use scenario would also be felt by the plants' local business and social communities only. The wider economic impacts would be mainly felt by Dometic as a company.

Therefore the geographic scope is defined as the affected manufacturing plants and their local business and social communities.

The geographical scope and relevant supply chain is depicted schematically in Figure 2.

Figure 2. Dometic's supply chain



Use number: 1 Dometic GmbH, Dometic Hűtőgépgyártó és Kereskedelmi Zrt.

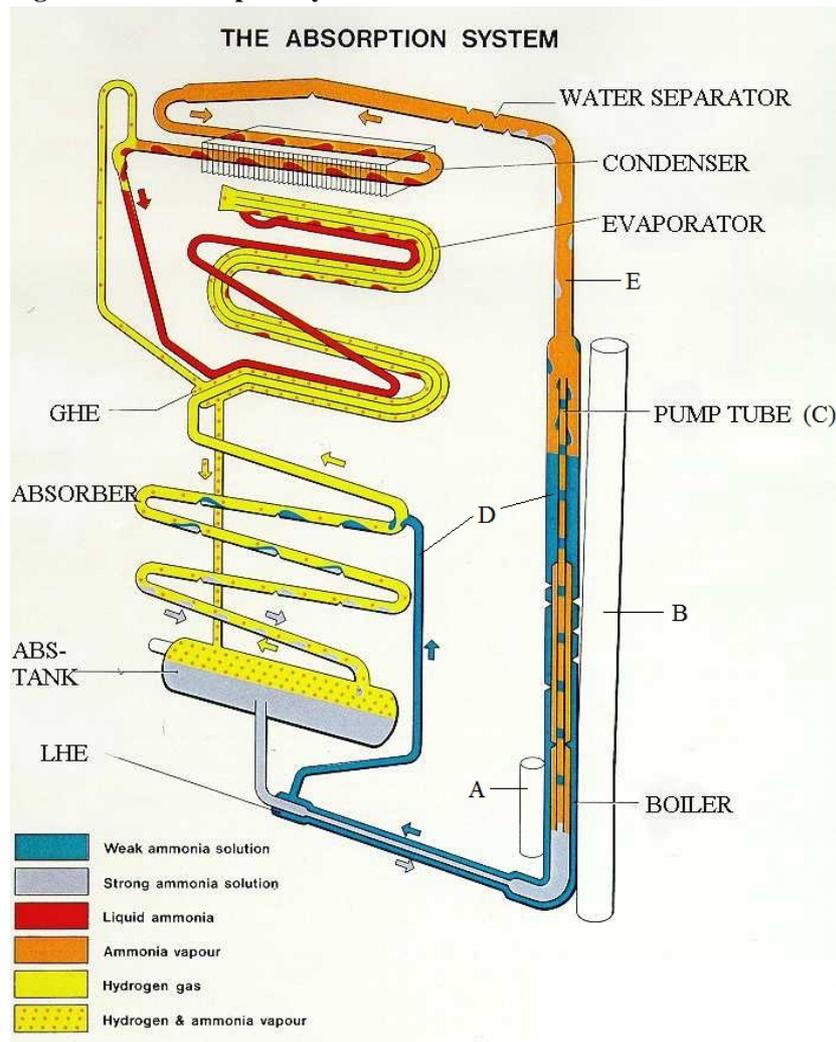
### 3. APPLIED FOR “USE” SCENARIO

#### 3.1. Analysis of substance function

##### 3.1.1. Absorption refrigeration

The absorption refrigeration technology was invented in 1922. A schematic picture of the absorption system is shown in Figure 3.

Figure 3. The absorption system



The unit can be run on electricity, kerosene or gas. When the unit operates on electricity, the heat is supplied by a heating element inserted in the pocket (B). As can be seen, the unit consists of four main parts - the boiler, condenser, evaporator and absorber. The gas central tube (A) is used on gas units, kerosene units and on multi-energy units (electricity/gas/kerosene), but not on units made for electrical operation only.

The unit charge consists of a quantity of ammonia, water and hydrogen at a sufficient pressure to condense ammonia at the ambient temperature for which the unit is designed.

Dometic cooling units contain a maximum of 500 g ammonia ( $\text{NH}_3$ ) and up to 10 g of hydrogen gas to pressurise the unit. The cooling solution also contains water with sodium chromate as corrosion inhibitor. The inhibitor prevents corrosion of the steel tubes. In the solution circulating the system sodium chromate is dissolved into sodium and chromate ions. Some chromate transforms into dichromate ( $\text{Cr}_2\text{O}_7^{2-}$ ) as the two exist in equilibrium in aqueous solution. Chromates oxidise iron to magnetite ( $\text{Fe}_3\text{O}_4$ ), which forms a stable layer on the surface of the tubing in the high temperature of the system. Magnetite is further oxidised to iron(III) oxide ( $\gamma\text{-Fe}_2\text{O}_3$ ) layer. Chromate is reduced to chromium oxide ( $\text{Cr}_2\text{O}_3$ ), which will spontaneously form a passive layer on top of iron(III) oxide. The chromium oxide layer protects the steel underneath from corrosion.

When heat is supplied to the boiler system, bubbles of ammonia gas are produced which rise and carry with them quantities of weak ammonia solution through the siphon pump (C). This weak solution passes into the tube (D), whilst the ammonia vapour passes into the vapour pipe (E) and on to the water separator. Here any water vapour is condensed and runs back into the boiler system, leaving the dry ammonia vapour to pass to the condenser.

Air circulating over the fins of the condenser removes heat from the ammonia vapour to cause it to condense to liquid ammonia in which state it flows into the evaporator. The evaporator is supplied with hydrogen. The hydrogen passes across the surface of the ammonia and lowers the ammonia vapour pressure sufficiently to allow the liquid ammonia to evaporate. The evaporation of the ammonia extracts heat from the evaporator, which in turn extracts heat from the food storage space, thereby lowering the temperature inside the refrigerator. The mixture of ammonia and hydrogen vapour passes from the evaporator to the absorber. Entering the upper portion of the absorber is a continuous trickle of weak ammonia solution fed by gravity from the tube (D). This weak solution, flowing down through the absorber, comes into contact with the mixed ammonia and hydrogen gases which readily absorbs the ammonia from the mixture, leaving the hydrogen free to rise through the absorber coil and to return to the evaporator. The hydrogen thus circulates continuously between the absorber and the evaporator. The strong ammonia solution produced in the absorber flows down to the absorber vessel and then to the boiler system, thus completing the full cycle of operation. All liquid circulation of the unit, except for the boiler, is purely gravitational.

Heat is generated in the absorber by the process of absorption. This heat must be dissipated into the surrounding air. Heat must also be dissipated from the condenser in order to cool the ammonia vapour sufficiently for it to condense. Free air circulation is therefore necessary over the absorber and condenser.

The whole unit operates by the heat applied to the boiler system and, for a good operation, it is of paramount importance that this heat is kept within the necessary limits and is properly applied.

### 3.1.2. Corrosion pattern of an absorption refrigerator in absence of inhibitors

Dometic's absorption cooling units are constructed in carbon steel because of its strength and good welding and cold-working properties. Generally carbon steel is considered to be fairly resistant to corrosion attack in aqueous ammonia solutions. Problems have mainly been claimed to be associated with stress corrosion cracking in water-free ammonia. However, because of the special environment and conditions (material, refrigerant, dimensions, flow pattern and temperature) of an absorption cooling unit in combination with high requirements on product performance, product safety and life time expectancy it is concluded that carbon steel is not itself stable. An additional factor, usually not encountered in similar systems (for example steam turbines), is the impossibility of performing continuous maintenance of the absorption system. In an absorption system operated without any corrosion protection, the carbon steel of the hot part of the system corrodes rapidly. The corrosion reaction rate depends on temperature and flow conditions. Above 100°C the corrosion rate becomes significant, which makes the hottest part (the boiler and pump tube where the temperature ranges between 150-220°C) of the absorption system particularly susceptible to corrosion.

The corrosion reactions, in the absence of an inhibitor, are believed to be cathodic hydrogen evolution and anodic metal dissolution. Cathodic oxygen reduction can be ruled out since oxygen is not present.

The typical service life of a refrigerator filled with ammonia and water without any inhibitor is less than one year. At that time magnetite crystals ( $\text{Fe}_3\text{O}_4$ ) are formed which blocks the liquid circulation resulting in a dry-out of the boiler and rapid progress of corrosion eventually resulting in leakage of cooling unit.

### 3.1.3. Function of sodium chromate

Sodium chromate's function is corrosion inhibition. Chromate forms a chromium/iron oxide film at the steel surface with good protective properties. Cr(VI) is reduced to less toxic Cr(III) in the formation of chromium oxide film. If the film is damaged, chromate or dichromate is supplied from the solution and the surface is re-passivated. It is estimated that 90% of Cr(VI) is reduced to Cr(III) in the first 2-3 years of operating time. At the end of the product lifetime it can therefore safely be assumed that, more than 75% of the Cr(VI) has been consumed<sup>2</sup>.

## 3.2. Market and business trends including the use of the substance

Dometic is a global company, with major markets and manufacturing facilities worldwide. The company can balance the local demand and supply within its own group. In general, Dometic expect its business to grow, which implies that natural reduction in production output (sodium chromate usage) is unlikely in Germany (Siegen) and Hungary (Jászberény) plants. The trend of usage of sodium chromate is dependent on the progress of the phase out plan.

As Dometic gradually switches to an alternative, there will be costs associated with building new production equipment to suit the production of new products (with inhibitor 7) in Europe. This cost will arise in any case, even when a sodium chromate related production line would be, according to the non-use scenario, built to China. Construction and installation of new equipment is currently [REDACTED]

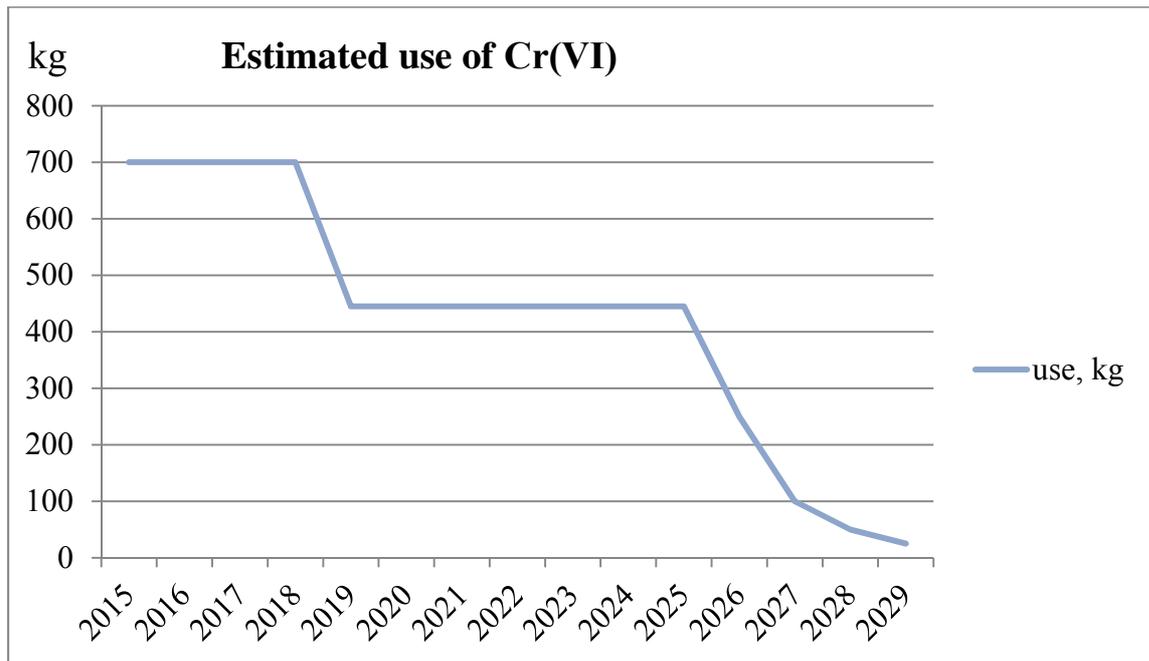
Products using inhibitor 7 are expected to be [REDACTED] more expensive than the ones using sodium chromate. [REDACTED]

[REDACTED] Nevertheless, the company has made the decision to substitute, despite the increased cost.

**3.2.1. Annual tonnage**

At the moment approximately 0.7 tons of Cr(VI) (equivalent to 2.1 tons of sodium chromate) is used in total at the two sites annually. In the future the tonnage development will be based on the phase out plan (Figure 4).

**Figure 4. Use of Cr(VI): declining trend between years 2015-2029**



In years 2015 to 2018 the annual use of Cr(VI) remains 700 kg/year until the roll out of first products with inhibitor 7 in 2018. Between 2019 and 2025 the amount used will remain at 445 kg/year until Dometic is ready to replace sodium chromate also in products with high boiler temperature. In 2025 the roll out of high temperature products with inhibitor 7 starts and the annual usage volume falls from 445 kg/year to 100 kg/year in 2027. Only 50 kg in 2028 to 25 kg in 2029 would be needed for the final time period.

### 3.3. Remaining risk of the “applied for use” scenario

Sodium chromate is included in Annex XIV based on three intrinsic properties: Carcinogenic (category 1B), Mutagenic (category 1B) and Toxic for reproduction (category 1B). The NOAEL levels for fertility and development toxicity of Cr(VI) compounds has been observed at relatively high levels (at mg/kg/d level)<sup>1</sup>. As is shown in the CSR the relevant exposure concentrations in this case are at µg/kg bw/d level, which means that risks of the toxicity for fertility and reproduction are adequately controlled in the current use and the impacts negligible. Cr(VI) compounds have the potential to induce both somatic and germ cell mutations. The consequences of mutagenicity can be severe. However, the most severe form, at the same time most common and best understood consequences of mutagenic toxicity is cancer. In conclusion, the focus of the current health impacts assessment will be placed on the risks related to the carcinogenicity.

Accordingly, the excess risk levels for the workers and general population (local) are estimated in CSR and are summarized below in Table 1.

**Table 1. Summary of excess risk levels and corresponding duration of exposure**

	<b>Excess lung cancer risk level</b>	<b>Excess intestinal cancer risk level</b>	<b>Duration of exposure</b>
Worker WCS1	$1 \times 10^{-4}$	$7.14 \times 10^{-7}$	1 hours/day
Worker WCS2	$8 \times 10^{-4}$	$5.71 \times 10^{-6}$	8 hours/day
Worker WCS3	$1.95 \times 10^{-3}$	$1.39 \times 10^{-5}$	1 hour/day
Worker WCS4	negligible	negligible	5 days/year
General population (local)	$3.29 \times 10^{-7}$	$3.87-3.91 \times 10^{-9}$	24 hours/day

For worst case scenario estimation, risk levels based on WCS2 can be chosen. The overall excess risk level is derived by adding the excess lung cancer risk level with the excess intestinal cancer risk level ( $8.06 \times 10^{-4}$  for worker, and  $3.33 \times 10^{-7}$  for the general population).

### 3.4. Human health and environmental impacts of the applied for use scenario

#### 3.4.1. Number of people exposed

There are two categories of population that are exposed: the workers and the general population.

In each factory, only selected people with proper training are allowed to work in the activities involving Cr(VI). There are reported to be less than 10 people per factory working with the activities, so a total of 20 workers are at risk. It is unlikely that other workers not involved in the Cr(VI) related activities will be at risk, because 1) the mixing and emptying activities are carried out in separate locked rooms; 2) the filling activities are carried out in the factory hall but with local exhaust ventilation; 3) the static measurement showed undetectable levels of Cr(VI), e.g. in the mixing room.

There are only two sources of release of Cr(VI), the Siegen factory in Germany and the Jászberény factory in Hungary. According to the CSR, there are two ESs, 1) Use at industrial site; and 2) Service life (consumer). There is release of Cr(VI) only from ES 1. In addition, the exposure through the inhalation route is much more significant than the oral route. For these reasons, it is considered that for the general population the combined exposure at the regional level is less relevant than the local man *via* environment exposure.

Siegen has a population of 99 403 (115 km<sup>2</sup>). Jászberény has a population of 26 622 (221 km<sup>2</sup>). So the population of the two cities (126 025 people in total) can be considered as potentially exposed *via* the environment to Cr(VI).

### 3.5. Monetised damage of human health and environmental impacts

The excess cancer risks can be monetised as:

$$\text{Monetised excess cancer impact} = \text{Excess risk level} \times \text{Population} \times V_{\text{mortal}}$$

( $V_{\text{mortal}}$ : Monetary value of one fatal cancer case)

Monetary values of fatal cancer cases are presented in Table 2 and 3 below.

**Table 2. Monetary values for fatal cancer cases, based on the ECHA Guidance**

	<b>Fatal cancer (mortality) Central value of statistical life based on the median value</b>	<b>Fatal cancer (mortality) Sensitivity value of statistical life based on the statistical mean value</b>
2003 WTP value based on NewExt (2004) – starting value in ECHA Guidance	1,052,000 € (2003)	2,258,000 € (2003)
Adjusting the 2003 values to the value of 2015*	<u>1,306,058 € (2015)</u>	<u>2,803,307 € (2015)</u>

\*Based on the Eurostat initial index of 94.75 for 2003 and end index of 117.63 for 2014 (multiplier of 1.2415) (Inflation calculator).

**Table 3. Health impacts based on estimated excess fatal cancer incidences**

Health impact value (€)	Based on central value	Based on sensitive value
Excess risk level (worker)	$8.06 \times 10^{-4}$	$8.06 \times 10^{-4}$
Population (worker)	20	20
Excess risk level (general population)	$3.33 \times 10^{-7}$	$3.33 \times 10^{-7}$
Population (general population)	126,025	126,025
Monetised value of one fatal cancer	1,306,058 €	2,803,307 €
Total (€)	75,864 €	162,834 €

So a worst case scenario for the health impacts of the continued use of sodium chromate will be 75,864 € to 162,834 € as shown in Table 3. However, one needs to take into consideration that the risk levels are derived based on the assumption of the continued exposure of 40 year working life (8h/day, 5 days/week) for workers, and an exposure of 70 years (24h/day, every day) for the general population. The temporal scope of the current use for the non-use scenario is only 12 years, so an exposure time based correction shall be applied (12/40 for workers and 12/70 for the general population). The corrected value of the worst case health impacts of the continued use will be 15,712 € to 33,724 €.

As a final comment, the above value was calculated based on 700 kg/year usage of Cr(VI), while in reality the annual usage will be lower during the examined time period. So the real impact will be lower also from this perspective.

## 4. SELECTION OF THE “NON-USE” SCENARIO

### 4.1. Alternative cooling technologies

As noted above, sodium chromate functions as a corrosion inhibitor of the carbon steel cooling system in absorption refrigerators. To make the function of sodium chromate redundant, Dometic would need to consider replacing the absorption cooling technology entirely. Currently there are two alternative cooling technologies available: thermoelectric and compressor refrigeration. Both of these technologies are Cr(VI) free.

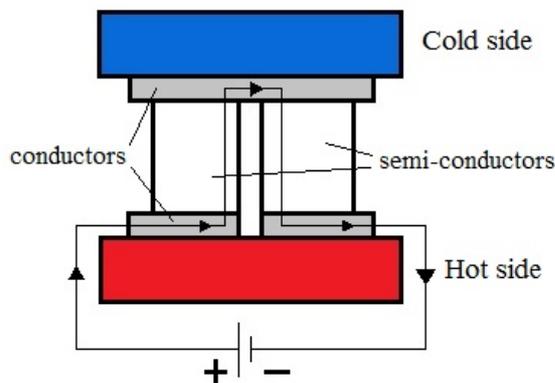
#### Thermoelectric refrigeration

In thermoelectric cooling systems, two sides composing of different materials are connected with semiconductors. When current flows through the system, heat is transferred from one side of the system to another, making one side cold and the other hot. The hot side is usually connected to a heat sink to prevent overheating. A schematic picture of thermoelectric

cooling system is depicted in Figure 5 below. Thermoelectric devices are commonly used in scientific applications such as coolers for microprocessors and lasers and thermal cyclers in molecular biology laboratories (PCR device). They are also used in some consumer products, for example portable coolers (camping) or wine coolers.

Its main disadvantages are high cost and poor power efficiency. Another major disadvantage, considering RV applications, is that it is not possible to engineer a freezer compartment with this technology. In addition, if thermoelectric refrigerators were used in RV applications they would need to run on alternative power supply since grid electricity is not always available. There are only two practical possibilities: either a battery and a solar cell or a battery and a fuel driven generator. A battery and a solar cell would allow autonomous use of only a very small thermoelectric refrigerator, which makes it a poor choice. The problems with the use of a battery and a generator are high primary fuel consumption and noise emissions from the generator.

**Figure 5. Simplified diagram of thermoelectric cooling system**



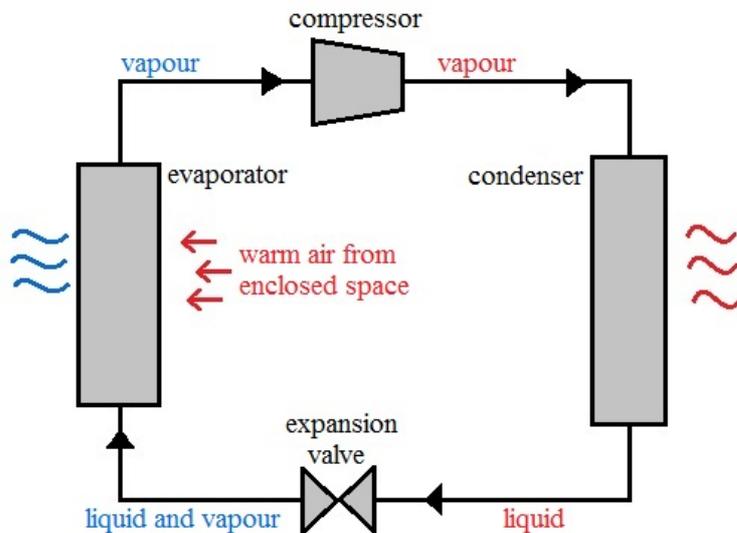
### Compressor refrigeration

Compressor refrigeration (Figure 6), or vapour-compressions refrigeration, is the most widely used refrigeration technology. Compressor refrigeration functions by circulating a refrigerant through the system in different phases. As shown in Figure 6, the refrigerant passes through the compressor and is compressed to a higher pressure, which also elevates the temperature of the vapour. The hot vapour proceeds through the condenser where it dissipates the heat extracted from the system and is subsequently condensed into liquid. After that, the liquid flows through an expansion valve where the pressure is abruptly reduced and therefore the liquid starts to evaporate, which also lowers the temperature of the liquid/vapour. In the final step the cold liquid and vapour mix pass through the evaporator, where heat from the space to be cooled is evaporating the liquid refrigerant, thus lowering the temperature of the enclosed space. Afterwards the cycle will start again.

Compressor refrigeration is used by Dometic in a number of applications, most commonly in household type refrigeration such as wine cellars, low end minibars and some products for

marine and trucks where more power is available. Autonomous use of compressor refrigerator is as problematic as it is for thermoelectric refrigerators. A solar panel large enough to power a compressor refrigerator would be too large for practical use ( $>1.6 \text{ m}^2$ ). There are also other important appliances in RV's that rely on the power from the solar panel. A power generator could be used, but only with high primary fuel consumption. There would also be noise emissions from the generator, which are not wanted in the close quarters of the RV.

**Figure 6. Diagram of compressor refrigerant system.** Blue and red texts depict cold and hot parts of the system, respectively.



### Conclusion on alternative cooling technologies

Dometic has developed its strategy over the years to provide refrigeration products to niche sectors like RV and lodging. In these sectors it is especially important that the products are able to run on variable energy sources and that they are noise and vibration free. Both thermoelectric and compressor refrigeration technologies are dependent on electricity for function and therefore these technologies are **not suitable for the mobile comfort niche market.** In fact, Dometic also manufactures products equipped with thermoelectric or compressor refrigeration technology. Currently there is a market for absorption refrigeration products and **Dometic has developed their business strategy to serve that market.** In conclusion, **Dometic needs the absorption refrigeration technology,** and currently sodium dichromate as a corrosion inhibitor as its function cannot be made redundant.

## 4.2. Efforts made to identify alternatives

### 4.2.1. Research and development

Since the 1930's, Dometic has been conducting research into finding possible alternatives for the corrosion protection of absorption refrigerators. The work and resource commitment to this work has increased continuously, amounting to around 7 M€ in last 20 years. Not only has a significant in-house commitment been made but Dometic has also worked with a number of external research institutes and universities on this issue. Several long-term projects have been undertaken with theoretical and practical studies on the corrosion process. Work has also been carried out with companies who are expert in corrosion protection when commercial inhibitors have been tested. The research has looked at alternative refrigerants, inhibitors, structural materials, surface treatment, surface coatings, design parameters and combinations thereof. In total 45 different alternatives were tested.

One inhibitor (inhibitor 7) has shown promising results in the environment of an absorption cooling unit (alkaline and temperatures up to 220°C). In particular, it seems to be functioning very well at temperatures below 180°C.

Therefore apart from testing of corrosion resistance there has been substantial work put into the handling of the inhibitor, including development of filling procedures and modifications to cooling units to allow a potential introduction.

The results also showed that inhibitor 7 as such cannot replace sodium chromate without certain important modification in the factory process. In addition, the long-term performance of inhibitor 7 in high boiler temperature refrigerators (suitable for RV refrigerators) is still under testing and it is too early to draw any conclusions.

More detailed information on the past and on-going R&D activities can be found in Annexes 3-5

- Corrosion studies 1920-1999
- Corrosion studies 2000-2007
- Corrosion studies 2008-2014

### 4.2.2. Data searches

New ideas in the search of alternative corrosion protection are invented in-house, by scientific and patent literature surveillance, external co-operation and through contacts with commercial companies. These ideas are tested on a long-term basis in running absorption cooling units and refrigerators. In parallel, detailed material analysis such as surface analysis are performed. Furthermore, theoretical studies are made to generate new ideas and explain experimental observations.

### 4.3. Assessment of shortlisted alternatives

#### 4.3.1. Alternative 1

As mentioned earlier, Dometic has identified only one possible alternative to replace the function of Cr(VI) in corrosion inhibition. This alternative is titled “inhibitor 7”.

##### 4.3.1.1. Substance ID, properties, and availability



Table 4. Substance information of alternative 1

Substance name	EC number	CAS number	Classification (CLP)	REACH status
[Redacted]	[Redacted]	[Redacted]	Eye irrit. 2A Acute Tox. 3 Acuatic Acute 1	Registered >1000 t/y

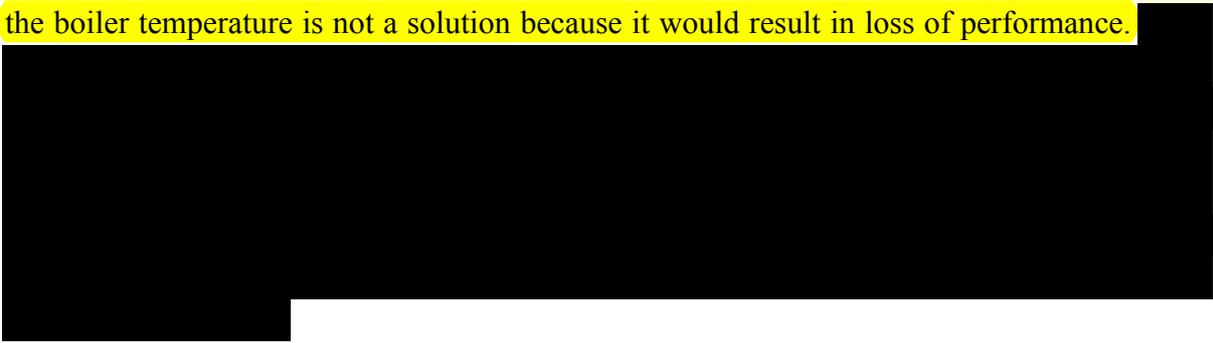
[Redacted] Inhibitor 7 is a mixture containing an inorganic salt and stabilisers.

##### 4.3.1.2. Technical feasibility of Alternative 1

The technical feasibility of the new inhibitor is still under investigation. As it was mentioned earlier, inhibitor 7 was able to protect the cooling units in low boiler temperatures. In higher boiler temperatures it did not function as expected. Dometic is currently working on the technical problems to enable inhibitor 7 to protect the cooling units from corrosion even in higher boiler temperatures. When the technical problems have been solved, testing of inhibitor 7 function will start. Thorough testing is mandatory for the validation of inhibitor 7 function. If the new inhibitor fails to protect cooling units from corrosion, leaks of refrigerant become more frequent. Premature leaks pose the biggest risk that could delay or ultimately stop the substitution of sodium chromate with inhibitor 7. Leaks would seriously impact customer satisfaction and consequently the image of Dometic’s brand. A leak in the cooling system would force the consumers to change their refrigerator. For example, consumers expect that RV refrigerator lifetime is as long as the lifetime of their RV. An average lifetime for an RV is 15 years, so the expected lifetime for an RV refrigerator has to match, or exceed, it. Prevention of premature leaks is a matter of product safety as well as customer satisfaction. In order to ensure that the corrosion protection properties of inhibitor 7 are adequate, tests with large enough populations for statistical analysis have to be conducted. Therefore, Dometic will launch new products to market only when adequate testing is done and they can be sure that products are safe for consumers and as durable as expected.

The cooling systems need to be redesigned and tested in all product groups as well, which is also a time limiting factor for the start of Cr(VI) phase out. One problematic issue has been

the corrosion of heat transfer welds. These welds are designed to transfer heat to the boiler. These areas are particularly susceptible to corrosion because of the concentrated heat passing through these spots from the electrical heating element and gas burner flue tube. Reducing the boiler temperature is not a solution because it would result in loss of performance.



In conclusion, the introduction of inhibitor 7 is not technically feasible by the sunset date.

#### ***4.3.1.3. Availability of Alternative 1***

Although the constituents of the new refrigerant with inhibitor 7 are commercially available and affordable, as stated before, the validation studies of inhibitor 7 function are still ongoing. The tests and steps that are planned to be conducted before the phase out of sodium chromate are discussed in section 2.3. All in all, Cr(VI) phase out could start, if everything goes according to plan, in 2018 and continue gradually through all product groups. The phase out of the last product group is planned to be finalized in 2029. Therefore, it is clear that inhibitor 7 cannot replace sodium chromate before **the sunset date of 21 September 2017.**

#### ***4.3.1.4. Economic feasibility and economic impacts of Alternative 1***

Inhibitor 7 is economically available and affordable. Investments associated with the replacing of Cr(VI) with inhibitor 7 and related unit cost increase are also feasible for Dometic.

#### ***4.3.1.5. Hazard and risk of Alternative 1***



Therefore, risk towards humans and environment is expected to be reduced compared to the use of sodium chromate.

#### ***4.3.1.6. Conclusions on Alternative 1***

The analysis above has demonstrated that although using inhibitor 7 is economically feasible and available, it is not technically feasible at the moment. Thus, it will not be ready to replace sodium chromate by the sunset date. However, Dometic has shown clear intention to make the replacement, evidenced by the phase out plan depicted in section 2.3 and roadmap for substitution in Annex 1.

### **4.4. The most likely non-use scenario**

The non-use scenario is a combination of establishing a production line in China for the products using sodium chromate and adjusting the product mix. The new production facility would first only be for cooling units' production, and later also for the full assembly line. The

main reason is that it is inconvenient to produce cooling system away from the product; normally they should be designed and produced together. Due to the new facility, the products have to be sent to Europe for sales, which results in additional transportation cost for Dometic in addition to the investment cost made. Using the new facility and bearing the transportation cost is estimated to last for 12 years, until the alternative substance, inhibitor 7, is able to be used for the whole production portfolio in the European production sites.

The non-use scenario and building the new production facility in China affects the whole supply chain; the European local business communities may lose subcontracting contracts which could cause unemployment. In Dometic, there would be adjustment in product mix that would lead to discontinuation of certain products, and the inability to fulfil the legal obligation of supplying legacy parts. The lack of closeness to customers and the reduced product portfolio **would erode Dometic's competitive advantage**, which may lead to weakened financial position. These effects are summarised in Table 5.

**Table 5. Summary of non-use scenario and consequences**

<b>The supply chain member</b>	<b>Implication in the impact analysis</b>
Dometic	<ul style="list-style-type: none"> <li>- Dometic would build a new production facility in China to produce sodium chromate containing products, and adjust the product mix.</li> <li>- There would be cost related to the direct investment for the new production facility in China.</li> <li>- There would be additional cost for transporting products back to Europe for sale.</li> <li>- Adjustment in product mix would lead to <b>discontinuation of certain products</b>, leading to loss of revenue/profit.</li> <li>- Dometic would suffer an erosion of competitiveness. This will translate into loss of market share and profit.</li> </ul>
Downstream users (RV, minibar & medical)	<ul style="list-style-type: none"> <li>- The unavailability of the legacy spare parts may translate into higher replacement cost</li> </ul>
Local business communities	<ul style="list-style-type: none"> <li>- The local business communities in Europe would lose service and subcontracting contracts.</li> </ul>
Public	<ul style="list-style-type: none"> <li>- Jobs may be lost in Europe.</li> </ul>

## 5. IMPACTS OF GRANTING AUTHORISATION

The impacts presented in this chapter are the differences in costs and benefits when comparing the non-use scenario with the in-use scenario. Monetised values are provided wherever available, but when the impacts have not been possible to quantify, they have been described qualitatively instead. The impacts have been divided into economic, social and wider economic impacts and are compared to the human health impacts.

### 5.1. Economic impacts

The economic impacts of the non-use scenario occur when building the new production facility in China and then returning the products to Europe for sales (additional transportation cost). Later in Table 6 the overall economic impacts are calculated. The discount rate used in economic impact calculations is 4% as recommended in the European Commission's Impact Assessment Guidelines<sup>3</sup>. The net present values are discounted to the year 2015. Below the impacts are described in detail.

#### Cost of the new facility in China

Due to the non-use scenario, a new production facility would be built in China. Cooling unit production and development is closely linked to the production. In the short term the cooling unit production would be built but eventually the entire production line with assembly would be established in China for practical and cost reasons.

When building up the production capacity in China there would be costs for processing, retooling, purchasing the production equipment, production space and project management and preparation at receiving end with buildings, testing, certifications etc. Due to the long lead times, and different production set-up in China, it would be necessary to retool most of the product tools and production equipment. It also includes severance on the giving end together with preparations, demounting etc. **The minimum cost to Dometic is 12 million euros for building up the cooling unit production line.**

**[REDACTED]** Building up the assembly line takes longer than the cooling unit line because of different qualification processes of the production.

The reason why new investment is needed is due to the differences in production mechanisms and the product portfolio between the European and Chinese factories. A tailored facility is needed for producing products meant for European market. In addition, Chinese authority

practice does not encourage transferring used foreign machineries to China, and therefore new tools and equipment need to be purchased.

The factory in China would be in use for 12 years which is the time needed to complete the phase out of sodium chromate with inhibitor 7 in Europe. This is also referring to the temporal scope of the analysis. [REDACTED]

In Dometic's experience, it is unlikely to be production cost savings in China. The wages and production costs are rising constantly there and China cannot be considered as a low cost country anymore. The wages have more than tripled in China during last decade<sup>4</sup>. The production cost is reaching the cost level of e.g. Hungary, which on the other hand has the geographic advantage to Dometic of being in Europe.

#### Additional transportation cost

When the products containing sodium chromate are manufactured in China, they need to be transported back to EU for sales. Based on Dometic's past experience, the transportation cost is estimated to be 10 euros/unit in average from 2017 to 2029.

As stated before, production in China would not generate cost savings and since production to the stock is not economically feasible in Dometic's products, the production has to be continuous and demand based. Therefore, the transportation cost is a real cost item for Dometic.

Based on the phase out plan, as shown in the Table 6, the amount of sodium chromate used in products that are produced in China and sent back to Europe for sale will gradually reduce: from 200 000 units/year in 2017 [REDACTED] to 7500 units/year in 2029.

#### Other economic impacts

Because of the new production line in China Dometic has to adjust the product mix produced. This causes loss of revenue. The adjustment leads to discontinuation of certain products, and inability to fulfil the legal obligation of supplying legacy parts for downstream users. Lack of closeness to customers and reduced product portfolio would erode Dometic's competitive advantage, which may lead to the company's loss of competitiveness and weakened financial

position. The new production facility also affects the local business communities in Europe and they may lose service and subcontracting contracts.

*Conclusion of the economic impacts*

Including the investment cost for cooling unit and assembly lines, the remaining value of the factory in China in year 2029 and products' transportation cost from Europe to China the total net present value for **Dometic's economic impacts would be 36,307,447 €.**

ANALYSIS OF ALTERNATIVES and SOCIO-ECONOMIC ANALYSIS

**Table 6. Economic impact calculation**

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Investment cost for cooling unit line, M€		■													
Investment cost for assembly line, M€		■	■	■	■										
Remaining value of the factory in China, M€															■
Pieces sold in EU market			■	■	■	■	■	■	■	■	■	■	■	■	■
Transportation cost per unit, €			■	■	■	■	■	■	■	■	■	■	■	■	■
Total cost of transportation, M€			■	■	■	■	■	■	■	■	■	■	■	■	■
Total cost of investments and transportation, M€		■	■	■	■	■	■	■	■	■	■	■	■	■	■
<b>NPV (2015), 4%, €</b>	<b>-36,307,447 €</b>														

## 5.2. Human Health or Environmental Impact

As stated in the section 3.5 the worst case human health impacts of the continued use of sodium chromate is estimated to be 15,712 € to 33,724€.

## 5.3. Social impacts

Dometic estimates around 55 jobs may be lost in Europe due to the non-use scenario.

In Germany the unemployment rate is relatively low (5%<sup>5</sup>), in Hungary it is slightly higher (7.7%<sup>6</sup>). However, finding new jobs would be challenging in both of these countries considering the education level of people working in the factories and rather limited job opportunities and local population of Siegen (99 403 inhabitants) and Jászberény (26 622 inhabitants). Sixty-five percent of the Dometic employees are blue-collar workers and 63% of all employees are males.

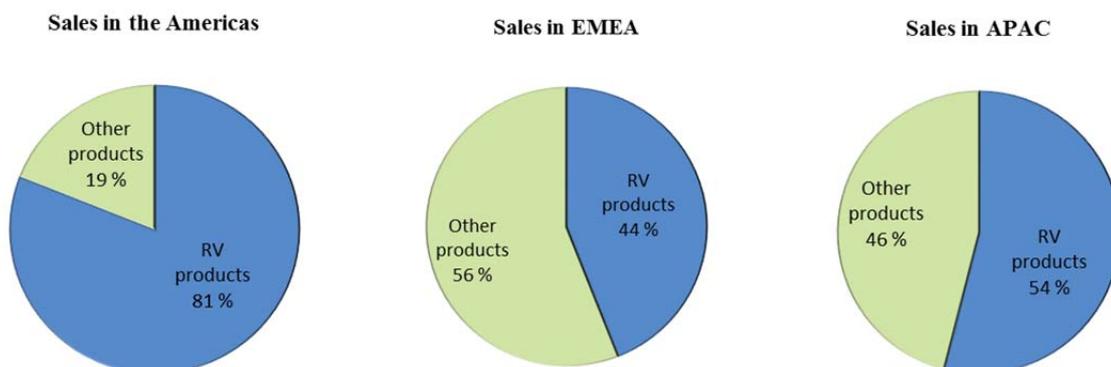
However when local labour legislation is taken into consideration and Dometic's own social responsibility principles, counting economic value for the 55 jobs lost would be highly speculative for the analysis. Hence this remains a qualitative argument and a potential threat to the social well-being.

## 5.4. Wider economic impacts

### 5.4.1 The importance of RV business to Dometic

RV products make a significant part of Dometic's business indicating roughly 60% of the net sales (2013) while 74% of it is for Original Equipment Manufacturers (OEM) and 26% for Aftermarket (AM). Most, 51%, of RV products are sold in the Americas, 36% in Europe, The Middle East and Africa (EMEA), and 13% in Asia Pacific region (APAC). On the other hand (Figure 7), RV business formed 81% of the business in the Americas, 44% in EMEA and 54% in APAC<sup>6</sup> Therefore these geographical areas in the business are mostly relying on RV products.

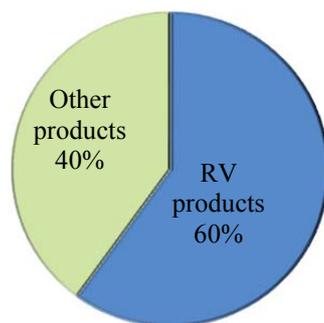
Figure 7. Dometic sales in different regions



In 2013 the net sales in the Americas was MSEK 2826 (319.9 M€) of which 81% (MSEK 2289.06 / 259.12 M€) was from RV products. The net sales in the EMEA region was MSEK 3678 (416.35 M€) of which 44% (MSEK 1618.32 / 183.19 M€) was from RV products, and in APAC region MSEK 1053 (119.2 M€) of which 54% (MSEK 568.62 / 64.37 M€) was from RV products. In total sales were 855.45 M€, while RV products formed 506.68 M€, resulting in ~60% of the net sales being for RV products (Figure 8).

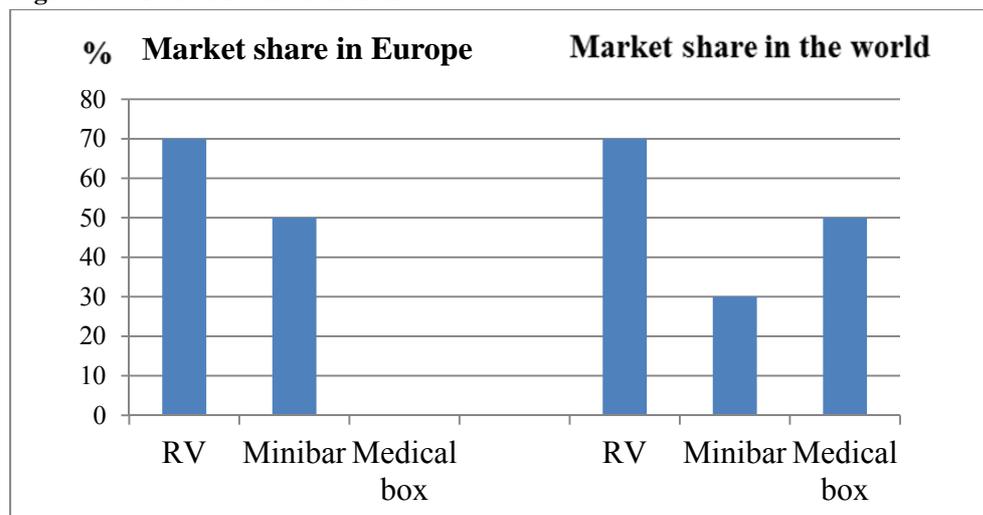
**Figure 8. Dometic net sales**

**Net sales in 2013**



Dometic’s markets shares in Europe and worldwide are shown below in Figure 9. Dometic’s market share in RV products is 70 % in both Europe and the world, which can be considered as a significant achievement and benefit. Minibars have rather large market share in the Europe, 40-50 %, and significant in the world market as well (20-30 %). Like in any OEM or project business the competition is intense. There are clear technical entry barriers for competitors to enter the market but at the same time the customers want to ensure that there is always competition in order to maintain low prices.

**Figure 9. Dometic’s market shares**



#### **5.4.2 Competitive landscape in the RV business area**

Dometic's products are perceived as key differentiators of quality in an RV, while representing a relatively small proportion of a recreational vehicle's total cost. Different products (refrigerators, windows, doors, kitchen equipment, toilet equipment) offered by Dometic itself are areas of low differentiation and with strong competition. There are many smaller players in each product areas. At the same time as the market is partly fragmented it is also dominated by a few RV OEMs with a strong bargaining power and relatively low substitution cost.

To cope with this, Dometic developed the strategy to position itself as a one-stop-shop supplier, focusing on quality, product range as well as services. One-stop-shop service is very important for Dometic in the field of RV's. Recreational vehicles are very complex products that contain many different product types. Since the industry is fragmented it would be very difficult for an RV producer to have to contact many different suppliers. It would also be very inconvenient for the final users to contact every supplier separately for service and support. Unlike the personal vehicle business, in RV the suppliers themselves are responsible for the services. With numerous amounts of different suppliers of components it would be difficult to have a European wide service network. Therefore it is more practical for one player to offer many products to setup service networks worldwide. Dometic can put together such set-up and it can be considered as a major competitive advantage.

For a one-stop shop supplier the importance of offering refrigerators is because of the end-users, hence close to 100% of all vehicles are equipped with a refrigerator. The ability to refrigerate food is very important for the mobile life style. The gas operated refrigerator is also a relatively complicated appliance due to its multi-fuel operation, long service life requirement, challenging environment and low noise. Thus not everyone can supply a refrigerator for this market. For other products such as stoves, lights and A/C etc., the competitors are in many cases specialised companies who are interested in the RV market even though it is, of itself, a niche market. Thus the competition comes not only from similar companies like Dometic but also from highly specialised experts. Dometic tries to cope with this through a wide offering, at the same time matching performance on every single item.

There are also other key one-stop-shop supplier companies in the market: competitor 1 and competitor 2. Both companies offer one-stop-shop for RV manufacturers although their product offering is less broad.

#### **5.4.3 Conclusions on wider economic impacts**

Dometic's vision is to be an innovator and trendsetter for people enjoying comfortable mobile lifestyle. The strategy is to expand the OEM stronghold, grow AM / retail business, accelerate new geographies and hence capture operational synergies. Dometic aims to serve

the market through two main sales channels mentioned: OEM and AM, provide the AM customers, wholesale distributors and dealers with products for their entire needs, and have a clear aspiration to be the preferred strategic partner in mobile comfort by adding value, products and services to all the customers and their customers. In this industry, Dometic is viewed as a leading mobile comfort supplier in all geographical areas thanks to the broad product portfolio, innovation capabilities and extensive global presence in supply chain, distribution and service support networks.

This strategy has been successfully implemented. As of now, refrigerators' turnover constitutes only 20% of the overall income.

The non-use scenario envisions the establishment of a new production line of cooling units/refrigerators in China. This would hamper Dometic's ability to put the above stated strategy into action, mainly for two reasons: lack of the closeness and quick reaction to the customer needs, and reduced product mix in the key product group (refrigerators) would harm strategic partnerships. Therefore there is a reason to believe that the non-use scenario would have wider negative impacts to Dometic's competitiveness as a company, whose consequence would be much bigger than the economic and social impacts described above. Its currently strong position as a market leader may be hampered, which could lead to significant financial losses.

### **5.5. Distributional impacts**

To support the socio-economic analysis an assessment of the distributional impacts of the benefits of continued use of sodium chromate are compared to the costs of continued use (Table 7).

**Table 7. Distributional impacts**

<b>Distributional analysis</b>	<b>Benefit of continued use</b>	<b>Cost of continued use</b>	<b>Comment</b>
Supplier	0	0	The supplier is a big chemical company with business operations worldwide who would have customers continuing to buy sodium chromate outside the EEA. The socio-economic impact on them is therefore expected to be marginal in the non-use scenario.
Dometic	36,307,447 €	0	The benefit of continued use is 36,307,447 € to Dometic in addition to avoiding the loss of market share and competitiveness.
Downstream (RV, minibar & medical) and end users	+	0	The loss of the non-use scenario is due to the lack of legacy parts which may translate into higher replacement cost. End customers' benefits of the continued use are unchanged level of quality, customer service and support by Dometic.
Public: EU	0	15,712 € to 33,724 €	Continued use of sodium chromate is a cost to the society from a human health perspective. However, since the risk of the current use is controlled to a level of low concern, the estimated human health impact would pose a relatively low cost of 15,712 € to 33,724 €.
	+	0	Maximum of 55 jobs may be lost in EU in the non-use scenario (excluding secondary impact following loss of competitiveness).

### 5.6. Uncertainty analysis

The analysis in this report is based on assumptions, whose uncertainties might affect the results of the calculations. Therefore an uncertainty analysis is necessary to be undertaken. The main uncertainties are considered to be the discount rate and the currency exchange rate (Table 8). Discount rates 4% and 15 % will be used, in addition to USD/EUR exchange rates 1.023 and 0.837.

**Table 8. Values used in the uncertainty analysis**

	<b>Baseline</b>	<b>Sensitivity analysis</b>	
Discount rate	4%	15%	
USD/EUR exchange rate	0.931831	+10%	-10%
		1.023	0.837

**5.6.1 Discount rate**

The economic impacts of building a production facility in China and cost of transporting products to Europe will be examined in Table 9 with Dometic’s Internal Rate of Return (IRR) of 15 %. Dometic uses this IRR value to measure profitability and desirability of investments and projects planned.

ANALYSIS OF ALTERNATIVES and SOCIO-ECONOMIC ANALYSIS

**Table 9. Uncertainty analysis of economic impacts with 15% discount rate**

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Investment cost for cooling unit line, M€		■													
Investment cost for assembly line, M€		■	■	■	■										
Remaining value of the factory in China, M€															■
Pieces sold in EU market			■	■	■	■	■	■	■	■	■	■	■	■	■
Transportation cost per unit, €			■	■	■	■	■	■	■	■	■	■	■	■	■
Total cost of transportation, M€			■	■	■	■	■	■	■	■	■	■	■	■	■
Total cost of investments and transportation, M€		■	■	■	■	■	■	■	■	■	■	■	■	■	■
NPV (2015), 4%, €	-36,307,447 €														
NPV (2015), 15%, €	-28,264,777 €														

As shown in the Table 10 below, with the discount rate of 4% the total net present value of the economic impacts is -36,307,447 €, while with the discount rate of 15% the net present value is -28,264,777 €.

**Table 10. Uncertainty analysis results: discount rate**

Discount rate	Net present value (NPV)
4%	-36,307,447 €
15%	-28,264,777 €

### 5.6.2 Exchange rate

Exchange rates are based on global factors. The contracts of transportation/shipping products from China to Europe are generally in USD. For the uncertainty analysis, the economic impact results are re-calculated with a 10% higher and 10% lower USD/EUR exchange rate. In Table 11 the net present values are calculated by using the new exchange rates.

At present the USD/EUR exchange rate is 0.931831<sup>7</sup>, with +10% being 1.023 and -10% being 0.837. In the basic economic impact calculation the additional transportation cost per cooling unit is 10 € being currently equivalent to 10.73 USD. In case of 10% higher USD/EUR exchange rate, the new actual value of the transportation cost per cooling unit would be 10.48 €. Similarly, with 10% lower USD/EUR exchange rate, new actual value per unit would be 8.98 €.

ANALYSIS OF ALTERNATIVES and SOCIO-ECONOMIC ANALYSIS

**Table 11. Uncertainty analysis of economic impacts with ±10% in exchange rate**

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Investment cost for cooling unit line, M€	■													
Investment cost for assembly line, M€	■	■	■	■										
Remaining value of the factory in China, M€														■
Pieces sold in EU market		■	■	■	■	■	■	■	■	■	■	■	■	■
<b>USD/EUR +10%</b>														
Transportation cost per unit, €		■	■	■	■	■	■	■	■	■	■	■	■	■
Total cost of transportation, M€		■	■	■	■	■	■	■	■	■	■	■	■	■
Total cost of investments and transportation, M€	■	■	■	■	■	■	■	■	■	■	■	■	■	■
<b>USD/EUR -10%</b>														
Transportation cost per unit, €		■	■	■	■	■	■	■	■	■	■	■	■	■
Total cost of transportation, M€		■	■	■	■	■	■	■	■	■	■	■	■	■
Total cost of investments and transportation, M€	■	■	■	■	■	■	■	■	■	■	■	■	■	■
<b>USD/EUR +10% NPV (2015), 4%, €</b>	<b>-36,832,291 €</b>													
<b>USD/EUR -10% NPV (2015), 4%, €</b>	<b>-35,192,154 €</b>													

As a result, the net present value of the economic impacts would be -36,832,291 € with 10% higher USD/EUR exchange rate and -35,192,154 € with 10% lower USD/EUR exchange rate (Table 12).

**Table 12. Uncertainty analysis results: exchange rate**

USD/EUR exchange rate	Net present value (NPV)
+10%	-36,832,291 €
-10%	-35,192,154 €

### 5.6.3 Conclusions of the uncertainty analysis

As shown in the previous calculations and Table 13 below, the baseline net present value is compared to the uncertainty analysis made with other variables. The net present value range is from -28,264,777 € to -36,832,291 €. The baseline for the economic impact is -36,307,447 €. With 15% discount rate the net present value is -28,264,777 € while the changes in the exchange rate lower or higher the net present value to -35,192,154 € and -36,832,291 €. As stated before, the human health impacts and costs of the continued use of sodium chromate is 15,712 € to 33,724 €, therefore it can be concluded that the socio-economic benefits of the continued use of sodium dichromate by Dometic outweigh the risks to human health in any case and on a wide range of different variables.

**Table 13. Conclusion of the uncertainty analysis**

	Baseline	Discount rate 15%	USD/EUR +10%	USD/EUR -10%
Net present value (NPV)	-36,307,447 €	-28,264,777 €	-36,832,291 €	-35,192,154 €

## 6. CONCLUSIONS

This report has examined the alternatives for sodium chromate and whether the socio-economic benefits of Dometic's continued using of sodium chromate outweigh the risks to human health.

In the AoA it was concluded that there is no feasible alternative for sodium chromate by the sunset date. However, Dometic is clearly engaged in replacing sodium chromate, demonstrated by the roadmap for substitution. Dometic will have to run necessary tests to make sure their products will be safe and they will perform as well as expected. New products could be introduced to the market gradually from 2018 on, starting from the ones with lowest boiler temperature. The products with higher boiler temperatures need more work before the new inhibitor can replace sodium chromate in them: the cooling units need to be redesigned and new safety equipment are included. In conclusion, the phase out of sodium chromate is planned to be finalized in 2029.

The human health impacts of the continued use of sodium chromate is estimated to be 15,712 € to 33,724 €. The main economic impacts include investment costs while building new production facility to China and transportation cost of returning the products to Europe for sales. The net present value of economic impacts is between -28,264,777 € and -36,832,291 €. There may be social impacts due to lost jobs in Europe. Wider economic impacts wise, there are serious threats to Dometic's competitiveness. The socio-economic analysis shows that the continued use of sodium chromate by Dometic overweighs the risks.

### 6.1. Comparison of the benefits and risk

In the Table 14 below the qualitative and quantitative impacts of the in-use and non-use scenarios are compared. The impacts are monetised when possible; the table also lists the qualitative impacts as losses or benefits.

**Table 14. List of quantitative and qualitative impacts related to the non-use scenario in comparison to the in-use scenario**

<b>Impacts</b>	<b>Difference between non-use and in-use scenario</b>	<b>Value</b>	<b>Monetised impacts in total</b>
Human Health impacts	Value of remaining risks	████████████████████	+15,712 € to +33,724 €
Economic impacts	Dometic: Cost of the new facility in China; cooling unit production line	██████████	NPV: -28,264,777 € to -36,832,291 €
	Dometic: Cost of the new facility in China; assembly line	██████████	
	Dometic: Additional transportation cost	██████████████████	
	Dometic: Remaining value of the factory in year 2029	██████████	
	Dometic: Loss of revenue due to reduced product mix	███	
	Local business communities: loss of subcontracting contracts	███	
	Downstream users of Dometic: unavailability of spare parts	███	
Social impacts	Maximum of 55 jobs lost might be lost in EU due to the new production facility in China	███	
Wider economic impacts	Qualitative argument: loss of competitiveness translated into loss of market share and profit	███	
<b>Summary</b>		<b>Cost of -28,231,053 to -36,816,579 M€ and significant loss of competitiveness</b>	

## 6.2. Information for the length of the review period

In the AoA section it was concluded that the shortlisted alternative, inhibitor 7, is not technically feasible by the sunset date. Therefore, Dometic will apply for 12 years review period for authorization.

The roadmap for substitution (Appendix 1) depicts the steps that Dometic has planned for substituting sodium chromate in absorption refrigeration products. According to the plan, sodium chromate could be replaced in some products already in 2018, but for other products testing and product development is still ongoing. It needs to be emphasized, that there is only one alternative, but many technical solutions into which the alternative needs to be fitted. New products would be released to the market in a staged fashion. The advantage in a staged introduction to the market is that it allows Dometic to combine the data from the testing of new products with the feedback from clients with previously released products. This allows a more comprehensive evaluation of inhibitor 7 function. In addition, if repeating problems are identified in one of the new product groups, necessary technological adjustments can be made before the next product group is introduced to the market.

Dometic is highly committed to replacing sodium chromate in refrigeration products, which is manifested by the fact that [REDACTED]

[REDACTED]. In addition to REACH authorisation, there are also other regulations that put pressure on replacing sodium chromate, most notably the ELV Directive 2000/53/EC and the RoHS Directive 2002/95/EC. ELV and RoHS regulations cover the Dometic RV refrigerator and minibar products, respectively.

Dometic feels that there would be no added value to society if they were granted a shorter review period. It has been clearly demonstrated in the application that the substitution will be carried out in any case, but needs to follow a strict phase out plan for good reason. If a shorter than 12 years review period is granted, it will only mean added expenses for Dometic as they would need to re-apply for authorization at a later date.

In conclusion, Dometic is applying for a 12 years review period based on the current phase out plan which demonstrates the commitment for replacing sodium chromate.

## 6.3. Substitution effort taken by the applicant if an authorisation is granted

Please see the roadmap for substitution in Appendix 1 and description of the phase out plan in chapter 2.3.

## 7. REFERENCES

<sup>1</sup> European Chemicals Bureau (2005). European union risk assessment report. “Chromium trioxide, sodium chromate, sodium dichromate, ammonium dichromate, potassium dichromate”. Luxembourg: Office for Official Publications of the European Communities.

<sup>2</sup> Dometic Group internal document (2015): Dometic Absorption EoL treatment 150117

<sup>3</sup> European Commission (2009). “Impact Assessment Guidelines”. 15 January 2009. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Brussels, 26.1.2011, COM(2011) 21. Available at: [http://ec.europa.eu/smart-regulation/impact/commission\\_guidelines/docs/iag\\_2009\\_en.pdf](http://ec.europa.eu/smart-regulation/impact/commission_guidelines/docs/iag_2009_en.pdf) (accessed 17.3.2015)

<sup>4</sup> Dometic Group (2013). “Annual Report 2013 Business Review”. Pages 10, 21, 25, 29. Available at: [http://www.dometicgroup.com/Global/4\\_Investors/AnnualReports/Dometic-Business-Review-2013.pdf](http://www.dometicgroup.com/Global/4_Investors/AnnualReports/Dometic-Business-Review-2013.pdf) (accessed 17.3.2015)

<sup>5</sup> International Labour Organization (ILO) (2013). Global Wage Report 2012/13: Wages and equitable growth. Geneva, International Labour Office. (accessed 24.4.2015)

<sup>6</sup> Eurostat (2015). Unemployment rate – annual data. Available at: <http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=tipsun20&plugin=1> (accessed 24.4.2015)

<sup>7</sup> Rates FX: Exchange Rates (2015). Available at: <http://www.ratesfx.com/rates/rate-converter.html> (accessed 23.4.2015)

**Annex – Justifications for Confidentiality Claims**

<i>Page numbers</i>	<i>Justification for confidentiality</i>
<p>7 9-11 24-26 44</p>	<p><b>Demonstration of Commercial Interest</b>                      The information regarding the phase out plan for the various products is an essential part of the business strategy of Dometic. The use of chromate as inhibitor in absorption cooling systems is industry standard without exceptions. Since there are currently no alternatives to chromate in the market any changes that impact the use of chromate has an impact on the industry and its ability to produce and sell products, hence a large commercial interest.                      In addition, technological developments that enable the use of the alternative will <b>provide a competitive advantage to Dometic Company over competitors.</b></p> <p><b>Demonstration of Potential Harm</b>                      The release of information related to the research on alternatives would be beneficial to Dometic’s competitors. Not only would they benefit from the knowledge on which alternatives that function successfully, but also from the ones that failed in testing. In addition they would benefit from the information related to the technological solutions. Dometic has had to develop new technologies also for handling the inhibitor and cooling system modifications in order to utilize the alternative. If this information would be open to competitors, it would allow the possibility to replicate the technological solutions for their own products. This would ultimately cause harm to Dometic’s competitive position. Furthermore, since the competition has production outside of Europe they are not affected by the REACH Regulation. The introduction of a new inhibitor requires very substantial resources in terms of both human resources and capital. Thus in the short term the position of Dometic vs outside producers is weakened. Often major changes are also connected to other changes such as design. Thus the disclosure of the AoA information would give the competition details about Dometic and the product development plans which would seriously harm competitiveness.</p> <p><b>Limitation of Validity of Claim</b>                      The claim for confidentiality on information regarding testing of possible alternatives and future testing of the selected alternative in accordance to the phase out plan and the technological developments will remain valid indefinitely.</p>
<p>18 28-29</p>	<p><b>Demonstration of Commercial Interest</b>                      The information regarding the economic figures is trade secrets of Dometic and should therefore be kept confidential due to competition issues.</p>

<p>31 38 40 43</p>	<p><b>Demonstration of Potential Harm</b> The release of Dometic’s individual cost items would give competitors an unfair advantage in the market as the items demonstrate Dometic’s cost structures and business plans. The release of such information could thereby cause harm to Dometic’s competitive position.</p> <p><b>Limitation of Validity of Claim</b> The claim for confidentiality on Dometic’s socio-economic figures will remain valid until 31 December 2020.</p>
<p><i>Appendices</i> 54 57-74</p>	<p><b>Demonstration of Commercial Interest</b> The detailed information regarding testing of possible alternatives, co-operation partners and general development strategy is the foundation for the finding of a suitable replacement for chromate. <b>Technological developments that enable the use of the alternative will provide a competitive advantage to Dometic Company over its competitors.</b></p> <p><b>Demonstration of Potential Harm</b> The release of information related to the research on alternatives would be beneficial for Dometic’s competitors. Not only would they benefit from the knowledge on which alternatives function successfully, but also from the ones that failed in testing. In addition they would benefit from the information related to the technological solutions. Dometic has had to develop new technologies in order to utilize the alternative. If this information would be known by competitors, it would allow the possibility to replicate technological solutions for their own products. This would ultimately cause harm to Dometic’s competitive position.</p> <p><b>Limitation of Validity of Claim</b> The claim for confidentiality on information regarding testing of possible alternatives will remain valid indefinitely.</p>

# APPENDICES

## Appendix 1 Roadmap for substitution

task already completed X →  
 planned task X →

Historical roadmap for start of corrosion experiments and external activities.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
<b>General investigation</b>										
Inhibitors	257,266	285	286,298,301,308	322	348	362,364	373			
Material	257		297,303,304,305,309	315,316,317,318	347					396
Surface treatment				320	340,350	364				
Design parameters		284	310,311	315,316,323	347,352					
Corrosion investigation methods					334,342,344,335	348,351,352	362			
End of life test							369			
External activities					University scans about 40 inhibitors	Consultation about different materials in production				
<b>Investigation of possible substitute called "inhibitor 7" in experiment list</b>										
Composition			312	319,326,329	336,341,345,353		369,376,377	378,386		
Concentration			312		336,346					397
Production adaption					341				391	
Heat transfer				327	338,339,345,346,349		369		374,391	
<b>Boiler temperature</b>					<b>337,339,353</b>	<b>359,372</b>				<b>393</b>
Access of inhibitor				327	338,339,345,346,349					
<b>Overheat protection</b>							369		374	
Cooling unit material					339,346,349				374	
Energy consumption										393
Performance										
<b>"Inhibitor 7" validation plan</b>										
Small scale filling equipment										
In house test for statistical evaluation										
Small scale field test - controlled population, high T										
Evaluation point/decision point of field test, high T										
Large scale field test - market test (low and high T)										
Design and construction of large scale production equipment in Jaszbereny										
Installation of large production equipment in Siegen										
Redesign of products and tooling										
<u>Development of overheat protection strategy</u>										
Approvals and certification of electronics										
Evaluation point/decision point RoHS exemption application										
Evaluation point/decision point on product ~150C										
Evaluation point/decision point on product ~200C										
Evaluation point/decision point on product ~210C										
Evaluation point/decision point on product >200C, special applications										
Phase out										
Estimated use of chromate (kg)										



## Appendix 2 Methods to evaluate alternatives

### Summary

The purpose of this document is to support the application for authorization of the use of chromate by describing the methods used for testing various means for corrosion protection in absorption refrigerators.

This summary gives a brief overview of the strategies used for the evaluation and is not intended to give a complete summary of all measurements done

### Laboratory investigations

#### Electrochemical measurements

Various standard electrochemical measurements have been employed, like EIS (Electrochemical Impedance Spectroscopy) and LPR (Linear Polarization Resistance) and LSV (Linear Sweep Voltammetry).

These measurements have been performed in Autoclaves but attempts have also been to make tests “In Situ” where electrodes have been inserted into the cooling units themselves. Due to the very high temperatures, pressures and the ammonia/water environment this have been proven to be very difficult.

The evaluation has been proven to be very difficult. One reason is the very long time lines. It is thus difficult to use short term corrosion rate measurements to estimate service life. In fact in some cases corrosion rates can be higher initially during formation of a passivating layer.

#### Weight-loss measurements

Several standard methods are used to determine the corrosion rate of carbon steel through weight loss measurements. The basis for the measurement is that a sample with known weight is exposed to the corrosive environment, the corrosion products are then etched away in a controlled way using certain chemicals that ideally does not influence the base metal. In this way it is possible to determine the amount of layers formed and also the extent of deterioration of the base metal. The method is described in e.g. **SS-ISO 8407**.

Such measurements have been made in autoclaves and “In-Situ” of the absorption refrigerators. The method is a relatively good screening method and if tests are made in the same environment the results are believed to be representative.

#### Hydrogen gas evolution

Since it is believed that **hydrogen evolution is the main cathodic reaction** attempts have been made to also measure the amount of evolved hydrogen. This has also been done inside actual cooling units filled with helium. The method however is difficult to employ for evaluation of oxidizing inhibitors since they will prevent the hydrogen evolution reaction but this does not necessarily mean that they stop corrosion but merely that the corrosion mechanism is changed.

## **Autoclave testing**

Various autoclave tests have been made, both for evaluation of inhibitors but also for various coatings. In the autoclave tests both electrochemical and other of the above methods have been used. Autoclave tests have also been used internally for evaluation of various coatings where the entire inside of the autoclave has been coated.

## **Surface analysis**

An array of various surface analyses has been used, including microscopy. The purpose has been to evaluate surface layers but also crystal structure in the metal for better understanding of reasons for leakages. Particularly worth mentioning is GDOES (Glow Discharge Optical Emission Spectroscopy) whose depth resolution results have given very valuable insights in the formation of the passive protective layers.

## **Service life evaluation**

Since the absorption system is a closed circulating system and high temperature and pressure it is very difficult to completely draw conclusions without very extensive real-life testing. Thus the most valuable tests have been made by testing the various solutions in actual refrigerators. This has been made by filling the cooling units with the refrigerant solution together with the inhibitor under investigation. The cooling units has then been started and operated continuously over long periods of time. At regular intervals some units have been stopped and cut open. The interior surfaces has then been investigated.

## **Continuous monitoring**

Due to the fact that corrosion effects the internal circulation it has also been possible to evaluate the extent of corrosion through the cooling performance and boiler temperature. Thus the most important parameter has been the boiler temperature that has been monitored regularly. Some cooling units have also been used in refrigerators to allow the cooling performance to be measured

## **Parameter studies**

The cooling unit testing has also been used to evaluate influence of parameters such as temperature. This has been done by modifying the pressure in the unit, also various other parameters such as influence of heat transferring surface area has been investigated.

## **Inhibitor degradation**

Inhibitor degradation is also an important measure. Here the cooling units have been equipped with sampling valves to allow measurement of inhibitor concentration at regular intervals.

## **New materials**

New materials have also been evaluated by producing entire cooling units and run for long period of time. The advantage with this method is that it also indicates the possibility to actually produce the cooling units and also possible impact on performance

## Internal field trials

The most severe environment is found in recreational vehicles with high temperatures, vibrations etc.

A test rig has therefore been constructed to simulate this, including tilting and bumping.

## Principle work-flow for evaluation of an inhibitor

1. Literature research to select options
2. Screening through short term testing and studies of literature data
3. Filling of cooling units for initial evaluation (<6months)
4. If initial evaluation is positive, fill a large set of units and run for a longer period. Regular destructive investigations made
5. Small internal field trial, e.g. by placing products in common areas etc.
6. External field trial, controlled placing of products into the market with regular follow up

### Appendix 3 Corrosion studies 1920-1999

#### Summary of Dometic (Electrolux) studies of corrosion in absorption refrigerators 1920-1999

##### Abstract

Since 1925, Electrolux has produced some 50 million absorption refrigerators. Today, Electrolux produces approximately 800.000 cooling units per year, of which 400.000 units are sold in Europe. The production is mainly located in Sweden, Germany, and Hungary. Absorption refrigeration is a unique heat driven technology that can be operated on gas (propane/butane), kerosene or electricity. Absorption refrigerators contain no moving parts and as a result they are completely silent and vibration free. Therefore, they are frequently used in hospitals, hotels, and small apartments. Furthermore, they are used in caravans, motor homes and other places where electricity is not readily available.

The Electrolux absorption cooling units are constructed in carbon steel because of its strength and good welding and cold-working properties. The refrigerant is an ammonia-water solution. The absorption cooling system is a completely closed system, which is pressurised with hydrogen gas. In order to prevent corrosion of the carbon steel cooling system a small amount of sodium chromate (between 5-20 grams) is added to the refrigerant. This amount corresponds to less than 2% by weight of the refrigerant.

In an absorption system operated without any corrosion protection, the carbon steel of the hot part of the system rapidly corrodes. The corrosion reaction rate depends on temperature and flow conditions. Above 100°C the corrosion rate becomes significant, which makes the hottest part (the boiler and pump tube where the temperature ranges between 130-200°C) of the absorption system particularly susceptible to corrosion.

The hexavalent chromium forms a protective passive layer, consisting of trivalent chromium oxide, at the steel surface. This is principally the same substance that protects stainless steel against corrosion.

Since the 1930's Electrolux has been conducting research into finding possible alternatives for the corrosion protection of absorption refrigerators. The work and resource commitment to this work has increased continuously. Not only has a significant in-house commitment been made but also Electrolux has worked with a number of external research institutes and universities on this issue. Several long-term projects have been run with theoretical and practical studies on the corrosion process. Work has also been carried out with companies who are expert in corrosion protection where commercial inhibitors have been tested. The research has looked at alternative refrigerants, inhibitors, structural materials, surface treatment and combinations thereof. As yet no viable alternative has been found that performs sufficiently with respect to product life, product safety, energy efficiency and product performance.

New ideas in the search of alternative corrosion protection are invented in-house, by scientific and patent literature surveillance, external co-operation and through contacts with commercial companies. These ideas are tested on a long-term basis in running absorption cooling units and refrigerators. In parallel, detailed material analysis such as surface analysis are performed. Furthermore, theoretical studies are made to generate new ideas and explain experimental observations. Today more than 200 refrigerators are running in long-term tests. Every year a substantial number of cooling units are started.

Electrolux realises that the present standard of product safety and product reliability must be fulfilled for an alternative to sodium chromate to be viable. Furthermore, there are expectations of long and maintenance free product life of an absorption refrigerator. These requirements make testing very

comprehensive and time consuming. In recent years, work has been directed to speed up the test procedure to be able to screen between different possibilities in a simpler and faster manner in order to be able to test more alternatives.

Several tests have been made with absorption cooling units both with and without inhibitors.

An absorption cooling unit filled with ammonia and water without any inhibitor will immediately be attacked by corrosion. Corrosion products will block the circulation and within less than one year the function ceases.

Using chromate, a chromium/iron oxide film is formed at the steel surface and no precipitates that block the circulation are formed. Chromate is slowly consumed and experience has shown that the service life exceeds 10 years of continuous operation.

A number of oxidising inhibitors besides chromate are known. Different oxidising inhibitors, not excluded by toxic or other unacceptable properties have been tested. Amongst them [REDACTED] and [REDACTED] have been tested most extensively. In all cases, the effect has been inferior to that of chromate.

Several [REDACTED] substances with inhibiting properties have been tested with inferior result compared to chromate.

The use of organic inhibitors as a substitute for chromate is increasing in many applications due to good efficiency and non-toxicity. Organic inhibitors are and have been under investigation. [REDACTED]

Several other construction materials beside carbon steel have been considered and tested.

[REDACTED] has been tested but due to poor stability at high temperature in combination with poor corrosion resistance, [REDACTED] is excluded as a viable material.

Electrolux has made several tests with [REDACTED] and combined with inhibitors. It should be emphasised that contrary to what is usually claimed, [REDACTED] is not, in itself, stable in the ammonia solution and it is therefore still necessary to find a complementary inhibitor.

[REDACTED] has been ruled out as construction material due to its poor resistance to ammonia vapour at high temperatures and towards hydrogen, in combination with poor welding properties and high costs.

Neither metallic nor non-metallic coatings have proved to be a viable alternative for corrosion protection, mainly because of difficulties in the coating process, risks of galvanic corrosion and due to low thermal conductivity of non-metallic coatings.

This document is a summary of activities and conclusions drawn from Electrolux corrosion studies of absorption refrigerators 1920-1999. It should be considered as a complement to the technical reports and studies available at Electrolux.

This document is strictly confidential and should not be distributed without approval from Electrolux.

## Absorption refrigeration

The continuous absorption type of cooling unit is operated using a limited amount of heat. No moving parts are employed. A schematic picture of the absorption system is shown in Figure .

The unit can be run on electricity, kerosene or gas. When the unit operates on electricity, the heat is supplied by a heating element inserted in the pocket (B). As can be seen, the unit consists of four main parts - the boiler, condenser, evaporator and absorber. The gas central tube (A) is used on gas units, kerosene units and on multi-energy units (electricity/gas/kerosene), but not on units made for electric operation only.

The unit charge consists of a quantity of ammonia, water and hydrogen at a sufficient pressure to condense ammonia at the ambient temperature for which the unit is designed. Electrolux cooling units contain a maximum of 500 g ammonia (NH<sub>3</sub>) and up to 10 g of hydrogen gas to pressurise the unit.

An additional ingredient of the cooling solution is water with an addition of sodium chromate as corrosion inhibitor. The inhibitor prevents corrosion of the steel tubes.

When heat is supplied to the boiler system, bubbles of ammonia gas are produced which rise and carry with them quantities of weak ammonia solution through the siphon pump (C). This weak solution passes into the tube (D), whilst the ammonia vapour passes into the vapour pipe (E) and on to the water separator. Here any water vapour is condensed and runs back into the boiler system, leaving the dry ammonia vapour to pass to the condenser.

Air circulating over the fins of the condenser removes heat from the ammonia vapour to cause it to condense to liquid ammonia in which state it flows into the evaporator. The evaporator is supplied with hydrogen. The hydrogen passes across the surface of the ammonia and lowers the ammonia vapour pressure sufficiently to allow the liquid ammonia to evaporate. The evaporation of the ammonia extracts heat from the evaporator, which in turn extracts heat from the food storage space, thereby lowering the temperature inside the refrigerator. The mixture of ammonia and hydrogen vapour passes from the evaporator to the absorber. Entering the upper portion of the absorber is a continuous trickle of weak ammonia solution fed by gravity from the tube (D). This weak solution, flowing down through the absorber, comes into contact with the mixed ammonia and hydrogen gases which readily absorbs the ammonia from the mixture, leaving the hydrogen free to rise through the absorber coil and to return to the evaporator. The hydrogen thus circulates continuously between the absorber and the evaporator. The strong ammonia solution produced in the absorber flows down to the absorber vessel and then to the boiler system, thus completing the full cycle of operation. All liquid circulation of the unit, except for the boiler, is purely gravitational.

Heat is generated in the absorber by the process of absorption. This heat must be dissipated into the surrounding air. Heat must also be dissipated from the condenser in order to cool the ammonia vapour sufficiently for it to condense. Free air circulation is therefore necessary over the absorber and condenser.

The whole unit operates by the heat applied to the boiler system and, for a good operation, it is of paramount importance that this heat is kept within the necessary limits and is properly applied.

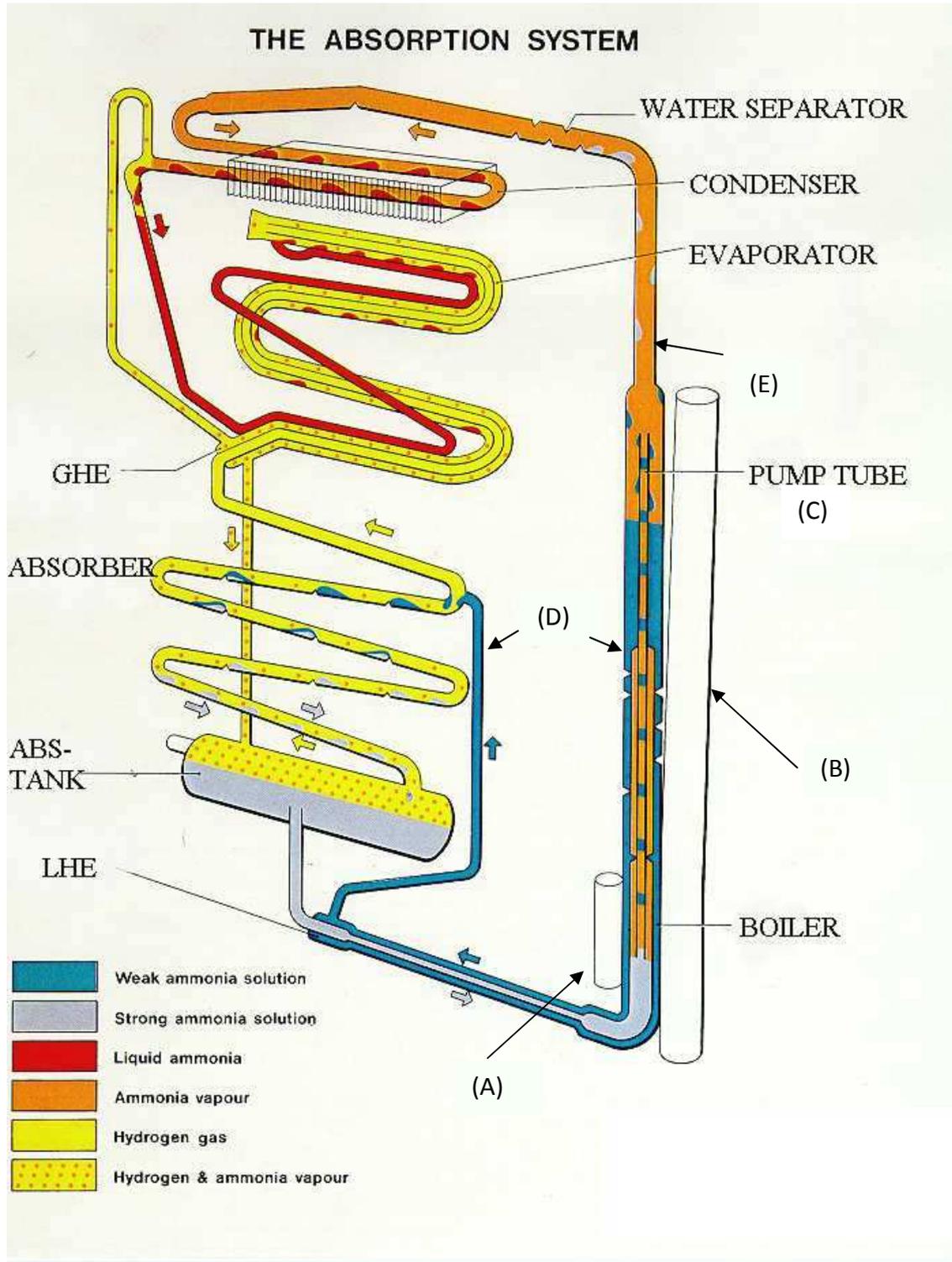


Figure 1. The absorption refrigeration system

## Electrolux corrosion studies

The corrosion studies involve three of Electrolux production facilities namely Motala, Siegen and Jászberény, where a large volume of short-term and long-term tests of inhibitors, new materials and new surface coatings are run. The long-term tests are typically run for 1-5 years and the corrosion pattern is studied by visual examination of the cooling unit, analysis of samples from the refrigerant and the gas-phase and by material surface analysis. At present more than 200 absorption refrigerators are running in long-term tests. Every year around 80 new units are started.

The production facilities also participate in studies of the general corrosion pattern. This includes studies of influence of temperature, flow conditions and design of the cooling unit on the corrosion rate. In parallel, the absorption refrigeration process has been studied and improved in order to decrease the temperature of the hot parts of the cooling unit since the temperature is believed to be the single most important factor for corrosion. As a result this will facilitate the search of an alternative inhibitor. Furthermore Electrolux Core Technology and Innovation (CTI) has participated in many studies, for example in the search of alternative material and surface coatings.

The corrosion studies have been co-ordinated by Electrolux Leisure Appliances Research and Development Department. It includes development of electrochemical- and weight loss-measurements for measuring the corrosion rate.

## External partners

Electrolux has always considered it as an important task to identify and initiate co-operations with external partners with special skills. Because of the special environment and conditions in an absorption cooling unit (material, refrigerant, dimensions, flow pattern and temperature) it is not possible to run corrosion studies without considering the absorption process. During the last 30 years co-operations have been run with:

████████████████████ has investigated the corrosion behaviour including failure analyses, participated in electrochemical measurement of inhibitor efficiency and studied galvanic corrosion effects associated with the use of stainless steel.

████████████████████ participates in the project in order to develop new surface coatings with better properties in combination with new inhibitors.

████████████████████ participate in analyses of the corrosion system including in situ measurements of the gas phase in the absorption system to determine corrosion rate through hydrogen evolution measurements.

████████████████████ with an extraordinary experience in development of inhibitors for high temperatures, are involved in development work for Electrolux. This includes high temperature electrochemical measurements.

████████████████████ has run electrochemical autoclave studies and analysed the corrosion system.

████████████████████ has run surface analyses in order to determine the effect of different inhibitors.

████████████████████ has investigated the corrosion behaviour including failure analyses, run surface analyses and participate in analyses of production related issues such as welding and production technology associated with the use of stainless steel.

████████████████████ has investigated new types of inhibitors and also participated in long-term testing.

████████████████████ has investigated different inhibitors and also participated in long-term testing.

*External Companies* have supplied Electrolux with several commercial inhibitors, which have been thoroughly tested.

## Carbon steel in aqueous ammonia

Generally carbon steel is considered to be fairly resistant to corrosion attack in aqueous ammonia solutions. Problems have mainly been claimed to be associated with stress corrosion cracking in water-free ammonia. However, because of the special environment and conditions (material, refrigerant, dimensions, flow pattern and temperature) of an absorption cooling unit in combination with high requirements on product performance, product safety and life time expectancy it is concluded that carbon steel is not stable itself, if these requirements are to be met. An additional factor, usually not encountered in similar systems (for example steam turbines), is the impossibility of performing continuous maintenance of the absorption system.

## Corrosion pattern of an absorption refrigerator in absence of inhibitor

The corrosion reactions in the absence of an inhibitor are believed to be cathodic hydrogen evolution and anodic metal dissolution. Cathodic oxygen reduction can be ruled out since oxygen is not present. The typical service life of a refrigerator filled with ammonia and water without any inhibitor is less than one year.

The amount of magnetite necessary to block the pump tube is very small compared to the total corroding steel area. However, it is not possible to increase the diameter of the pump tube since the thermo-siphonic pump and the absorption process will then cease to function.

It is believed that the blocking magnetite does not solely originate from the pump tube itself. Iron is probably dissolved in other parts of the cooling unit and transported to the pump, either as free ferrous iron or as an iron ammonia complex, where magnetite is formed by a dissolution-precipitation mechanism. The boiler tube for example has a large area and the highest temperature. It is thus believed that the major amount of corrosion products is produced here.

At a pH around 12 and the actual temperature, the solubility of iron should be low, even at elevated temperature. However, one has to consider the increased solubility of iron due to formation of different  $\text{Fe}^{2+}$ - $\text{NH}_3$  complexes.

A hypothesis to explain the observed behaviour has been formulated.

One other factor is the effect of changing ammonia concentration in the liquid. The ammonia-water solution is a two component system and when liquid is transported along the pump tube, richer and richer ammonia vapour will form, leading to a reduced ammonia concentration in the liquid.

The iron precipitates are found as magnetite crystals. It is not clear whether magnetite is formed immediately or if an iron hydroxide is precipitated first and subsequently rearranged to magnetite. Bohnsack has discussed the kinetics of the formation of magnetite.

## Corrosion pattern in presence of oxidising inhibitors

Oxidising inhibitors are generally believed to be the most efficient inhibitors available, although in recent years the use of organic inhibitors has increased. [REDACTED]

[REDACTED]. A number of oxidising inhibitors exists. The most efficient oxidising inhibitors are the hyperosmiates and pertechnates, although their use is limited due to their poisonous and radioactive properties, respectively. Chromates are considered to be the third most efficient inhibitor family. Other oxidising inhibitors are [REDACTED]. All of the before mentioned inhibitors have the ability to form a protective layer on the steel surface. Other types of oxidising substances such as nitrite, oxygen and peroxides may also offer corrosion protection under some circumstances.

The protective properties of oxidising inhibitors are obtained by the formation of a passive layer. In the case of carbon steel, the passive layer consists of hematite ( $\gamma\text{-Fe}_2\text{O}_3$ ). In the case of stainless steel, passivity is offered by a thin  $\text{Cr}_2\text{O}_3$  oxide film. Magnetite ( $\text{Fe}_3\text{O}_4$ ) is not considered a true passive oxide. The passive layers formed by presence of inhibitors are not thermodynamically stable in the absence of an inhibitor. Thus, oxidising inhibitors are sometimes known as dangerous inhibitors since they may in fact increase the rate of corrosion if the concentration drops under a certain threshold limit.

With nickel, the passive nickel oxide is formed immediately on top of the base material. This ensures a thin defect free passive film with good protective properties which is one reason to add nickel to stainless steel. Contrary to the situation with nickel, the passive layer of hematite ( $\text{Fe}_2\text{O}_3$ ) cannot be formed directly on top of the steel surface. Instead magnetite ( $\text{Fe}_3\text{O}_4$ ) is first formed and hematite is formed on top of this magnetite layer. This makes it more difficult to form a thin defect free hematite layer and this is the reason for the less protective properties of the passive film on iron compared to a passive film on nickel.

The poor protective properties of passive iron can be improved by stabilisation by another substance. For example, when chromate is used, chromium oxide ( $\text{Cr}_2\text{O}_3$ ) is formed, similar to stainless steel. With [REDACTED] it is more difficult to reach an efficient protection since [REDACTED] merely oxidises steel [REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

## Inhibitors

### Oxidising inhibitors in absorption refrigerators

#### *Chromate*

Chromate was discovered to be a very efficient corrosion inhibitor in absorption refrigerators in the late 1920's. The use of chromate was also patented by Electrolux. As already noted, chromate forms a chromium/iron oxide film at the steel surface with good protective properties. If the film is damaged, chromate is supplied from the solution and the surface is re-passivated. Chromate is slowly consumed but experience has shown that the service life exceeds 10 years of continuous operation. Eventually, when all the chromate is consumed, the protective film is stable enough to continue to protect the steel surface for an additional period of time.

#### *Nitrite*

Nitrite is also widely used as corrosion inhibitor. Nitrite has been extensively tested as corrosion inhibitor by Electrolux and was also patented. The original purpose of the exchange to nitrite was to overcome some operational problems associated with a low solubility of chromate in pure ammonia.

This problem was later solved by design changes. The corrosion protection properties of nitrite were tested but found to be inferior compared to chromate. First, the protective properties of the passive layer formed by nitrite are less efficient and second, nitrite is rapidly consumed at high temperatures. The service life for a unit inhibited by nitrite is around one year. Subsequent investigations by Electrolux indicate that the corrosion rate is one third compared to the case with no inhibitor. Contrary to the uninhibited units, the units inhibited by nitrite did not stop due to blockage in the pump tube. Instead, corrosion products in the lower part of the boiler tube block the cooling unit. Most probably the transport of Fe(II) iron to the pump tube is hindered since nitrite oxidises Fe(II) to Fe(III). Fe(III) cannot exist as free ions due to a too low solubility in an alkaline environment. Furthermore, the solubility of Fe(III) ions is not increased by complex formation with ammonia. The following corrosion mechanism is assumed: nitrite oxidises the steel surface to form hematite. However, the surface oxide is not dense enough to offer a full protection but allows the corrosion reaction to continue. The oxide grows thicker and thicker and eventually parts of the oxide film fall off and forms a blockage in the bottom of the boiler. Similar to the uninhibited unit, very little corrosion products are necessary to disturb function.

### *Other oxidising inhibitors*

██████████ have all been tested but the result was not very promising. ██████████ can also be excluded due to their toxic properties whereas ██████████ can be considered non-toxic. The oxidising power of ██████████ itself is low and it is beneficial to increase the performance by maintaining a certain level of oxygen or another oxidiser such as ██████████ in the cooling unit. ██████████ in combination with oxygen was patented for corrosion protection in ammonia absorption refrigerators. Electrolux has tested this patent, ██████████ alone and also combinations of ██████████ but not found the corrosion inhibiting properties of ██████████, alone or in combination, a viable alternative to chromate.

### **Other inhibitors**

There exists a number of non-oxidising substances with inhibiting properties. The function of these vary, with some stabilising the oxide layers formed in the presence of oxidising inhibitors and others forming a protective film on top of the surface. Many different substances have been tested and found inferior to chromate. For example ██████████

██████████  
██████████  
██████████ Some of these substances will be commented on further below.

██████████

██████████ is claimed to have inhibiting properties in ammonia-water and ██████████. ██████████ is claimed to lower the solubility of the iron oxide and thus lower the rate of corrosion. As shown by ██████████ the solubility minimum of magnetite is found at pH around 12. The effect of small amounts of ██████████ are small and too large amounts are detrimental. Electrolux has extensively tested ██████████ and the conclusion is that ██████████ is not viable alternative to chromate.

██████████

██████████ in combination with ██████████. Electrolux tested ██████████ in combination with ██████████ and other substances in early 1980's and found it to be insufficient as compared to chromate. Despite of the fact that theoretically ██████████ ██████████. An inhibiting effect of

██████████ is thus not expected. Increased oxidising properties could be expected at elevated temperatures but as already noted the effect is not promising.

██████████

████████████████████ inhibitor for aqueous systems. ██████████ was studied by ██████████ and ██████████. They concluded that ██████████ is efficient at pH as high as 11. There are different theories about the function of ██████████ as a corrosion inhibitor. For example, it is thought that ██████████

████████████████████

██████████ is precipitated. Another theory claims that protection is achieved by ██████████ and ██████████ which transforms into a corrosion resistant film.

██████████ added as ██████████ has been tested by ██████████. ██████████ was subsequently patented by ██████████. ██████████ as corrosion inhibitor in absorption refrigerators has also been patented by ██████████. Electrolux has extensively tested ██████████ in different combinations. A positive effect has been noted but problems with ██████████ consumption have not yet been overcome.

## New construction materials

A possible solution of the corrosion problem would be to exchange carbon steel as a construction material into a material with better corrosion resistance in the absorption system. The reasons for using carbon steel are its excellent strength in combination with good welding- and cold-working properties. However, several other materials have also been considered.

### Metallic materials

Due to the high pressure and high temperature of the absorption system the outer surfaces must be made in a metallic material.

██████████

██████████ is claimed to be reasonably corrosion resistant in aqueous ammonia even at elevated temperatures. However, at high temperature its strength is reduced and the temperature-pressure combination encountered in absorption cooling units would mean that creeping of the material would be a severe problem. Electrolux has manufactured and tested a unit in ██████████. The test stopped after a few months and white ██████████. It is believed that the construction constraints of the absorption refrigerator makes it very sensitive to corrosion products although the general corrosion rate could be considered low. Due to the ██████████

████████████████████ is excluded as a viable material.

██████████

██████████ is considered to be resistant towards corrosion attack in aqueous ammonia. Entire units ██████████ have been manufactured and tested by Electrolux. The service life of these units was a few years before they stopped due to corrosion. This shows that contrary to what is stated in the literature, ██████████ is not entirely stable in aqueous ammonia. The reason for this is not known. However, one theory could be that ██████████

████████████████████.

Furthermore, Electrolux has made several tests where parts of the cooling unit are made of ██████████ in combination with an inhibitor. However further work has to be done in order to find a suitable combination. ██████████

████████████████████. It should be mentioned that an inhibitor is necessary in this case as well.

### *Titanium*

Titanium is resistant to most of the strong acids and bases. The corrosion resistance towards ammonium hydroxide is good. It is said to be an excellent material for use in 28% ammonia both at 25°C and 100°C. The corrosion rate of titanium, in 28 % ammonium hydroxide, is claimed to be 0.003 mm/year at room temperature and nil at 100°C. Titanium is also resistant to a boiling solution of ammonium nitrate. However, its resistance towards ammonia and water vapour is remarkably bad. The claimed corrosion rate is 11.2 mm/year at 222°C. The reason for this is possibly related to its inability to form a protective surface oxide. Furthermore, Titanium Metals Corporation explains that extremely high corrosion rates in ammonia/water vapour could be related to the dissociation of ammonia into hydrogen which results in hydrogen embrittlement in the titanium.

Titanium is readily cold worked and could be machined with conventional machine tools. Titanium is difficult to weld due to the fast formation of oxides at the surface. The possibility to fuse carbon steel and titanium by welding is not known. Titanium is an expensive metal and the bulk cost is 27 times that of carbon steel.

Due to the poor resistance towards ammonia vapour and hydrogen (hydrogen is used as inert gas in absorption refrigerators) in combination with the poor welding properties of titanium, it has been ruled out as construction material.

### **Non-metallic material**

Pump tubes made in ██████ and ██████ has been tested. Due to the ██████ of these materials the function of the cooling unit is disturbed which leads to excessive corrosion of surrounding metallic parts. It has thus been concluded that ██████ cannot be used in heat transferring areas, which are the area's most susceptible to corrosion.

### **Surface coatings**

Both metallic and non-metallic coatings have been tested. The major and common problem of the coating is the complex geometry of the absorption cooling unit with several concentric tubes which makes it difficult to reach all surfaces and to coat evenly.

### **Metallic coatings**

Using metallic coatings, there is a risk for galvanic corrosion. Different ██████ coatings have been tested but the result was that the coating peeled off from the carbon steel surface. Since ██████ will probably be more noble in this environment one can also expect severe galvanic corrosion if the coating is damaged. It has therefore been concluded that ██████ coating is not a viable alternative to sodium chromate.

Different surface ██████ techniques have also been tested. Among them the technique described by ██████ where the steel surface is ██████. It was found that the effect on corrosion rate was minor. The reason is believed to be the poor corrosion protective properties of iron oxides as already discussed in connection to the use of ██████ as a corrosion inhibitor.

### **Non-metallic coatings**

Similar to non-metallic materials, non-metallic coatings also have low thermal conductivity, which leads to high temperatures at the steel-coating interface. This leads to instability and risks of a locally high rate of corrosion if the coating cracks. Different ██████ coatings have been tested but these detached quite rapidly from the carbon steel surface. ██████ has also been considered but was

concluded not to be a viable alternative due to the thickness of the coating and low stability at high pH.

## Conclusions

### Inhibitors

An absorption cooling unit filled with ammonia and water without any inhibitor will immediately be subject to corrosion. Iron ions are dissolved from the surfaces, transported to the pump tube where they are precipitated as magnetite crystals and finally block the pump tube within less than one year.

Using chromate, a chromium/iron oxide film is formed at the steel surface and no precipitates that block the circulation are formed. Chromate is slowly consumed but experience has shown that the service life well exceeds 10 years of continuous operation.

Alternatives to chromate have been searched for within the group oxidising inhibitors and also within other inorganic and organic substances with alleged inhibiting properties. However, no alternative to chromate has yet been found.

### Materials

Several other construction materials, beside carbon steel, have been considered and tested. All non-iron-based materials have been ruled out as construction materials for reasons such as poor strength at elevated temperatures, poor corrosion resistance or poor heat conduction.

However, as already mentioned such an inhibitor has yet to be found. Galvanic corrosion is also a problem that has to be overcome.

### Coatings

Neither metallic nor non-metallic coatings have proved to be viable alternatives to sodium chromate mainly because of difficulties in the coating process and due to low thermal conductivity of non-metallic coatings.

## Appendix 4 Corrosion studies 2000-2007

### Abstract

Many experiments have been performed since 2000 in order to reduce the corrosion inside absorption cooling units. The problem has been approached in different ways and could be divided into the following main groups: inhibitors, materials, coatings and design parameters. The experiments have been completed with studies of over-heat protection and non-laboratory function tests.

Several inhibitors have been tested since 2000 both by Dometic and by co-operation partners (research institutes). In the environment of an absorption cooling unit (alkaline and temperatures up to 200 C) there is one inhibitor (called “inhibitor 7”) that has shown promising result in particular.

Complete cooling units made of [REDACTED] have been thoroughly tested. It must be remembered that stainless steel does corrode in this type of application and an effective inhibitor is therefore still needed. [REDACTED] is also harder to weld and bend which complicates the manufacturing process.

Different types of inorganic coatings have been tested. None of the coatings have been successful.

A few studies have been made in respect to the design parameters. The corrosion is most severe in the hottest parts of the cooling units and it is shown that the heat transfer area is a sensitive area for corrosion. Studies have been made in order to improve these areas in respect to corrosion.

To evaluate the life length of units filled with “inhibitor 7” it is necessary to increase the statistical number of cooling units. Therefore, a filling station is under construction. Performance and energy consumption will also be further investigated.

## Corrosion studies 2000-2007

### Activities and experiments

#### Inhibitors

Several inhibitors have been tested since 2000 both by us and by co-operating institutes. [REDACTED]

[REDACTED] They used electrochemical techniques as well as traditional corrosion studies to choose the inhibitors most suitable for absorption cooling. In the conclusion of their study they recommended [REDACTED].

[REDACTED] are intended to work up to 150 °C that is much below the temperature in most of Dometic appliances (approximately 200 °C). They have been tested in minibar cooling units there the temperature stays at about 150 °C, but the corrosion was severe.

The fourth inhibitor has been extensively tested both before and after the report from the university. This inhibitor is referred to as “inhibitor 7” in the following text. It has shown promising results and may be a possible substitute for chromate.

#### *Inhibitor 7*

Initial experiments with this inhibitor showed that a protective layer was formed. This is important as chromate works in a similar way. The oldest cooling units (boiling temperature ~195 °C) filled with “inhibitor 7” [redacted] except sodium chromate that still is the best inhibitor. [redacted]

It seems to be a relation between the inhibitor concentration and the corrosion rate. [redacted]

There is one problem related to higher inhibitor concentrations. [redacted]

[redacted] It is therefore not certain that a higher inhibitor concentration will be positive in the long run, [redacted]

Experiments have been done with additives to stabilise the inhibitor to be able to decrease the “inhibitor 7” concentration. This has however not been successful.

A problem with “inhibitor 7” is the filling of the cooling units. In production today the inhibitor (sodium chromate) is mixed together with the ammonia in two different concentrations of ammonia. This makes it simple to vary the ammonia concentration in different cooling units. Due to the special properties of “inhibitor 7” [redacted]

#### *Inhibitor 1*

Inhibitor 1 has been used in a number of experiments. Some of the cooling units have [redacted] with rather good initial results. Unfortunately have the long-term results been disappointing. Hematite is formed and the inhibitor breaks down rather fast.

#### *Commercial inhibitors*

A number of commercial inhibitors have been tested. None of these have reduced the corrosion significantly.

## Materials

[REDACTED]

It must be remembered that [REDACTED] does corrode in this type of application. An effective inhibitor is therefore still needed. [REDACTED] is also harder to weld and bend which complicates the manufacturing. It is also more expensive.

Cooling units have been equipped with the entire boiler including the liquid heat exchanger made in [REDACTED]. Other units have had only [REDACTED]. Most of these units have been run with "inhibitor 1". Many problems have occurred with [REDACTED] but units with [REDACTED] better results. The degradation of "inhibitor 1" has been lower compared to units without [REDACTED].

Units with [REDACTED] have been run using "inhibitor 7". [REDACTED]  
[REDACTED]  
[REDACTED]  
[REDACTED]

### *Material 4 pump tube*

Units run without inhibitor [REDACTED]. A cooling unit running without inhibitor will of course be subject to general corrosion, but if pump tube blockage could be avoided the unit would probably be working for a much longer time. [REDACTED]  
[REDACTED]  
[REDACTED]  
[REDACTED]  
[REDACTED]  
[REDACTED]

[REDACTED]  
[REDACTED]  
[REDACTED]  
[REDACTED]

[REDACTED]  
[REDACTED]  
[REDACTED]  
[REDACTED]  
[REDACTED]

## Coatings

Experiments have mostly been performed with small rings coated with different layers. The layers have consisted of three different materials. The rings have been run inside cooling units and weight loss measurements have been performed. In one experiment was the inner

surface of some cooling units treated with a gas to achieve a protecting coating. None of the coatings have been successful.

### **Design parameters**

#### *Access of inhibitor*

[REDACTED]

#### *Heat transfer*

By examining cooling units it has also been shown that the heat transferring [REDACTED]

[REDACTED]

The last years have the weld quality been improved in production. This has made the welds less corrosion sensitive.

#### *Boiler temperature*

The corrosion rate is generally decreasing together with the boiler temperature. The boiler temperature can be decreased in different ways. The problem is that the performance usually deteriorates. It is especially hard to keep the freezer performance when the boiler temperature is decreased. Another difficulty is to keep performance in high ambient temperatures. By using ventilation fans it could be possible to compensate for this, but more work has to be done to examine this.

### **Overheat protection**

The corrosion rate is increased when the boiler temperature is increased. [REDACTED]

[REDACTED]

### **Caravan simulation**

It cannot be excluded that mechanical stress during driving could cause corrosion products to loosen and gather in the liquid heat exchanger. If a cooling unit is tilted more than a few degrees the pumping will cease. This will cause a higher boiler temperature that will increase

the corrosion rate. 13 units both with and without stainless steel parts have been run in a test rig for simulated driving conditions. The test includes tilting and bump simulation. The units are equipped with boiler wrappings around the boiler instead of heat transferring welds. [REDACTED]

### **Filling station**

To be able to fill a larger amount of cooling units with “inhibitor 7” a small-scale filling station has been developed and constructed.

The filling station has been used for filling minibar units (see below).

### **Non-laboratory function test**

#### *Minibars*

Most experiments regarding “inhibitor 7” have been performed with free-standing cooling units. To increase the number of units and investigate the behaviour of the inhibitor during ordinary use in refrigerators a non-laboratory function test was started. Minibars were chosen as the boiler temperature is low and it is rather easy to keep track of the units. [REDACTED]

To follow up the test, the boiler temperature will be measured regularly. **If the boiler temperature has increased, this may indicate that the unit has corroded.** The minibar should then be exchanged and the interior of the cooling unit will be visually inspected. As many minibars can be in operation after 15 years, the non-laboratory function test should continue for at least seven years. So far the results have been good. As the boiler temperature is rather low and the operating environment is different, the results cannot be directly transferred to the caravan units.

### **Performance test**

To examine the long-term performance of ”inhibitor 7” high boiler temperature refrigerators, an experiment was started 2007. 10 “inhibitor 7” refrigerators are compared with five standard chromate refrigerators. It is too early to draw any conclusions from this experiment.

### **State of the art**

It will be difficult to replace sodium chromate. It is important to minimise corrosion in all details. Considering the experimental results during the last years, the concept for this should be:

1. Inhibitor: “inhibitor 7”

2. [REDACTED]

3. [REDACTED]

4. [REDACTED]

5. The boiler temperature should be as low as possible.

All of these measures will mean more or less large adjustments of the products and the manufacturing equipment.

Depending on type of refrigerator will point 2 and 5 lead to [REDACTED]  
[REDACTED]  
[REDACTED]

[REDACTED] The life length of a RV is about 15 years. Customers expect the same life length from the refrigerator. This is also a matter of product safety as the risk for a corrosion-induced leak is limited if the refrigerator will be scrapped/recycled at the same time as the RV. The life length is in other words critical both for customer satisfaction and product safety. The statistical numbers of units using “inhibitor 7” are still very few to be able to foresee an estimated service length. The project continues and in the next coming years we will start a considerable number of tests as described in the roadmap.

## Appendix 5 Corrosion studies 2008-2014

### Abstract

Out of the vast amount of tests made without any other substances, coatings or materials none has come close to the observed behaviour of inhibitor 7. Therefore, since 2008 all work has been focused on inhibitor 7. The decision has been based on the continuous positive results in particular with specially adapted cooling units running at intermediate temperatures.

Inhibitor 7 has certain properties that make it difficult to handle. Therefore apart from testing of corrosion resistance there has been substantial work put into the handling of the inhibitor, [REDACTED]. In addition, to ensure a safe and reliable introduction, strategies for monitoring of the function is being developed.

The results are still positive but it has been shown that the inhibitor as such cannot replace chromate without certain important modifications in the [REDACTED] and we also believe that a new inhibitor will require a more elaborated [REDACTED]. Not because the inhibitor as such is [REDACTED] but merely due to the fact that we lack the experience gained from chromate during its 90 years in service.

- Continued studies in units have been conducted
- Ongoing field-trial still show positive results
- [REDACTED] has been constructed, built and tested. This has shown that the [REDACTED] can be controlled.
- [REDACTED] has been done and preparations are ongoing for construction drawings although further tests need to be conducted before it can be put into use.

### *Abstract 2007 as reference*

Many experiments have been performed since 2000 in order to reduce the corrosion inside absorption cooling units. The problem has been approached in different ways and could be divided into the following main groups: inhibitors, materials, coatings and design parameters.

The experiments have been completed with studies of over-heat protection and non-laboratory function tests.

Several inhibitors have been tested since 2000 both by Dometic and by co-operation partners (research institutes). In the environment of an absorption cooling unit (alkaline and temperatures up to 200 C) there is one inhibitor (called "inhibitor 7") that has shown promising result in particular.

Complete cooling units made of [REDACTED] thereof have been thoroughly tested. It must be remembered that [REDACTED] does corrode in this type of application and an effective inhibitor is therefore still needed. [REDACTED] is also harder to weld and bend which complicates the manufacturing process.

Different types of inorganic coatings have been tested. None of the coatings have been successful.

A few studies have been made in respect to the design parameters. The corrosion is most severe in the hottest parts of the cooling units and it is shown that the heat transfer area is a sensitive area for corrosion. Studies have been made in order to improve these areas in respect to corrosion.

To evaluate the life length of units filled with “inhibitor 7” it is necessary to increase the statistical number of cooling units. [REDACTED]

Performance and energy consumption will also be further investigated.

## **Corrosion studies 2008-2014**

Previous studies have been summarized in detailed elsewhere.

Due to the focus on Inhibitor 7 there is a significant reduction in general studies.

## **Activities and experiments**

### **Inhibitor**

No new inhibitors have been tested

### **Inhibitor 7**

Initial experiments with this inhibitor showed that a protective layer was formed. This is important as chromate works in a similar way. The oldest cooling units (boiling temperature ~195 °C) filled with “inhibitor 7” have been in operation [REDACTED]

It has been concluded that the suggested concentration provides sufficient protection in units operating at a boiler temperature up to 180 °C working in a stable environment but that more work is required for products with boiler temperature above.

The conclusion from [REDACTED]

[REDACTED] The suitable concentration range has also been established through testing, the concentration range needs to be a optimum between rate of consumption, potential negative effects at higher concentrations and handling of the inhibitor in filling and storage.

### **Materials**

No new materials have been tested

### **Coatings**

No new coatings have been tested

### **Design parameters**



A problem with “inhibitor 7” is the filling of the cooling units. In production today the inhibitor (sodium chromate) is mixed together with the ammonia in two different concentrations of ammonia. This makes it simple to vary the ammonia concentration in different cooling units. Due to the special properties of “inhibitor 7”, the filling of cooling units will be more complex [REDACTED]

[REDACTED] Another difficulty is how to make fast and accurate analyses of “inhibitor 7” in production.

[REDACTED]

Strategies for quality control (e.g. concentration control) of the inhibitor has also been developed. Also they are considerably more complicated compared to the relatively simple determination of chromate concentration through simple titration. In this case a combination of different methods are needed. However, it has been determined that such measures can be applied also in a production environment.

### **Factory relocation**

The work with the filling station was partly delayed due to the economic recession that forced a transfer of the Motala factory to US. Test filling station, test rig for RV simulation and also test units have been relocated to the Siegen factory.

### **State of the art**

It will be difficult to replace sodium chromate. It is important to minimise corrosion in all details. Considering the experimental results during the last years, the concept for this should be:

1. Inhibitor: “inhibitor 7”
2. [REDACTED]
3. [REDACTED]
4. The boiler temperature should be as low as possible.

All of these measures will mean more or less large adjustments of the products and the manufacturing equipment.

[REDACTED]

[REDACTED] The life length of a RV is about 15 years.

Customers expect the same life length from the refrigerator. Considering the user pattern of a European RV refrigerator we do not see a general problem. To address the fact that the corrosion inhibitor 7 is a new inhibitor we need to continue with field trial and also intend to take additional measures on the [REDACTED].