ANALYSIS OF ALTERNATIVES

and

SOCIO-ECONOMIC ANALYSIS

Legal name of applicant(s): Ariston Thermo SpA

Submitted by: Ariston Thermo SpA

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

Use title: *Use of sodium chromate as an anticorrosion agent of the carbon steel in sealed circuit of gas absorption appliances up to 0.70% by weight (as Cr6+) in the refrigerant solution*

Use number: *#1*

CONTENTS

TABLES

FIGURES

LIST OF ABBREVIATIONS

AfA	Application for Authorisation
AoA	Analysis of Alternatives
APF	annual performance factor
ASHP	Air source heat pump
CBA	Cost Benefit analysis
$Cr6^{+}$, Cr(VI)	hexavalent chromium
CSR	Chemicals Safety Report
DALY	Disability adjusted life years
ECHA	European Chemicals Agency
EEA	European Economic Area
EHPA	European Heat Pump Association
EHP	Electrical heat pump
ELR	Excess lifetime risk
ERDF	European Regional Development Fund
EU Commission	European Commission
GAHP	Gas absorption heat pump
GHP	Gas heat pump
GDP	Gross Domestic Product
GDHP	Gas-driven Heat pumps
GWP	Global warming potential
(H)ALT	(High) Accelerated Life Test)

HP	Heat pump
HVAC	Heating, ventilation, and air conditioning
NZEB	Nearly Zero Energy/Emission buildings
Na_2CrO_4	Sodium chromate
NH3	Ammonia
ODP	Ozone development potential
QALY	Quality adjusted life years
PPAP	Production part approval
RES	Renewable energy sources directive
R&D	Research and Development
SEA	Socio-Economic Analysis
TWA	Time weighted average
TWh	Terawatt hour
UK	United Kingdom
VCM	value cancer morbidity
VSCC	Value of statistical case of cancer
VSL	value of statistical life
WTP	Willingness to pay

DECLARATION

We, Ariston Thermo SpA, 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 (20 February 2019) 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: [signature] Date, Place: 20/2/19, FABRIANO (AN)

Paolo Petracca, Albacina Plant Manager, Ariston Thermo spa

Signature: [signature] Date, Place: 18 FEB 2019, Agrate

Luigi Tischer, R&D Program Manager, Ariston Thermo Innovative Technologies srl

1 SUMMARY

This combined analysis of alternatives and socio-economic analysis has been performed for the u*se of sodium chromate as an anticorrosion agent of the carbon steel in sealed circuit of gas absorption appliances up to 0.70% by weight (as Cr6+) in the refrigerant solution.*

Gas Absorption Heat Pumps (GAHP) are seen as one of the keys to achieve the targeted aims of CO_2 emission reduction set by the European Commission until 2050. The GAHP can be seen as a replacement technology for the boiler technology with higher efficiency using 40% less primary energy input and less CO2 emissions due to the use of renewable energy sources. Such energy savings result in 40% savings on heating costs for the end-consumer. Target market for the GAHP will be residential buildings and the retrofit sector. Ariston Thermo SpA is one of the major players in the heating, ventilation, and air conditioning industry and expected to be the first one to launch a commercial GAHP on the residential market.

The GAHP works with a natural refrigerant solution based on NH_3 and H_2O (with zero GWP and zero ODP), which mandatorily requires the use of a corrosion inhibitor. Based on the performed analysis of alternatives, Ariston Thermo SpA comes to the same conclusion as other applicants for authorisation with very similar use scenarios, that currently no suitable alternative is identified, which meets the requirements set by the GAHP technology, to replace the use of sodium chromate as corrosion inhibitor. Ariston Thermo SpA is investing in R&D into two directions: testing programs are started to further decrease the concentration of sodium chromate to the lowest level compatible with GAHP applications and, in parallel, Ariston Thermo SpA is signing currently long-term agreements with local universities to initiate an intensive research for the identification of suitable alternatives.

The most likely non-use scenario for Ariston Thermo SpA would be the move of the complete GAHP program to Far-East. A move to Far-East would result in a delay of GAHP product launch of at least 4 years and additional costs and profit reduction for Ariston Thermo SpA. Furthermore, the public will not profit from the advantages of the GAHP within the transition period. Such a delay would result in costs for the non-use scenario considering the discount rates of 36,489,490€ (15%) up to 50,232,841€ (4%). A complete move to Far-East similarly will weaken the market position of Ariston Thermo SpA as non-

EU competitors will receive an easier access to the market. In general, this will mark the end of the European leadership on the GAHP technology.

The new planned production line in Albacina (near Fabriano (AN), Italy) considers the highest safety standards, which result in a very low calculated exposure levels as demonstrated in the Chemical Safety Report (CSR). The monetised adverse impact on human health can be quantified between 216 € and 362 €. The socio-economic analysis shows a total benefit of continued use considering a discount rate of 15% of 36,489,128 € (low bound) to 36,489,274 € (high bound) and a benefit of continued use with a discount rate of 4% of 50,232,625 € (low bound) to 50,232,479 (high bound). Consequently, the analysis approves that the benefits of the continued use outweigh the risk for human health.

Ariston Thermo SpA is highly committed to replace sodium chromate as corrosion inhibitor. However, identification of alternatives and testing on suitability under GAHP use conditions will be a long process as presented within the road map for substitution under chapter 2.4.1. In conclusion, Ariston Thermo SpA is applying for a 20-year review period until 2039.

2 AIMS AND SCOPE OF THE ANALYSIS

2.1 Background information

The largest heating market in Europe is the retrofit segment, where low-efficiency heating systems are installed. Renovating and upgrading this building stock to a lower energy consumption profile will be one of the most substantial challenges of the upcoming years. The building stock tends to evolve very slowly (in Europe its rate is estimated lower than 1% per year). Technologies that are compatible with existing buildings are needed to accelerate the de-carbonization of heating, in particular in the existing buildings with high temperature emission systems (radiators). Gas heat pumps are one of the few solutions, which can guarantee high efficiency even in such high-temperature applications.

Gas absorption heat pump (GAHP) is a heating technology developed in Europe for the building sector, which can contribute substantially to energy conservation and the reduction of CO_2 emissions. The natural gas driven absorption heat pumps differ from a conventional electric heat pumps by the fact that the compression of the refrigerant is driven by a “thermal compressor” rather than an electric compressor.

Ariston Thermo SpA is one of the major industry players for heating, ventilation, and air conditioning (HVAC) systems for thermic comfort (wall-hung boilers, water heaters, heat pumps, etc.). Currently, the research and development department is engaged on the development of gas absorption heat pumps. Most of the top competitors in the boiler industry have announced a program involving the development of sorption technologies, i.e. adsorption and absorption. However, none of them offers a residential GAHP product within their commercial portfolio yet.

Ariston Thermo SpA is apparently the first company to reach the development stage to ask for authorisation for the use of sodium chromate in gas absorption heat pumps and to plan the commercialization of the GAHP.

Therefore, Ariston Thermo SpA will deeply refurbish a recently purchased production site in Albacina for the manufacturing of renewable energy products (solar thermal, electrical heat pumps, gas absorption heat pumps). The manufacturing of the GAHP products is planned to start as early as the release date of the authorization.

The following chapters will explain the mode of operation of a gas absorption heat pump, the necessity of sodium chromate as a corrosion inhibitor in the GAHP and the benefits of granting the authorisation, which will simultaneously enable the commercial product launch of gas absorption heat pumps.

2.1.1 Decarbonisation of the European Union and the position of the European Commission on development of gas absorption heat pumps (GAHP)

The European Union through its Roadmap for decarbonisation in 2050 has set a very ambitious aim in the reduction in greenhouse gas emission of about 80% compared to the year 1990. A study performed by Fraunhofer IWES/IBP (2017) investigated the requirements in the heating sector for Germany to achieve the aims set by the European Union. The findings can be transferred to all other European countries. The results of the study show that a reduction of 70-72 million tons of CO_2 by 2030 is needed to meet the target. Furthermore, considering the current market prices of around 20 € per t of CO_2 emissions (European Energy Exchange AG, 13.11.2018), a failure of the reduction would cost over 1,400,000,000 €.

Within the Fraunhofer study, the key factors are: the phase out of oil heating and a decline of energy use of 25% compared to 2015 levels. Another key factor will be the closure of the so called "*heat pump gap*". Based on current trends about 2 million heat pumps will be installed in Germany by 2030, but according to the results of the study 5-6 million heat pumps are needed. To bridge this gap, heat pumps should be installed not only in new buildings, but also in the existing buildings (retrofit) sector. The retrofit sector is the application area for which the gas absorption heat pumps are designed.

The development of gas absorption heat pumps (GAHP), which is a technology invented in Europe, has been highly encouraged by the EU Commission to support the decarbonisation of the heating sector across Europe. This new technology is the key to fulfil the 2050 decarbonisation target set by the EU. Besides the known polluters (mobility *in primis*), the residential buildings are one of the major contributors in CO_2 emissions. Residential buildings represent at the moment over 60% of the building stock in Europe. The building sector alone accounts for over 38.1% of the general energy consumption, and about 36% of greenhouse gas emissions in the EU whereupon over 80% of the energy consumption of buildings is based on cooling and heating (Eurostat, 2014).

While new constructions are often highly efficient and classified as "nearly Zero Energy/ Emission buildings" (NZEB), they contribute only a very small part of the building stock: Conversely the residential buildings have by far the largest potential on energy consumption reduction (effect of the extremely large stock of buildings and the large possible saving starting from the current poor energy efficiency). More than 35% of Europe's buildings tend to be venerable, dating back more than a half-century and the renewable rates are exceedingly slow with renewal rates of less than 1%. Heating in the existing building stock is primarily provided by conventional inefficient boilers with radiators driven by fossil fuels or electricity. A first essential step forward has been made in 2015 when the production and sale of conventional boilers was replaced by condensing boilers by law (European Regulation known as "*Ecoboiler Lot1*"). Solutions to make existing buildings even more efficient are needed to fulfil the medium to long terms decarbonisation aims. GAHP are seen as the future solution in the heating of residential buildings. They are so-called one of the key enablers. GAHP extract heat from ambient air by means of a thermodynamic cycle activated by gas rather than using electricity, which is still largely predominantly generated using fossil fuels (a mix of coal, oil and natural gas). Gas absorption technology is currently mainly used in larger buildings (e.g. hotels and schools). The most significant potential for emission reduction using this technology is seen in small residential buildings rather than the large buildings. This is exactly the sector Ariston Thermo SpA is focussing on.

To exemplify Figure 1 shows a chart prepared by UK - Department for Energy and Climate Change (DECC) that illustrates the expected future market development of the different heating technologies in UK. The role of GAHP technology appears of strategic relevance.

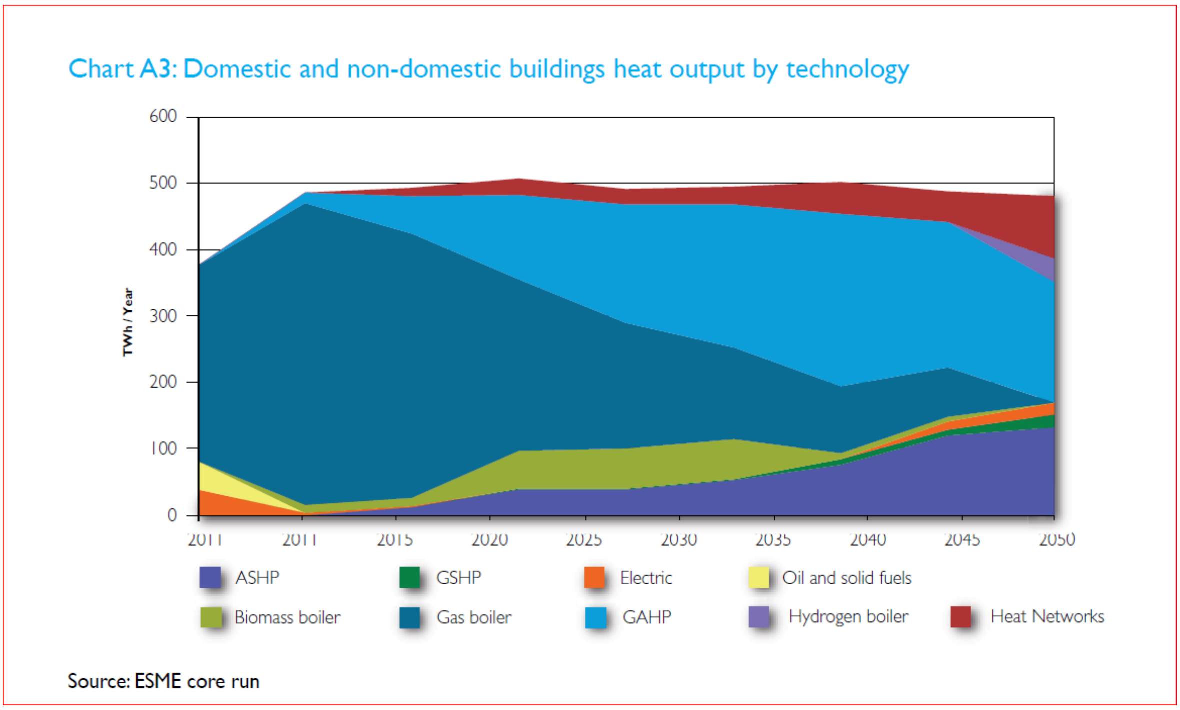

Figure 1 Overview on future heating technology in *domestic* and *non-domestic* buildings

According to the market outlook, GAHPs are seen as a superior technology to replace the conventional gas boiler technology until 2050 in support of the energy transition. To establish the basis for such a market growth a rethinking of the technology is needed since the current GAHP technology needs to be designed for residential market applications and for high volume manufacturing. To this aim European Commission has initiated, the Heat4U program under the EU's Seventh Framework Programme for Research and Technological Development in 2011 to develop suitable products in the area of single-family detached residential homes.

2.1.1.1 Heat4U project (budget in excess of 10 M Euro)

Within the HEAT4U project under the Seventh Framework Programme (FP7) promoted by the European Community first prototypes of the GAHP have been developed for the single-family detached residential homes sector. Within this project, 14 among the most important European organisations in the energy, industrial and research field took part. The results of the project confirmed that absorption heat pumps powered by gas are one of the key enablers to achieve energy efficiency and RES adoption targets for 2020 and beyond. The GAHP technology can increase by at least 35% the energy efficiency compared to the best condensing boilers even at temperatures below -20°C. GAHPs are ready to use with no particular building work or retrofit.

The Heat4U project ended in October 2014 with the clear statement that the GAHP is an appropriate technology ready for commercial deployment.

2.1.1.2 i-GAP project (budget in excess of 8 M Euro)

The i-GAP project which is co-financed by the Regional Operational Programme of the European Regional Development Fund (ERDF ROP) with a term from 2014-2020 of the European Commission aims to develop the technology of small gas absorption heat pumps for residential building heating. The objective of the project is to quantify the benefits, to size the market and the energy system impacts of a development of GAHP-based technology solutions and to develop the manufacturing processes to exploit the potential offered by the technology. Ariston Thermo next to D&P, Gefran, Politecnico di Milano, Sintea and Snam are the vital partners of this project.

With a project duration of 1st October 2016 till 4th June 2020 the authorisation for the use of sodium chromate as an anti-corrosion inhibitor in gas absorption heat pumps reflects a critical milestone.

Today, Ariston Thermo SpA is preparing for the launch of this product on the residential market.

2.2 Aim of the analysis

Sodium chromate (Na_2CrO_4; EC 231-889-5; CAS 7775-11-3) has been identified as a substance of Very High Concern (SVHC) (according to Article 57(a) of Regulation (EC) No 1907/2006 (REACH). It was included in Annex XIV of REACH due to its CMR properties: Carcinogenic (category 1B), Mutagenic (category 1B) and Toxic for reproduction (category 1B). Therefore, applications for Authorisation (AfA) for continued use of sodium chromate in the European Union after the sunset date 21st September 2017 are necessary. As sodium chromate is considered as a non-threshold substance, the authorisation will be prepared under the socio-economic analysis (SEA) route as adequate control of risks arising from the use of the substance cannot be demonstrated in accordance with Annex I, section 6.4 of Regulation (EC) No 1907/2006.

Sodium chromate is used in the case of Ariston Thermo SpA as an anticorrosion agent of the carbon steel in the sealed circuit of gas absorption appliances up to 0.70% by weight (as Cr6+) in the refrigerant solution.

The following chapters of this document will show that there are no suitable alternatives available to meet the appropriate specificity of the anticorrosion agent and highlight the benefits against the already existing technologies. Supplementary, the aim of this analysis is to show that the economic and environmental benefits of implementing this product in the heating market sector outweigh the risk to human health. Additionally, the application emphasises the support of the European Commission to GAHP technology for the decarbonisation of heating across Europe.

2.3 Scope

2.3.1 Temporary scope

The temporary scope of the socio-economic analysis is set as 20 years after the request for start of authorisation expected in 2020. This equals in a review period until 2039. All economic, social and wider economic effects are considered until this point.

The same time period is considered for the human health impacts. With the stop of production, the possibility of sodium chromate exposure stops, too. An exposure of Chromium (VI) by the end products even if they have a longer lifetime (estimated lifetime of a boiler is 24 years) than the 20 years of the review period, as described in the CSR 9.0.2.2 is extremely unlikely as the refrigerant solution containing sodium chromate is used in a sealed circuit. In addition, during the initial product lifetime, the substance reduces to the non-hazardous Cr (III) and adheres to the inner surface of the carbon steel pipes. The same mechanism takes place in the environment, so that, after a short period of time, the initial concentration of Cr (VI) is drastically reduced.

2.3.2 Geographical scope

The socio-economic analysis focuses on the EEA region. Sales and business information are currently based primarily on European geographical areas where gas boilers are dominating and heating demand is high. While most promising market opportunities lie in Europe, it is not unlikely that the product will be sold in future developments to further countries outside Europe.

Human health effects are only considered for the region next to the production facilities in Albacina. In accordance with the European Union Risk Assessment Report (2005) released chromium (VI) is expected to be reduced to non-hazardous chromium (III) in most situations in the environment. Therefore, in accordance with the EU RAR (2005) the assessment of the health impacts is conducted only for the local scale, the near area around the production site. The wider regional background is not assessed.

2.4 Substitution strategy

Ariston Thermo SpA is very aware of the health and environmental issues of sodium chromate.

At the same time, Ariston Thermo SpA, after extensive research on all possible alternatives, has come to the conclusion that currently no alternative exists to-date and that the only viable option for GAHP appliances is sodium chromate (with all possible precaution while minimising the concentrations).
Therefore, in the implementation phase of the GAHP technology in the heating market, Ariston Thermo SpA do want to rely on the proven capability of sodium chromate to properly act as an inhibitor, not to jeopardise the overall perception of reliability and safety of the GAHP technology in the market with an unproven inhibitor. Consistently with the above statements, Ariston Thermo SpA is also committed to invest in two directions:

- Monitoring research activity at university and research labs for new solutions and patents that could address the issue of protection of carbon steel in GAHP;

  - resulting from above-mentioned research activities, further testing on alternatives under industrial scale as well as long term in-service use will be performed.

- Testing programmes to progressively decrease the concentration of sodium chromate to the lowest possible level compatible with GAHP application;

Ariston Thermo SpA invests in R&D approximately Blank #1 of its total revenues; out of this, approximately Blank #2of R&D expenses are devoted to the GAHP program. An amount of ca. Blank #3is invested in the first version of the GAHP technology.

Detailed plans of the substitution strategy including timelines for the different steps are described within chapter 2.4.1.

2.4.1 Road-map Substitution

As indicated above, Ariston Thermo SpA invested already a lot in the development of the first GAHPs version. Ariston Thermo SpA is willing to expand their research and development efforts to further improve the GAHP technology and to expedite the replacement of sodium chromate.

Replacement of sodium chromate as corrosion inhibitor in the GAHP is a very challenging task due to the high requirements set by the operating environment:

- high temperature (approx. 200 °C),
- high pressure (approx. 20 bars),
- toxic substance (ammonia),
- sealed container (welded steel vessel),
- presence of corrosion and erosion phenomena (cavitation due to boiling of the refrigerant solution);
- geometry of vessels and welded joints which affect corrosion and erosion speed;
- corrosion of steel unacceptable during the lifetime of the appliance (it will cause an equipment fault)
- lifetime expectancy of decades (even slow corrosion could cause a fault);

All operating requirements will be described in more detail under chapter 3.1.4. The named operating aspects need to be considered during the validation process. Especially the long lifetime expectancy of more than 24 years is a critical aspect for the validation duration. Ariston Thermo SpA anticipates that based on the requirements a replacement process from research to market implementation will take up to 20years or even longer, which reflects also the review period.

Figure 2 Roadmap for substitution illustrates the different steps Ariston Thermo SpA will perform and the timelines within these steps.

Overall the evaluation of a possible replacement either for a drop in substance alternative or a technical alternative can be divided into 5 different steps:

- Monitoring/Research
- Identification
- Validation

- Product development
- Market implementation

Monitoring/Research:

Ariston Thermo SpA consults several patent search databases and tools on a frequent basis to monitor scientific literature and publications on steel corrosion inhibitors. Such search is not limited only to the HVAC sector but also by other industries facing similar challenges.

Furthermore, Ariston Thermo SpA starts an own research program for the identification of new inhibitors by engaging research institutions with specific know-how on corrosion processes. Currently the company is finalising a Strategic Agreement with the local university Blank #4 where the corrosion subject will be thoroughly and methodically investigated.

Identification:

As soon as a new possible alternative is detected an identification step will be started. The possible candidates for replacement are screened by comparing their chemical composition, properties and expected action principle. After a first examination possible candidates will investigated further to define suitable candidates to enter the validation step.

For pre-selection, alternatives will be tested in small scale testing under laboratory settings.

A testing under laboratory settings in a small scale cannot be considered as a meaningful testing method. The results can only be taken into account as an indication.

Nevertheless, such a pre-selection needs to be done to verify suitable candidates for the statistically meaningful validation which is only possible in a real appliance testing.

All in all, the identification including the small scale testing could take up to 3 or more years.

Validation:

Real appliance testing under ALT (Accelerated Life Test) or in HALT (High Accelerated Life Test) conditions is the only statistical meaningful validation method and therefore, an essential step to identify a suitable alternative. This testing cannot be replaced by any testing under laboratory scale or with any modelled software simulations. The current state of art of the corrosion phenomena does not allow any comparable results.

This validation step is by far the longest activity in the complete substitution road-map. It will take in total more than 5 years.

Even with prolonged operation of such samples under highest ALT or HALT conditions, which will include 24h/d in high temperature regions of more than 200°C and 4 times the working hours of a normal use (8000h/y compared to approx. 2000h/y), it is unlikely to draw conclusive statements for the whole lifetime of the appliance in less than 5 years.

Such testing will not only include high costs of the construction of the samples, but also the cost of operating such appliances for the entire duration of the accelerated tests. An order of magnitude of such validation test phase for a single candidate inhibitor will easily exceed 100,000€.

Within this analysis the performance of an inhibitor can be roughly assessed by the amount of produced incondensable gases. A full assessment is only possible by interrupting endurance testing, dissecting components and inspecting the inner part of vessels with metallurgy inspection technologies.

To perform such a validation step Ariston Thermo Innovative Technologies (R&D Center of Ariston Thermo for innovative/renewable technologies) is investing in creation an endurance test area where the above described validation tests will be performed.

Product development:

After the validation step, the final product suitable for the alternative and consumer needs need to be developed and designed. The way from a prototype to a final product ready for market implementation requires several steps which need to be developed or at least redesigned, like the production process including the production line and the training of the workers. The time from a prototype to a final product ready for market implementation can take another 5 years.

Market implementation:

The final step is the market implementation which is the final step for sodium chromate replacement. Due to the difficult market structure and the very high market entry barriers as described in chapter 3.2.1, which includes training of the retailers and installers, the product launch can take up to additional two years.

In total a period of around 20 years is expected from the detection of a possible alternative to the replacement of sodium chromate as corrosion inhibitor.

A similar timescale can be drawn for the development of a new technology e.g. an alternative thermodynamic cycle, an alternative coating for the vessel or an alternative material for the vessel. A development of a new technology would require a start from the scratch, which requires an even longer development phase as shown in Figure 2.

In parallel to the evaluation of possible alternatives, Ariston Thermo SpA will further focus on the concentration reduction of sodium chromate in the sealed circuit. This activity has already started with the aim to limit to the minimum possible the quantity of inhibitor used in GAHP technology.

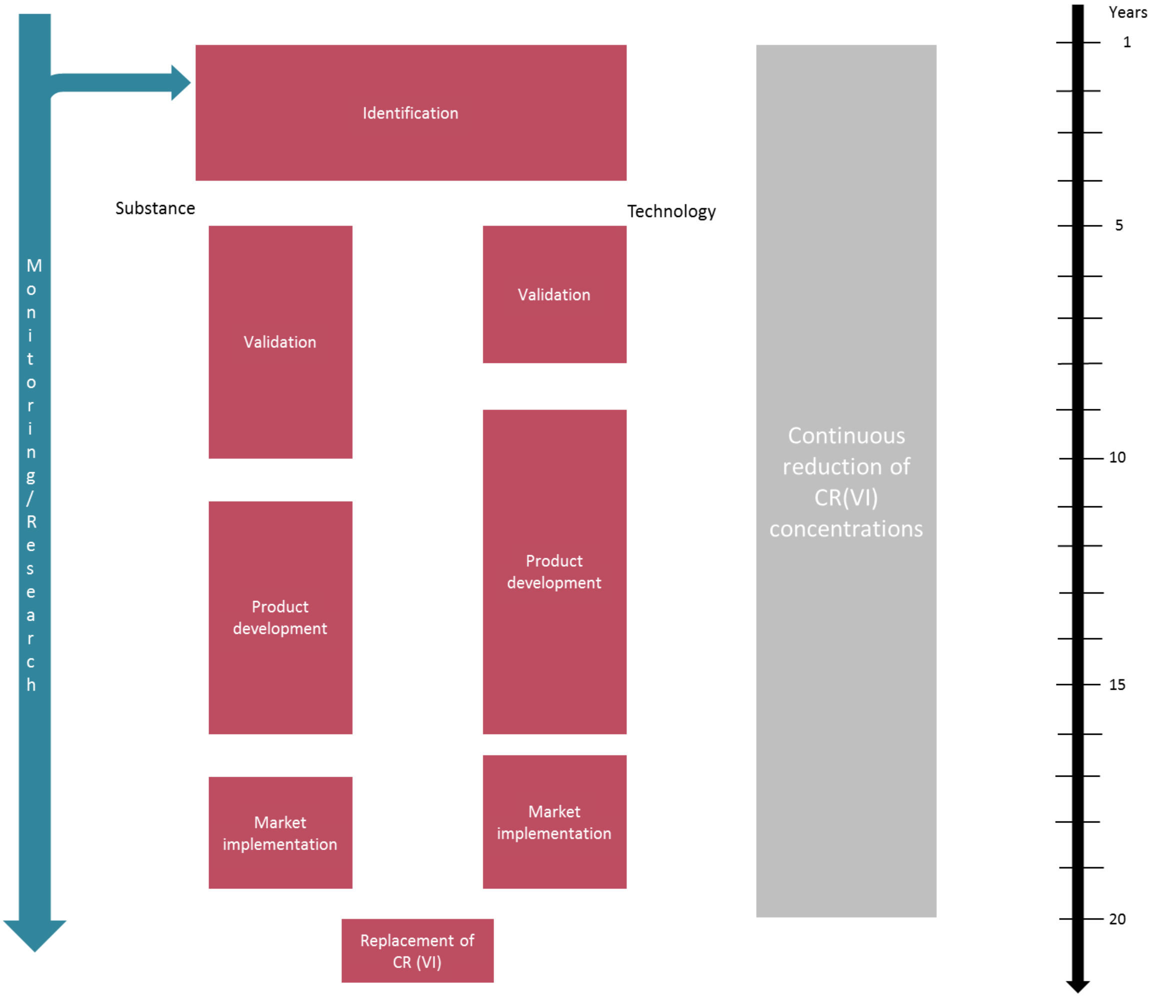

Figure 2 Roadmap for substitution

3 APPLIED FOR "USE" SCENARIO

3.1 Analysis of substance function

The following chapters will address the technology of the gas absorption heat pump, its benefits, the specific problem associated with corrosion, and consequently the functional requirements of a suitable corrosion inhibitor. In addition, the role, as well as the function of sodium chromate as an appropriate corrosion inhibitor, will be addressed.

3.1.1 Process of gas absorption heat pumps

"Heat pump" is the scientific name for devices that transfers heat from low temperature to high temperature level.

Regrigerator vs heat pumps

The most common application of heat pumps is the generation of cooling effect (refrigerators, chiller, fridges). A more recent application of a heat pump is efficient generation of heating for buildings (often called "heating heat pumps" or simply "heat pumps").

Indeed heat pumps use the same priciple as refrigerators or fridges, except that the useful effect of the thermodynamic cycle is considered as the "heat released at the condenser" instead of the "cooling at the evaporator".

In an "absorption refrigerator" (largely used for hotel minibars and caravans/yacht fridges) the heat is extracted ("useful effect") from inside the cabinet and dissipated on the back of the cabinet (as "waste").

In an "absorption heat pump" (GAHP) the outside air is (further) cooled down to extract heat that is elevated in temperature and transferred to the space heating.

Therefore "gas absorption refrigerators" and "gas absortpion heat pumps" use exactly the same thermodynamic principle.

Indeed the authorisation case of Ariston Thermo SpA reflects the same scientific case as the authorisation requested by Dometic GmbH (ID 0030-01). This company has been granted an authorisation for their use of sodium chromate in absorption refrigerators, which, thermodinamically speaking, are "gas absorption heat pumps" and that from the corrosion point of view have the same (or less) challenges.

The application of authorisation for Ariston Thermo SpA will focus on the absorption technology where refrigerant solution (water-ammonia) flows continuosly in a sealed circuit made by steel and subject to high temperatures and pressures.

Compression vs. absorption heat pumps

Essentially, the basic functions of compression heat pumps are (Figure 3):

1. the use of a renewable source of energy (air, water, ground) to heat the refrigerant during evaporation in the evaporator,
2. a system to elevate the pressure and temperature of such refrigerant (compressor),
3. a heat exchanger to release the heat by means of condensation of the refrigerant in the condenser and
4. an expansion valve to return the refrigerant to the conditions that allows evaporation.

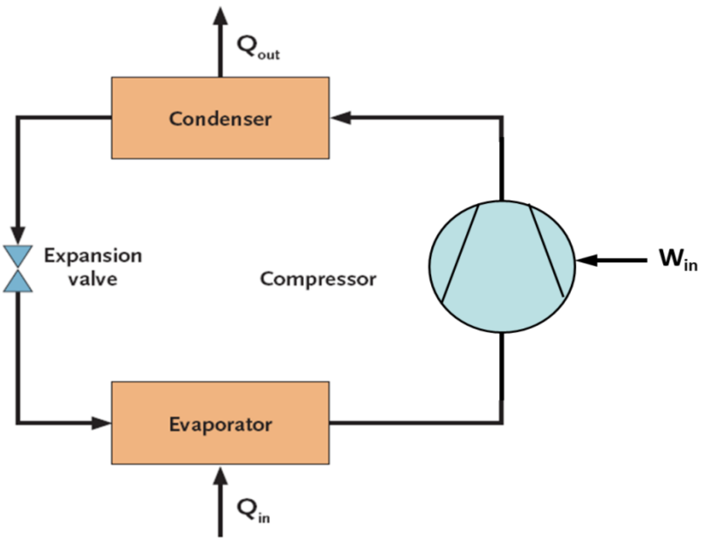

Figure 3 Mode of operation of compression heat pump

The main and essential difference of an “absorption heat pump” compared to a “compression heat pump” technology is that the compression of the refrigerant by means of an *electrically actuated mechanical compressor* is replaced by a *thermal compressor* driven by a natural gas burner (see Figure 4 below). This thermal compression is composed of a phase of absorption (releasing heat), and a phase of desoprtion driven by the gas burner. The refrigerant used for the absorption heat pump is a water-ammonia solution.

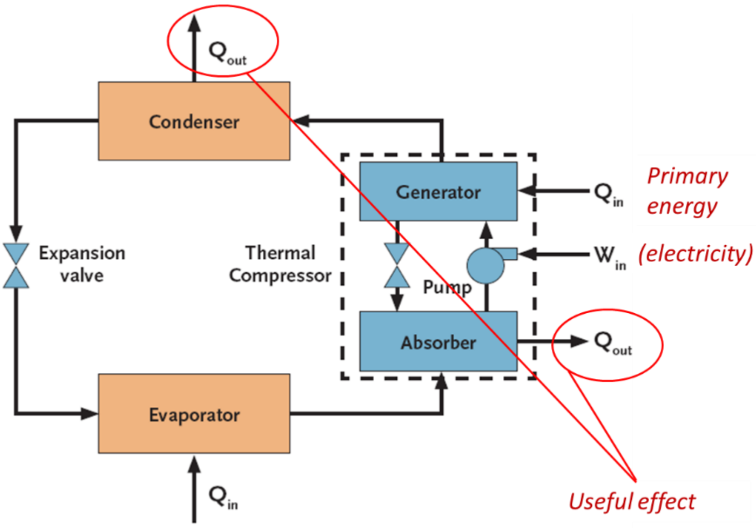

Figure 4 Mode of operation of a gas absorption heat pump GAHP

The process of the GAHP starts with the heating of the refrigerator solution in the generator by natural gas. The heating separates the gaseous refrigerant (NH_3) from the liquid sorbent (H_2O). The high concentrated gaseous ammonia at high pressure gets liquified under emission of heat at the condenser. Then the condensed refrigerant passes through an expansion valve to reduce the pressure. Due to the low pressure of the refrigerant, heat from the environment can be used at the air heat exchanger to evaporate the ammonia refrigerant again. In the gaseous form, the refrigerant flows into the absorber where it is absorbed by the low pressure sorbent (H_2O). This exothermal reaction releases again heat which is transferred to the heating system. The liquid solution is then carried by a solution pump which needs only a small energy input back into the burner where the circuit starts again (see Figure 5 below).

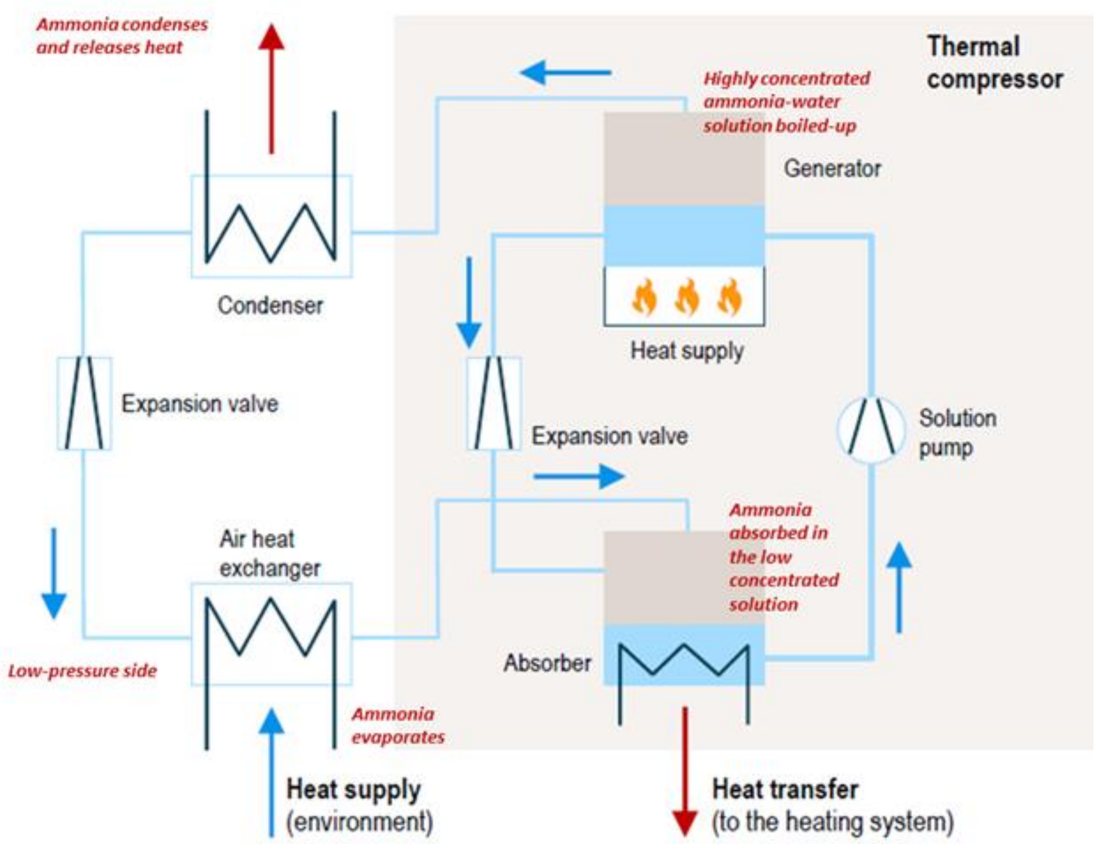

Figure 5 GAHP process

Using this thermal compressor technology creates two useful thermal effects: in the Absorber and in the Condenser.

This thermodynamic principle has some relevant and important implications:

- it uses renewable energy
- it uses primary energy (heat from combustion of natural gas) instead of final energy (electricity obtained in large part from conversion of a mix of fossil fuels)
- it is not subject to decay in performance, unlike mechanical compressors that loose efficiency at high delta-pressures resulting from high delta-temperatures (thermal lift)
- it avoids the noise associated with the presence of a mechanical compressor

As a consequence, the GAHP technology:

- belongs to the renewable energy technology according to the European Commission statement
- allows for cost effective heating offering substantial economic saving on gas bill

- enjoys a seasonal space heating efficiency on primary energy (on high temperature applications) in excess of 125% (measured on “radiator”, according to EN12309, expressed as GCV, and including auxiliary electrical consumption). For comparison condensing boiler technology will reach approx 95% and electrical compression HPs will reach similar performances.
- allows the development of very quiet heat pumps.

3.1.2 Benefits of the technology

The use of gas absorption heat pump is considered to solve the current questions which a standard condensing boiler system cannot do.

- Modern gas condensing boilers have an efficiency of around 95%: how to further improve?
- How to exploit better the chemical energy of a fuel to generate heat by adding an amount of renewable energy?

In addition to the potential to solve the critical problems of a condensing boiler, the GAHP technology shows several further benefits.

The primary energy gas as the energy source shows currently the lowest CO_2 emission of all fuels (burning oil, fuel oil, and LPG). The CO_2 emissions of gas (0.184kgCO2/kWh) are at the moment significantly lower compared to electricity based on information of the UK government as shown in Figure 6. A breakeven point regarding CO_2 emission is expected in 2025 for regular boilers, obviously depending on the development of renewable electricity production. The results of the UK government can be read across to the EU (Treasury 2018).

Assumptions about emissions factors for different fuels

		2013	Future trajectory – 2030 status
Natural Gas	$kgCO_2e/kWh$	0.1841	Constant - As 2013
Burning Oil	$kgCO_2e/kWh$	0.2456	Constant - As 2013
Fuel Oil	$kgCO_2e/kWh$	0.2688	Constant - As 2013
LPG	$kgCO_2e/kWh$	0.2145	Constant - As 2013

Source: Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal, Tables 1-20: supporting the toolkit and the guidance

ELECTRICITY	2013	2014	2015	2016	2017	2018	2019	2020	2021
Services $kgCO_2e/kWh$	0.508	0.483	0.437	0.346	0.313	0.295	0.272	0.233	0.220
Industrial $kgCO_2e/kWh$	0.498	0.474	0.429	0.339	0.307	0.289	0.266	0.229	0.216

ELECTRICITY	2022	2023	2024	2025	2026	2027	2028	2029	2030
Services $kgCO_2e/kWh$	0.231	0.202	0.198	0.181	0.159	0.168	0.149	0.128	0.110
Industrial $kgCO_2e/kWh$	0.227	0.198	0.195	0.177	0.156	0.165	0.146	0.126	0.108

Figure 6 Emission outputs of CO_2 per energy source. Green book supplementary guidance Tables 1-10

The gas absorption heat pump technology itself encompasses many benefits compared to the existing heating technologies besides the described advantages of natural gas use.

Compared to the best condensing boiler technology, the GAHP technology would result in savings of 40% primary energy and consequently, 40% savings in heating costs (see Table 1). Besides the savings on primary energy, GAHP technology would also result in 40% less emissions of CO_2 for space heating and domestic hot water (DHW) functions.
Space heating and DHW functions account for 40% of total energy demand in Europe (The European Heat Pump Association EEIG (EHPA) 2010).

Considering a generic example for a comparison of existing heating technologies (boiler) with GAHP technology, savings on heating costs for the end users can corresponds to approx. 700-800 €/year for an average European family as shown in Table 1 below.

Table 1 Heating and CO2 emission costs for boiler technology and GAHP technology (general example)

Building heating demand for detached/semidetached existing building	25,000	kWh/year	
Gas prices for household consumers (average European Area)	0.07	€/kWh	Eurostat (online data codes: nrg_pc_202)
Heating costs (Boiler technology)	~1,750*	€	* gas prices can vary between the European countries
Carbon content natural gas	0.1842	CO_2kg/kWh	Obtained from Figure 6
CO_2 production for detached/semidetached existing building	4,605	kg/unit/year	
Current market price of CO_2 certificates	20	€/tCO_2	European energy exchange AG
CO_2 Emission costs (boiler technology)	92	€	
Savings on primery energy, and savings on energy costs by GAHP technology	40	%	
Heating costs (GAHP technology)	~ 1050*	€	
Savings on heating costs GAHP compared to boiler technology	~ 700*	€	
CO_2 Emission costs (GAHP technology)	~ 55	€	

Although electrical heat pumps use higher amounts of renewable energy than the gas absorption heat pumps, the performance of both technologies is comparable in terms of energy use and CO_2 emission reduction, when the primary energy input is considered with the European Commission imposed Energy Conversion factor of 2.5. Indeed, due to the efficiency (40%) of the average European electric power generation, the renewable energy used by a EHP need to be offset by the primary energy used to generate the electricity that activate the EHP. Figure 7 shows that GAHP needs the same primary energy input as an electric heat pump to deliver a certain amount of heating energy due to the direct transformation of primary energy into thermal energy. For such a comparison, an annual performance factor (APF) of 3.3 for the electric heat pump and 1.3 for the absorption heat pump is assumed (The European Heat Pump Association EEIG (EHPA) 2010).

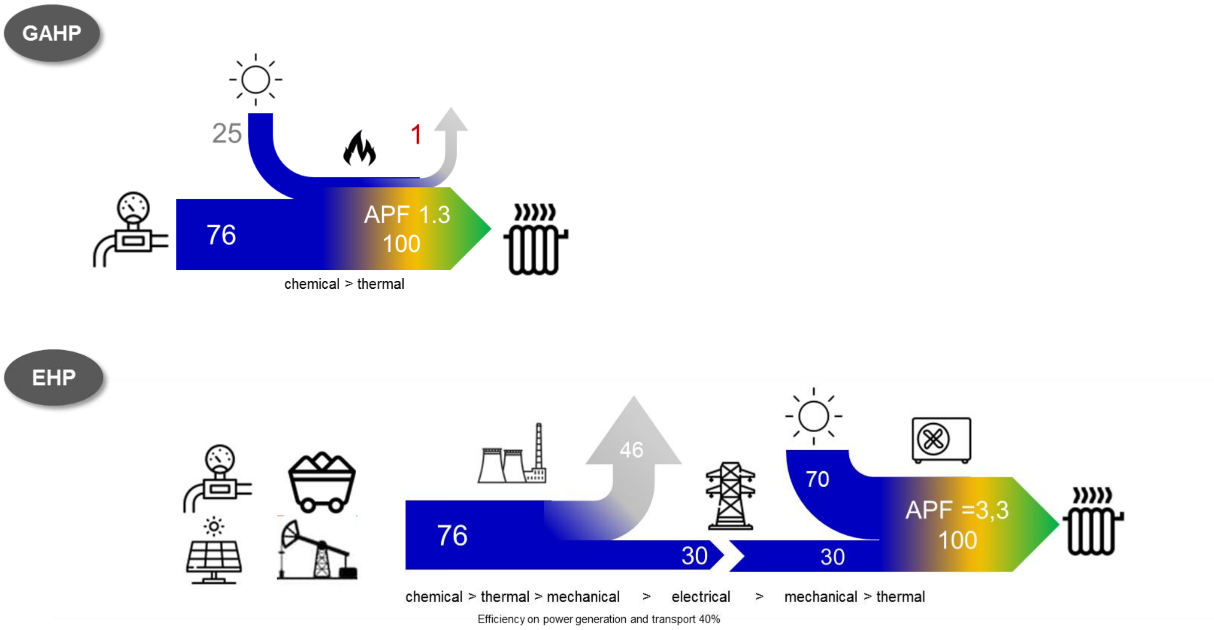

Figure 7 Heat output per energy input comparison according EHPA, 2010

Additionally, GAHP technology shows the lowest emission of PM10 (particulate) and NOx among all heating technologies according to European Commission JRC (2013).

Furthermore, a complete electrification of heating would need in most cases an update of the energy grid and the electrical infrastructure (generation, transmission and distribution) due to high seasonality demand according to British Department of Energy & Climate change (2014b). Implementing the GAHP technology in the EU heating market and using natural gas as the vehicle to introduce renewable energy, are considered two actions that could contribute in postponing or reducing significant investments (approx. 100 billion €) in electrical grid upgrade.

GAHP technology uses a water-ammonia as refrigerant solution. Such ammonia water refrigerant solution features with a Global Warming Potential GWP of zero and an Ozone Depletion Potential ODP of zero, the GAHP technology has no fluorinated gas (F-Gas) emissions and is therefore exempted from the F-Gas Directive that affects electrical heat pumps.

GAHP is currently the only heating option available introducing a substantial amount of renewable energy in existing buildings as the electrical heat pump efficiency severely deteriorates when it is installed on the radiator based system as it is the case for most existing buildings.

When installed, the GAHP offers an alternative of a cost-effectiveness renewable solution which complies with existing and future legislations and norms (Energy Performance of Buildings Directive (EPBD), Eco Design (ErP Directive), Renewable Energy Sources Directive (RES/RED). Also, due to the seasonal space heating efficiency >125% product based on GAHP technology meet the criteria for the EU Ecolabel and the Energy labeling A++ set by the European Commision (2013).

The energy-efficient performances of the GAHP technology have been recently demonstrated by the above mentioned European Research Consortium named HEAT4U as documented in the final report by the European Union (2015).

Therefore, the GAHP technology is of paramount importance for the entire European heating industry and not only for Ariston Thermo SpA.

3.1.3 Corrosion issue

The sorption process is based on the physical principle of "absorption of ammonia into water". The sealed circuit needs to be made of material compatible with ammonia and water. Currently the only commercially available material able to withstand the demanding functioning environment (temperature, pressure, erosion by cavitation and chemical reactions) is steel. The use of the ammonia water refrigerant solution raises two problems related to corrosion: on the one hand side stress corrosion cracking by ammonia and on the other hand side corrosion due to the presence of water as the water ammonia refrigerant solution is converted to the compounds ammonia and water (gaseous and liquid state) during the circular process. Welded carbon steel in pure ammonia can be subject of failure by stress corrosion cracking (SCC). Stress corrosion cracking can be triggered by air containment in ammonia (Teel 1980). The much more critical effect causing high corrosion is the high temperature of the refrigerant ammonia water solution and the change of its physical state. The latter are prerequisites to ensure the thermodynamic performance to the appliance which is able to fulfil product specifications with high pressure and temperatures up to 200 °C to deliver an output temperature of 70 °C to the radiators of the end-users.

The corrosion of steel (as described by equation 1) as well as thermal decomposition of ammonia (as described by equation 2) can form non-condensable gases in the refrigerant solution which could result in a reduction of efficiency or even in a complete breakdown of the GAHP (Harald Moser et al. 2013).

Possible gas formation reactions are

$$3Fe + 4H_2O \rightarrow Fe_3O_4 + 4H_2 \qquad (1)$$

$$2NH_3 \rightarrow N_2 + 3H_2 \qquad (2)$$

Because the working fluid recirculates in a substantially closed system within the absorption system apparatus, the non-condensable hydrogen accumulates in the system and hampers the condensation and absorption of ammonia from the vapour phase reducing the absorption and condensation capacity of the apparatus significantly.

During the corrosion of steel (as described by equation 1) carbon steel is transformed into iron oxide, which results in reduction of strength of the metal which further reduces the wall thickness of the equipment. The reduced thickness could lead to a complete breakdown of the system as soon as a situation in which the system cannot withstand the functional requirements as described under chapter 3.1.4 like an inner pressure of 26 bar. Such a performance breakdown can cause emissions of toxic ammonia.

Rust particles from the corrosion process may furthermore create sludge in the machine or even block the valves in the system.

Corrosion/erosion in GAHPs is a very slow process. Effects of corrosion can materialise after 5 to 10 years without precognition. Even though corrosion is a very slow process, it is the major problem regarding the functionality of the GAHP product. Current expected average service life of a boiler in the EU is currently 24 years, which imposes an equivalent duration of the corrosion prevention period. GAHPs are in principle low maintenance products, in addition the system is sealed and as a consequence the weakness of the material will not be recognised in advance.

To avoid corrosion, the refrigerant solution needs to run in a contained oxygen free system using a corrosion inhibitor

3.1.4 Functional requirements regarding GAHP and a reliable corrosion inhibitor

AristonThermo SpA product design requires the delivery of very high water temperatures (radiators up to ~70°C) even in case of very cold weather conditions during winter. The difference in temperatures between the sink (radiator) and the source side (outdoor air) of the thermodynamic cycle is named "thermal lift". In the case of space heating heat pumps, this thermal lift can easily reach 80 °C. To achieve such thermal lift levels while maintaining a good thermal efficiency, GAHP appliances use a water/ammonia thermodynamic cycle named GAX-GAHP, where the temperature inside the desorber can reach 200 °C.

Refrigerant units for fridges or in general for cooling units do reach a much lower thermal lift (usually 40 °C). In these operating conditions the desorber temperature can be limited to approximately 150°C to 160°C.

It needs to be pointed out that in parallel to the increase in desorbing temperature, also the desorbing pressure tends to increase. GAX-GAHP cycle might frequently be operated in excess of 20 bars, while absorption cooling cycles usually feature lower maximum pressures (10-15 bars).

For this reason, the corrosion inhibitor in a GAHP heating application is intrinsically facing a substantially more challenging environment compared to a cooling application.

Table 2 summarises all requirements for the corrosion inhibitor, which are needed to ensure that the benchmarks set by the product design requirements are fulfilled. Only if all conditions are fulfilled, the corrosion inhibitor can be seen as reliable and therefore compliant to the requirements of the application.

Table 2 Requirements for alternatives

Benchmark	Requirements
Corrosion resistance - Under anaerobe conditions - In high NH_3 concentrations - Protection in different aggregated state - Protection at high pH values	- Process takes place in sealed circuit under anaerobe conditions - Concentrations up to 40% NH_3 in water - In boiling conditions up to 100% NH_3 - Change of aggregated phases from liquid to gaseous and back to liquid - pH values >7
High operating temperature	- Process takes place in boiling conditions up to 200 °C
High operating pressure	- Pressure up to 26 bar
Long lifetime service	- Expected average service life of a boiler in EU is currently 24 years (Kemna et al. 2017)
	- No service or refilling requirements
Prevention of gas formation	- Prevention of H_2 gases - Prevention of building non-condensable gases
Market availability	- Commercially easily available
Industrial scale	- Usable under industrial scale
Hazardous substance profile	- Substance should not have analogue health concern (no SVHC)
Technical requirements (for GAHP)	- Efficiency with very high “thermal lift” up to 80°C (high temperature supply to radiators with low outside temperature in cold winter) - Use of renewable energy - Operating cost saving for end user

	- Impact on energy grid networks - Emissions (CO_2, PM, NO_x; VOCs)

3.1.4.1 Function of sodium chromate

Since development of water ammonia absorption cycle (refrigeration) in the early 1900, the issue of protecting the metallic surfaces has raised. Many efforts have been made over the last 50 years by all major manufacturers of absorption appliances (chillers), often in conjunction with external laboratories and universities to identify alternative substances for preventing corrosion in this category of product.

However, so far only chromium (VI) compounds (sodium chromate) have been indicated as proven and reliable.

The functionality of sodium chromate as anticorrosion agent under the above stated functional requirements is proved and tested. Based on the product characteristics and the consumer demands, one of the major aspects is the reliability of the function during the total lifetime of the system exceeding even the average of 24 years.

In basic media sodium chromate as corrosion inhibitor oxidises iron on the steel surface and forms a protective layer which contains iron oxide and chromium (III) oxide:

$$9\,Fe + 8\,Na_2CrO_4 + 8\,H_2O \rightarrow 3\,Fe_3O_4 + 4\,Cr_2O_3 + 16\,Na\,OH \qquad (3)$$

This passivating film builds a very effective protection of carbon steel against corrosive processes and possesses self-healing ability as shown in Figure 8. Where the barrier film is damaged new chromate is supplied from the solution to react with iron und rebuild the Cr (III) oxid/ironoxid film.

The corrosion inhibition for carbon steel by chromate is effective without the presence of oxygen, furthermore up to high temperature and pH ranges. This corrosion protection is proved stable and active over a long time. It has no adverse effect on the function of the ammonia absorption heat pump process.

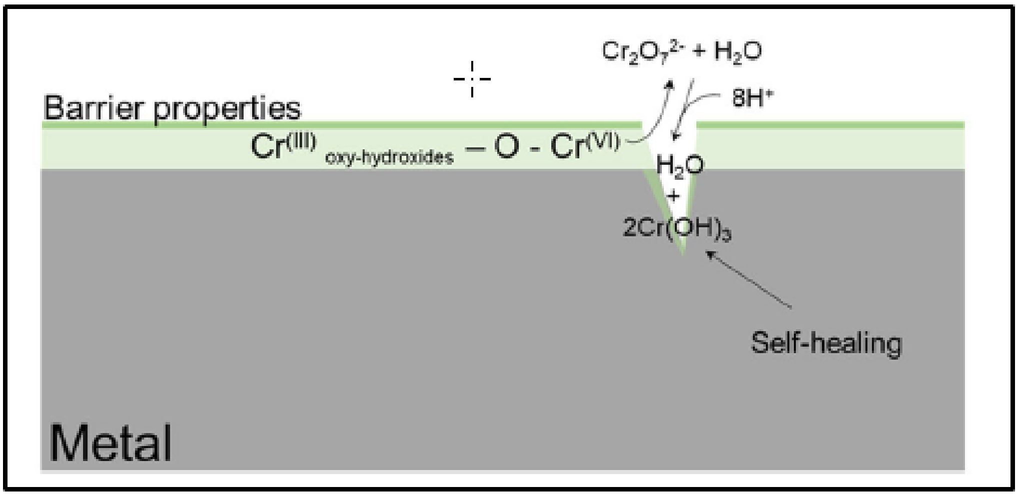

Figure 8 Passivation process of Chromium (VI) (Gharbi et al. 2018)

Possible alternatives and their functionality concerning the requirements given in Table 2 are assessed in chapter 4.3.1.

3.2 Market and business trends including the use of the substance

The heating market in Europe utilises annually around 6.9 Million units of heating supply with an estimated turnover of approximately 6.9 Billion €/year. This is excluding side businesses like planners and installers, which will increase the estimated turnover around the 15 Billion €/year level. The five major suppliers dominate the market for commercial and domestic boiler and other heating equipment. The companies Bosch Thermotechnology (Germany), Vaillant (Germany), Viessmann (Germany), BDR Thermea (the Netherlands) and Ariston Thermo SpA are holding a market share of over 60% of the European market for heating equipment (Ecoheatcool and Euroheat & Power 2006).

All major players in the heating industry invested in the sorption heating technology (either in the adsorption or absorption technology).

This can be seen as a clear indication that the market for the GAHP technology exists and all market parameters are ready for deployment of the technology. The key fundamental market driving aspects are in place: legislation and normative urge for more efficient heating products and the environmental sensitiveness of the end users is increasing the interest for solution that reduce carbon foot print for heating and it operating costs. Future development of energy costs, as well as specific incentives for the installation of GAHP products, will have a huge impact on the market business trends. The following subchapters will analyse all potential drivers of growth and potential market barriers in detail, which influence the represented business case.

Ariston Thermo SpA is progressing on product development and preparing the launch of the first residential GAHP products on the market.

However, it can be anticipated that, with a successful product deployment, all other major competitors will follow shortly after.

Not only the European companies are investing in this technology, but also the USA DoE (Department of Energy) is subsidising several research and development projects on GAHP product development. Already several US start-up companies are announcing prototypes based on water ammonia with the intention to enter the market. In addition to companies, universities are now focusing their research on residential GAHP.

Currently, the commercial market implementation of GAHPs has turned into a real race.

3.2.1 Market entry barriers

The heating market in the retrofit sector is an *oligopoly* market clearly dominated by a few significant players. The heating market itself cannot be seen as a standalone market. It is influenced by many participating markets, like the electricity, oil and gas market as well as boiler market.
The condensing boiler technology is currently the dominating technology in the retrofit market. The whole market structure builds high market entry barriers for new products.

The thermodynamic cycle of gas absorption is known since the early 1900, but the technical difficulties in the product and process development have postponed the product launch on the market until now. Only very few experts on a worldwide basis are available with competence on the thermodynamic cycle of gas absorption heat pumps. The product design needs to meet all criteria set by the end-user, such as low demand of space, low noise, high efficiency, low running costs, low service and maintenance costs and a long lifetime. Next to the technical specification, the manufacturing process is of critical importance to achieve the required performance, reliability and cost targets. Such expertise of the GAHP manufacturing process is even more scarse.

These technical challenges result in up-front technology investments of several millions of Euro. Even higher investments could be expected as no supply chain exists for the GAHP technology components. As of today, manufacturers need to design and manufacture all components internally. Today the GAHP manufacturing imposes a 100% vertical integration, which is very atypical for the heating sector. Typically, components for condensing boiler or electrical heat pumps are supplied by third parties and only assembled at the production site.

The heating market is known as a market with low economic dynamism and slow market adaptions due to the very long expected lifetime of a boiler. For the introduction of a new product, high upfront market investments and involved dissemination, communication of a new technology in an existing market is mandatory. Due to the market structure, the lack of awareness needs to be addressed not only for the end-users, but also for the installers and building developers to open a broader sales channel.

Another major barrier for the technology is the critical view of the end-user concerning innovations. Heating supply is something, which the end-user does not want to think about after installment. Therefore, new products need to be reliable and proven. Currently only sodium chromate fulfills the requirements for a long time reliable corrosion inhibitor. Immature technology will not break down the market barriers. Rather the contrary, it will build new barriers and slow down the market entry process. Product trust is essential in the heating market. Figure 9 summarises the main barriers.

Barrier	
	Limited supply chain for GHP – and lack of confidence from the industry as a whole to invest in developing it. Small number of players will proactively push to establish the supply chain – but may take time.
	Limited sales channels and routes to market create challenges for accessing the technology
	Lack of awareness of gas HP technology amongst end-users
	Lack of awareness of gas HP technology amongst installers
	Lack of awareness of GHP amongst building developers, and critically, specifiers - meaning gas HP are typically not even being considered as an option / alternative to gas boilers during the building design or specification stage.
	Upfront cost of technology

Figure 9 Overview on market barriers for Gas Heat Pumps (GHP or GAHP)

After the initial introduction phase, the described barriers will progressively disappear and the market is expected to grow substantially in a few year times. Creation of a sub-component European industry, involving several competitors could increase the speed of cost reduction that in turns will accelerate the adoption.

3.2.2 Drivers of market growth

The development of gas absorption heat pumps is based on several drivers of growth which makes the effort and investment in this technology justifiable, despite the above mentioned barriers.

The need to find ways to decarbonise the on-gas grid retrofit sector is, on the one hand, one of the major challenges for the government and industry, especially for countries in which heating with fossil energy sources is dominating and, on the other hand, one of the major drivers of growth. Gas absorption heat pump products could be a strong option in this sector, especially because they are suitable for the “retrofit” market.

Gas utilities perceive the strategic value of transforming “natural gas” from a “fossil fuel” into a “renewable energy vector”. This overall strategy drives their involvement in support of GAHP technology. Indeed, they have already shown a clear interest in gas heat pumps for residential application through involvement in R&D and trails. This strong support across Europe is another driver of growth. In addition, such involvement can will be instrumental to address the lack of awareness.

This stepwise increase of awareness for the product needs to be transferred to customers and the government. The most significant barrier for future growth will be the lack of understanding of the technology potential and of the fact that gas absorption heat pumps are the most cost effective “renewable” way of heating existing buildings. Recognition and development of methodologies for the inclusion of gas heat pumps in, e.g., thermal regulations incentive schemes will be crucial for unlocking the potential market for gas heat pumps. The relevant European Regulation “Energy related Product - Lot 1” (also known as “*Ecoboiler*” (European Commission JRC, 2013)) already includes provisions for GAHP products. In several European countries, the GAHP products are already eligible for substantial incentives (tax credits or subsidies for end users).

With a growing market potential, further boiler companies will enter into the market. With products emerging in the next years and with the reach of attractive price points, more marketing effort will be put in place by these companies to acquire market share in this new growth opportunity. This competition will result in lower retail prices and will make the product even more attractive for the end-user. Reaching the right price-point together with the efficiency will boost the attractiveness to replace the existing boiler technology with a GAHP.

Another driver of growth next to the market competition could be the gas and electricity prices and their expected trajectories. The purchase decision by the end-user is indeed not only determined by the purchase costs, but also the operating costs. Running costs and possible payback time are as crucial as purchasing costs. In most European countries, the heating cost for an end user of a retrofit application does not decrease by means of adoption of an electrical heat pump. This fact is severely affecting the growth rate of renewable heating in this dominant market segment. In absence of a cost effective and renewable solution for the retrofit market, this market will be forced to remain dominated by non-renewable solutions.

The following diagram illustrates the effect on running cost of the energy price ratio ($kWh_{electrical}/kWh_{gas}$).

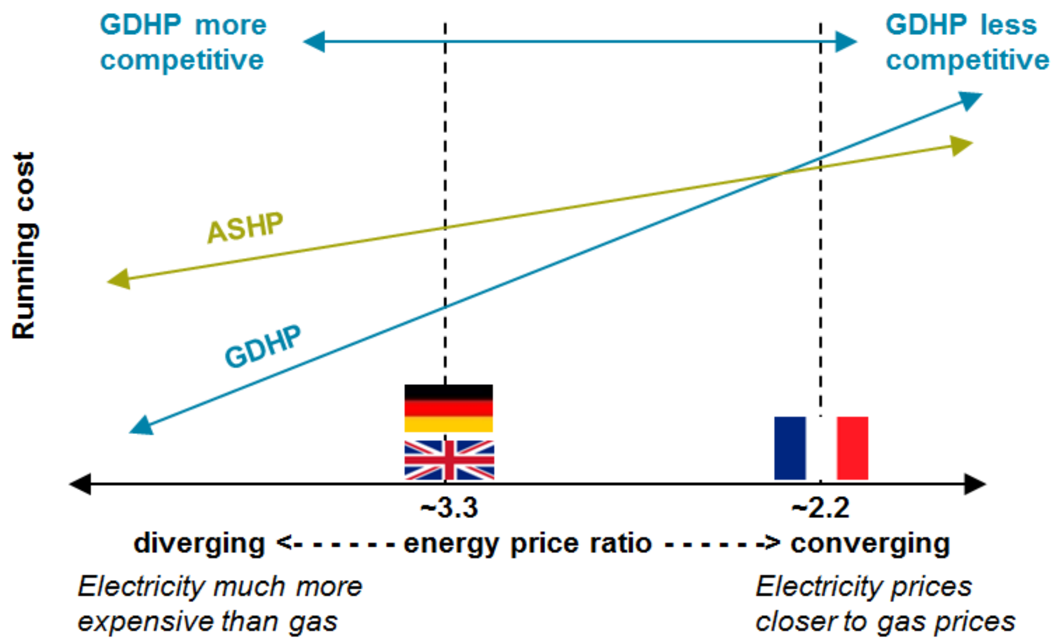

Figure 10 Competitiveness GAHP (or GDHP: Gas Driven Heat Pump) against EHP (ASHP: Air Source electrical Heat Pump) according energy price ration (British Department of Energy & Climate change with assistance of Delta-ee, 2014b)

Over the next decades the expected energy transition will continue to increase this ratio based on a faster rise in electricity prices than in gas prices.

With the drivers mentioned above (growth and the suitability of the product for new buildings and the retrofit sector), the GAHP market share is expected to growth substantially over the next few years to a significant percentage of existing boiler business. It is in many aspects considered as “the boiler replacement” technology. Different analyses of possible market penetration of the technology have been elaborated in the past years (even on behalf of local government and European Commission). According to Delta Energy & Environment (2012) traditionally heating appliance sales fall by 130,000 units per year by 2025 what equals a reduction of 22%. A mix of low carbon technologies, including GAHPs, are expected to close this gap. Gas heat pumps will be the key growth market with a “double-digit” growth rate. In 2025, the market share is expected to be ~ 15% for the moderate thermal demand properties (22 MWh/yr.). According to these studies, a direct displacing of boilers is expected to start in the early 20ies with the commercial launch of first products. Focusing on existing homes with moderate thermal demand, most renewable technologies have long payback periods. Only the gas heat pump technology achieves short payback times.

Comparing this trend of the market for EHP with the potential of the GAHP market, a similar scenario could be estimated or even a higher growth as the GAHP technology will not only focus on the new building segment (where EHPs are primarily sold), but will target the much larger existing/retrofit market.

3.2.3 Business case

Based on the information described above in chapter 3.1.2, Ariston Thermo SpA sees a great potential for the implementation of GAHP into the market. Based on own market researches, Ariston Thermo SpA estimates for the [redacted] Blank #5 [redacted] more than Blank #6 Million suitable households with a high thermal demand of more than Blank #7 [redacted].

Blank #8

Figure 11 Suitable households per country

Based on this potential, a business case was created. Sales are planned to start after authorization release expected in 2020. The estimation on sales and revenues are established for the review period of 20 years until 2039. It is very hard to estimate sales and revenues for the GAHP, as there are many different external factors like building norms and legislation, energy costs technology awareness and price competitiveness as well as the number of competitors in GAHP technology and further drivers of growth and market barriers as described in the chapters 3.2.1. Due to the high level of uncertainties, a meaningful business case can be only established for the first 5 years after product launch. Within the first five years, sales are estimated to be around Blank #9 with profit of around Blank #10 Profitability of GAHP product line is expected to be not lower than #11 of the turnover.

Table 3 indicates a business model on best knowledge with a growth rate not higher than #12 till the production maximum is reached. The production limit in the Albacina plant of #13 units/year is reached in year 2031 resulting in a yearly profit of Blank #14. For the following years till 2039 the maximal production utilisation is considered.

The authorisation is requested for a total amount of substance not higher than 1.4t/y of Cr(VI) over the 20 year review period.

Table 3 Expected sales GAHP 2020-2039

Blank #15

For the production of new GAHP products, a new manufacturing site dedicated to renewable energy technologies Blank #16 in Albacina is built. An existing manufacturing site was specifically purchased and will be rebuilt for the needs of the renewable energy technologies. The GAHP production line will initially take only a portion of the complete manufacturing site. Nevertheless, the investment costs of the program before the product launch exceed #17 Million € (total CAPEX). Additionally, the R&D costs directly before product launch cumulated to #18 Million €. Additional investments are planned in both CAPEX and R&D costs for following the market demand of the product. In addition, specific R&D costs are planned for the search of alternatives and the product improvement. These costs are expected to exceed Blank #19 €/year. The direct material costs for the use of sodium chromate based on current market prices will not exceed 0.5% of total direct costs.

3.2.4 Annual tonnage

The tonnage band for this application will be <10 tonnes per year. Should manufacturing annual volumes reach maximum production capacity during the review period, the amount of sodium chromate will equal to a maximum of 4,360kg/year (equivalent to 1,400 kg of Cr(VI)).

Although the amount of sodium chromate is expected to rise within the review period as result of the product ramp up, the contribution of its use to the total amount used of Cr (VI) in the EU is absolutely negligible. As Ariston Thermo SpA stated in chapter 2.4 substitution strategy the primary goal in the first step is to reduce further the amount of sodium chromate used in the GAHP units.

For the chemical safety report, a yearly amount of 1,400 kg Cr (VI) (equivalent to 4,360 kg Sodium chromate) was taken into account for the indirect exposure for the public via the environment.

3.3 Remaining risk of the “applied for use” scenario

The Table 4 and Table 5 present the outcome of the exposure assessment for the use of sodium chromate in the new production line.

For the worker contributing scenario 1 “Delivery and storage of the barrels containing the aqueous sodium chromate solution” exposure is unlikely. Consequently, it will not be considered any further within the SEA.

Table 4 Remaining risk for worker

Excess lifetime risk (ELR) worker					
	Exposure concentration, Inhalation, local, site-of-contact- long-term µg/m³	Oral via non-respirable fraction: Local, site-of-contact tumors, long-term µg/kg bw/day	Working days per year	ELR (inhalation) per CS	ELR (oral) per CS
Worker CS2	9.50E-04	1.36E-04	260	3.80E-06	2.71E-08
Worker CS3	8.20E-06	1.17E-06	260	3.28E-08	2.34E-10
Worker CS4	5.00E-08	7.14E-09	4	3.08E-12	2.20E-14
Worker CS5 a+b	4.60E-01	6.57E-02	5	3.54E-05	2.53E-07

Table 5 Remaining risk for the general population

Excess lifetime risk (ELR) general population		
inhalation	Exposure concentration [µg/m³]	ELR
local	1.07E-07	3.10E-09
oral	Exposure concentration [μg/kg bw/day]	ELR
local	4.67E-08	3.74E-11

Based on its chemical properties, Chromium (VI) will be reduced very fast to the non-hazardous Chromium (III). Therefore, the remaining risk for the general population is only assessed for the local scale (near area to the production site). Exposure concentrations are therefore taken from the industrial scenario under alkaline conditions.

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

3.4.1 Number of people exposed

Three operators only, one maintenance technician and two production line operator, per day will be able to cope with the planned workload. At least three maintenance technicians and five production line operators will be trained to perform the different tasks. In total a maximum of 8 workers could get in direct contact with sodium chromate.

Released chromium (VI) is expected to be reduced to non-hazardous chromium (III) in most situations in the environment. Therefore, the assessment of the human health impacts is conducted only for the local impact, the near area around the production site. The wider regional background is not assessed in accordance with European Union Risk Assessment Report (2005).

Around 100 to 1000 (at a later stage) employees will be working at the new manufacturing plant for renewable energy products and less than 1000 inhabitants are living in the near surrounding of the manufacturing plant, which could be exposed indirectly via drift. Also, the valley location of Albacina surrounded by mountains up to 1000 meter altitude supports the fact that exposure to a wider region is unlikely. Therefore, the default assumptions of 10,000 inhabitants in the near area to the point source are considered as conservative approach for the exposure to the general population.

3.5 Monetised damage of human health and environmental impacts

The following sections analyses and quantifies the impact of a continued use of sodium chromate as anticorrosion agent for gas absorption heat pumps. The quantification of the impacts allows in a further step the evaluation of the risk and benefits for the continued use. The assessment has been conducted in accordance with the “Guidance on the preparation of socio-economic analysis as part of an application for authorisation” (European Chemicals Agency, 2011).

As sodium chromate is considered a non-threshold CMR substance, a monetisation of the damage of human health regarding carcinogenic risk becomes mandatory. Toxicity to fertility and reproduction is not addressed any further in the SEA as the risk can be considered as adequately controlled (RCR<0.01) based on the outcome of the risk assessment presented in the CSR.

In accordance with the agreed carcinogenicity dose-response analysis for Cr(VI) containing substances in the RAC-27 meeting dated 4th December 2013 (RAC/27/2013/06 Rev.1) the assessment of damage of human health of workers is limited to inhalation (lung cancer). Dermal exposure to Cr(VI) presents no cancer risk to humans. For the general population the oral exposure of sodium chromate via the food chain (man via environment oral) is also considered. This leads to an additional risk of intestinal cancer.

Ariston Thermo SpA is aware of the reference values as stated in Table 6 below, agreed by the RAC-27 meeting based on the results of a study endorsed by ECHA. Therefore, these values are taken forward for the risk assessment and for the assessment of the excess lifetime risk (ELR) for the assessment of the human health impacts.

Table 6 Reference values human health impacts

	TWA Cr(VI) exposure concentration (1 µg/m^3)
Excess lung cancer risk in EU workers	4×10^{-3}
Excess lung cancer risk in the general population	2.9×10^{-2}
Excess intestinal cancer risk in EU workers	2.0×10^{-4}
Excess intestinal cancer risk in EU workers	8×10^{-4}

Background cumulative lifetime risk of dying from lung cancer in the age of 0 to 74 in EU males is 48/1000 (Globocan 2008)

Background cumulative lifetime risk of dying from intestine cancer in the age of 0 to 74 in Germany is 9/1000 in females and 16/1000 in males (IARC 2008)

The assessment in the CSR is based on a worst-case approach, which will lead to an overestimation of human health impacts. The results of the exposure and subsequent risk assessment are derived using a modelled approach as the production plant is at the point of the application still in the development phase. During the set-up of a new production line it is ensured that the highest safety standards will be applied. Therefore, it is likely that the modelled results overestimate the human health impacts. Considering the highest production volumes for the complete review period will also lead to an overestimation of the risk for the general population. Nevertheless, as there are high uncertainties linked to the development of the new production line and the training of new workers, Ariston Thermo SpA considers this worst-case approach as essential to underline the impacts of a continued use.

3.5.1 Monetarisation of cancer risk – Willingness to Pay (WTP)

The human health impact is based on the prediction of the total health damage based on the outcome of the risk assessment. To transfer this outcome into a quantifiable monetary value two methodological approaches can be used. One possibility is the assessment based on disability or quality adjusted life years (DALY or QALY). This approach is within this SEA not followed any further. The second approach, i.e. willingness to pay (WTP), is taken into account for the assessment of the health impacts of sodium chromate in the case of Ariston Thermo SpA. This method estimates the willingness to pay of people for reducing the risk of dying or avoiding illness. Such values have been estimated in the recent years at EU level and other parts of the world, including a critical review of the ECHA study from Anna Alberini and Milan Ščasný (2014) on the WTP of 2014 by the European Chemicals Agency (2016). These values have been obtained for the monetarisation of the cancer risk.

For the following assessment the original values from the Anna Alberini and Milan Ščasný (2014) study (5,000,000 €) are taken into account as high-bound values and the values based on the robustness check performed by European Chemicals Agency (2016) are considered as lower bound (3,500,000 €) for the value of statistical life for cancer (VSL). The derived value of morbidity due to cancer (VCM) (410,000 €) is considered for the lower bound as well as for the high bound.

Since the WTP has been derived in 2014, an adjustment needs to be performed to the year of granting the authorisation to make the costs and benefits comparable within this SEA. Therefore, the prices for the health risk are adjusted by a price adjuster to the year 2020. In order to adjust the prices, the GDP deflator of the EU-28 issued by the statistical office of the European Union (Eurostat) is used.

Starting point of this price index was 2010 (100). The last complete annual data is 2017 with an arithmetic deflator value of 108.128 (Q1: 107.739; Q2: 108.239; Q3: 108.000; Q4: 108.512). This GDP is equivalent to an annual growth rate of 1.011 as shown in Table 7.

Table 7 Annual growth factor for WTP

Annual growth factor	
Annual growth index (2017 average)	108.128
Reference value (2010)	100
Average annual growth factor (2010-2017)	1.011

The average annual growth factor is used to extrapolate the values from 2014 up to the assessment year 2020. The adjusted values by the GDP deflator are presented in Table 8 below.

Table 8 Willingness to Pay

	Value of statistical life for cancer (VSL)		Value of morbidity due to cancer (VCM)	Total VSL + VCM	
	low bound	high bound		low bound	high bound
2014 WTP values (ECHA 2016) based on Alberini and Ščasný (2014) (€)	3,500,000	5,000,000	410,000	3,910,000	5,410,000

Adjusted reference values to 2020 (€)	3,742,452	5,346,359	438,401	4,180,853	5,784,761
Growth rate WTP	$1.011^{(2020\text{-}2014)}$				

In line with the ECHA review report (2016) additional information need to be taken into account to derive a value for one cancer case.

Following assumptions are taken into account in this SEA to derive the total costs of one cancer case.

- Latency period for developing lung cancer among workers is assumed to be 10 years according to Brown et al. (2012). For small intestine cancer the latency period is regarded to be 26 years (Nadler and Zurbenko 2014)
- Additionally, not all cancers are ending fatal. Based on information provided by the International Agency for Research on Cancer (IARC), the risk to die from lung cancer (both sexes) is 86% and for small intestine (colon) the risk is 44%.
- The value of future health impacts underlies a discount rate. The ECHA SEA guidance (2011) recommends a social discount rate of 4%. However, it can be considered that individuals increase their willingness to pay for health and safety in correlation to their own living standards. Consequently, a lower discount rate can be applied. For the following assessment, discount rates of 2% and 4% are chosen for the monetisation of the health impacts.

Taking these additional assumptions into consideration the value for one cancer case could be derived using the following equation:

$$Value\ of\ cancer\ case$$

$$= Discount\ factor\ x\ (fatality\ probability\ x\ VSL + value\ of\ cancer\ morbidity)$$

One lung cancer case can be monetised in this SEA for sodium chromate with the values stated in the Table 9 and Table 10 below.

Table 9 Value of lung cancer case

Lung cancer	Higher bound		Lower bound	
Value of cancer case	3,402,324	4,131,496	2,470,477	2,999,940
Discount rate	4%	2%	4%	2%
Latency period (Brown et. al. 2012)	10			
Fatality probability (based on cancer factsheets south Europe) http://globocan.iarc.fr/Pages/fact_sheets_cancer.aspx	86%			

Small intestinal cancer cases can be monetised with the following values.

Table 10 Value of small intestinal cancer case

small intestinal cancer	Higher bound		Lower bound	
Value of cancer case	1,006,611	1,667,724	752,066	1,246,001
Discount rate	4%	2%	4%	2%
Latency period (Nadler & Zurbenko, 2014)	26			
Fatality probability (based on cancer factsheets south Europe) http://globocan.iarc.fr/Pages/fact_sheets_cancer.aspx	44%			

3.5.2 Excess lifetime risk (ELR)

Excess lifetime risk expresses the additional risk of cancer due to exposure to a carcinogenic substance over the lifetime of an individual.

To assess the impact of exposure by the continued use of sodium chromate in relation to the monetised cancer cases it is common practice to present the final conclusion in terms of excess lifetime cancer risk.

The ELR can be calculated by the dose-response values given in Table 6 and the exposure concentrations calculated in the CSR.

$$Excess\ lifetime\ risk = dose - response\ \left[\frac{\mu g\ Cr\ (VI)}{m^3}\right]\ x\ concentration\ \left[\frac{\mu g\ Cr\ (VI)}{m^3}\right]$$

The values of the dose response relationship as agreed by RAC-27 refer to working lifetime exposure (40 years) and continuous working daily exposure of 8 hours on 260 working days, corresponding to a full-time working equivalent (FTE). For the general population a lifetime exposure of 70 years is considered by the dose-response relationship. As Cr(VI) metabolises very fast in the environment to the non-hazardous Cr(III), the excess lifetime risk will immediately stop with the end of the review period. Therefore, the equation for the excess lifetime risk can be adapted for the workers by the following time factors:

Lifetime exposure:

$$\frac{Review\ period\ [years]}{Lifetime\ exposure\ [40\ years]}$$

As not all processes are taking place every day an additional time factor on the working days could be applied in some cases.

The standard working days for Italy are less than 260 days/year. As extra shifts could not be excluded, a working day adaptation will be only performed for infrequent processes as defined in the CSR.

Working days:

$$\frac{Working\ days\ per\ year\ [d]}{Annual\ working\ time[260\ d]}$$

For the general population a time adaptation in the lifetime exposure needs to be considered as well.

Lifetime exposure:

$$\frac{Review\ period\ [years]}{Lifetime\ exposure\ [70\ years]}$$

3.5.2.1 Worker

With the timely adaptions as described in chapter 3.5.2 the following equation for every worker contributing scenario can be taken into account for the calculation of the ELR.

$$ELR\ (\text{local worker; inhalation}) = \frac{Review\ period}{40}\ x\ \frac{Working\ days\ per\ year}{260d}\ x\ 4E^{-03}\ per\ \frac{\mu g\ Cr\ (VI)}{m^3}\ \text{x concentration}\ \left[\frac{\mu g\ Cr\ (VI)}{m^3}\right]$$

$$ELR\ (\text{local worker; oral}) = \frac{Review\ period}{40}\ x\ \frac{Working\ days\ per\ year}{260d}\ x\ 2E^{-04}\ per\ \frac{\mu g\ Cr\ (VI)}{m^3}\ \text{x concentration}\ \left[\frac{\mu g\ Cr\ (VI)}{m^3}\right]$$

The final ELR values for the monetisation of risk are presented in Table 11.

Within Table 11 the numbers of potential exposed workers are considered, too.

Table 11 Excess Lifetime Risk workers

	Total ELR under consideration of the single contributing activities and involved workers can be extracted from the table below. Excess lifetime risk (ELR) worker for review period (20 years)							
	Exposure concentration Inhalation: µg/m^3	Exposure concentration oral via non-respirable fraction: µg/kg bw/day	Working days per year	ELR (inhalation) per CS	ELR (oral) per CS	Number of workers	Total ELR per CS (lung cancer)	Total ELR per CS (intestinal cancer)
Worker CS2	9.50E-04	1.36E-04	260	1.90E-06	1.36E-08	3	5.70E-06	4.07E-08
Worker CS3	8.20E-06	1.17E-06	260	1.64E-08	1.17E-10	5	8.20E-08	5.86E-10
Worker CS4	5.00E-08	7.14E-09	4	1.54E-12	1.10E-14	5	7.69E-12	5.49E-14
Worker CS5 a +b	4.60E-01	6.57E-02	5	1.77E-05	1.26E-07	3	5.31E-05	3.79E-07
						=Total of 8 workers		

3.5.2.2 General population

With the timely adaptions as described in chapter 3.5.2 the following equation for the general population can be taken into account for the calculation of the ELR.

$ELR\ (local, general\ population, inhalation)$

$$= \frac{review\ period}{70}\ x\ 2.9E^{-02}\ per\ \frac{\mu g\ Cr\ (VI)}{m^3}\ \text{x concentration}\ \left[\frac{\mu g\ Cr\ (VI)}{m^3}\right]$$

$ELR\ (local, general\ population, oral$

$$= \frac{review\ period}{70}\ x\ 2.9E^{-02}\ per\ \frac{\mu g\ Cr\ (VI)}{m^3}\ \text{x concentration}\ \left[\frac{\mu g\ Cr\ (VI)}{m^3}\right]$$

In accordance with European Union Risk Assessment Report (2005) released chromium (VI) is expected to be reduced to non-hazardous chromium (III) in most situations in the environment. Therefore, the assessment of the health impacts is conducted only for the local impact, near area around the production site. The wider regional background is not assessed. Within the new production site planned in Albacina 100 employees are planned to work. The population in the near the production site is less than 1,000 persons. Therefore, it is considered as a reasonable approach to take the default value 10,000 indirectly exposed people. This value is taken into account for the further calculation of the ELR for the general population.

The results of the total ELR for general population considering all mentioned aspects above are shown in Table 12 below.

Table 12 Excess lifetime risk for general population

Excess lifetime risk (ELR) general population for review period (20 years)				
inhalation	Exposure concentration [µg/m^3]	ELR	Number of potentially exposed people	**total ELR Man via environment**
local	1.07E-07	8.87E-10	10,000	2.84E-05
oral	Exposure concentration [µg/kg bw/day]	ELR	Number of potentially exposed people	**total ELR Man via environment**
local	4.67E-08	1.07E-11	10,000	1.07E-07

3.5.3 Monetisation of health impacts for continued use

The Table 13, Table 14 and Table 15 describe the costs of the remaining risk based on the outcome presented above for workers and the general population in a monetised value.

Table 13 Cancer costs worker

Cancer costs worker (€) (20 years review period)	Discount rate			
ELR x value of cancer case	4%		2%	
	Lower bound	Higher bound	Lower bound	Higher bound
lung cancer	145.4096470	200.2571455	176.5732439	243.1754323
small intestinal cancer	0.8426881	1.1279057	1.3961409	1.8686809
total	146.25	201.39	177.97	245.04

Table 14 Cancer costs general population

Cancer costs of general population (€) (20 years review period)	Discount rate			
ELR x value of cancer case	4%		2%	
	Lower bound	Higher bound	Lower bound	Higher bound
lung cancer	70	97	85	117
small intestinal cancer	0.080278	0.10745	0.13300	0.17802
total	70.17	96.63	85.24	117.39

Table 15 Total cancer costs for continued use

	4%		2%	
Overall	Lower bound	Higher bound	Lower bound	Higher bound
Total costs (worker + general population (€)	216	298	263	362

4 SELECTION OF THE “NON-USE” SCENARIO

4.1 Efforts made to identify alternatives

4.1.1 Research and development

Research:

Ariston Thermo SpA is a manufacturer of HVAC appliances and acts as downstream user of sodium chromate. Ariston Thermo SpA has a deep knowledge on heating and cooling appliances, but no direct knowledge on the chemical corrosion process. The absorption business itself is a complete new branch for Ariston Thermo SpA. Given this an intensive research and testing of alternatives has not been possible for Ariston Thermo SpA so far.

In fact, Ariston Thermo SpA has a research and development department, but this department focuses currently on the development of this new product category. Ariston Thermo SpA itself has not the capacity and knowledge to do researches on the substance basis now. In order to acquire the prior status-of-the-art on inhibitors and to search for alternatives, AristonThermo engaged one of the most prominent scientific consultant Blank #20 in the specific domain.

Consequently, research on alternatives is limited to literature, the input from consultancy and already identified possible alternatives. Therefore, Ariston Thermo SpA has to rely on literature and on authorisation data for very similar use scenarios of other applicants in e.g. ammonia absorption cooling systems.

Following other applicants, who have submitted already an application for authorisation for similar uses (for further details see Table 16). All the uses refer to the same specific application of sodium chromate as inhibitor of corrosion for carbon steel systems using water-ammonia absorption cycles (either in “cooling” or in “heat pump” mode).

Table 16 Information on other applicants applying for authorisation on a similar use

Authorisation ID	Company name	Use name	Status
0030-01	Dometic GmbH	The use of sodium chromate as an	Commission decided

		anticorrosion agent of the carbon steel cooling system in absorption refrigerators up to 0.75% by weight (Cr6+) in the cooling solution	
0074-01	TOTAL Raffinerie Mitteldeutschland GmbH	Use of sodium dichromate as a corrosion inhibitor in an ammonia absorption deep cooling system of a methanol synthesis plant.	Commission decided
0075-01	• Jacobs Douwe Egberts DE GmbH • Dr. Otto Suwelack Nachf. GmbH & Co. KG • Européenne de Lyophilisation S.A.	Use of sodium dichromate as a corrosion inhibitor in ammonia absorption deep cooling systems as applied in the industrial production of freeze dried products such as coffee, herbs, spices and comparable products.	Commission decided
0042-01	ARLANXEO Netherlands B.V.	Use of sodium dichromate as corrosion inhibitor in ammonia absorption	Commission decided

		deep cooling systems	
0104-01	Borealis Plastomers B.V.	The use of sodium dichromate as in-situ corrosion inhibitor in a closed water/ammonia absorption cooling system	Opinions adopted
0124-01	• H&R Ölwerke Schindler GmbH; • H&R Chemisch-Pharmazeutische Spezialitäten GmbH	Use of sodium dichromate as corrosion inhibitor in ammonia absorption deep cooling systems, applied for the dewaxing and deoiling process steps of petroleum raffinate.	Opinions adopted

All of them indicated in their analysis of alternatives, that no suitable alternatives are currently available. An additional performed literature - and patent research did not indicate any other promising alternatives than the ones stated by other applicants. Ariston Thermo SpA considers that the granting of the authorisation for these uses, indeed provides further evidence that at the moment no suitable alternatives are present.

As the GAHP is a new product development, Ariston Thermo SpA cannot to date contribute with any new findings.

Therefore, Ariston Thermo SpA has chosen in the first step sodium chromate as anticorrosion inhibitor for the GAHP system, which fulfils all requirements of the product to ensure a safe use of the GAHP with all advantages of the technology for the end-consumer, the energy policy makers and the environment.

As corrosion is a very slow process in such systems and the expected performance lifetime of such heating appliance is very long with at least 24 years, a long term testing on industrial scale will be required for every identified alternative. The research and development department will focus in the future on long term testing of identified alternatives. Ariston Thermo SpA will spend in excess of Blank #21 per year on the research and development department.

Nonetheless, Ariston Thermo SpA performed in the following chapter 4.2 an assessment of alternatives based on the requirements for the GAHP.

Development:

ArsitonThermo SpA has developed its GAHP thermodynamic cycle for heating purposes. In collaboration with Consultancy. Ariston Thermo SpA defined themselves high targets, which are:

- use for the more challenging GAX-GAHP application a concentration of inhibitor not higher than what used in the cooling application already available on the market (0.75%).
- Improvement of the current standard as much as possible without affecting the overall system integrity of the appliance.

The theoretical analysis and testing phase performed so far allows AristonThermo SpA to achieve both targets. Indeed, AristonThermo SpA reduced the concentration of sodium chromate to 0.70%, which not only improves current accepted industry practice, but also achieves such lower level in a substantially more challenging environment as described in chapter 3.1.4.

4.1.2 Data searches

For the investigation of possible alternatives, a literature and a patent search was performed, whereby the focus was on patents. Most currently available literature on corrosion inhibitors for water/ammonia cycles focus on cooling applications.

Among the few experts with competence on the thermodynamic cycle of gas absorption heat pumps a permanent exchange of information takes place. Ariston Thermo SpA has created a well-established information network with universities and research institutes, suppliers and other HVAC companies to ensure direct information transfer on alternatives. Furthermore, AristonThermo SpA is relying on several consulting companies and universities to understand the existence of proven alternatives.

As ammonia absorption cooling systems and GAHPs of Ariston Thermo SpA have a similar construction scheme and identical operating conditions within sealed circuit, the technical requirements on effectiveness of a possible corrosion inhibitor are the same. Therefore, besides literature review and information network, further sources of information for Ariston Thermo SpA are the publicly available Analysis of Alternatives of companies, which have applied for the use of chromium (VI) or already have obtained authorisation in absorption refrigerators.

4.2 Identification of known alternatives

Among the known alternatives, Ariston has identified two different level of alternatives:

- Alternative 1: Substitution of sodium chromate as corrosion inhibitor
- Alternative 2: Replacement of GAHP technology

In the following sections, these alternatives are described and assessed in details.

4.2.1 Alternative 1: Substitution of sodium chromate as corrosion inhibitor

Within the following section, the most promising substance alternatives for sodium chromate as corrosion inhibitor in GAHPs are discussed. In Table 17 substances which are known to be corrosion inhibitors are mentioned. The assessment of the technical suitability of the alternative drop-in substances includes functional requirements (corrosion resistance, effectiveness at high operating temperature, high pH and high pressure, long lifetime service, prevention of gas formation), hazardous substance profile, experience at industrial scale and economic criteria (market availability) as outlined in Table 2 in section 3.2 .

Table 17 List of substance alternatives

No	Name	Characteristics / Literature
1	Soluble silicon compounds	Sodium silicate, potassium silicate, lithium silicate, silicic acid, tetramethoxysilane (Agrawal et al., US Patent 5,342,578) Water glass (Keller, US Patent 9,644,143 B2)
2	Molybdates	Sodium molybdate (Shams El Din and Wang, 1996) Molybdate in a complex mixture in absorption cooling systems (Downey, US Patent 5,547,600) Molybdate in heat exchanging apparatus in presence of oxygen (Takagi et al., US Patent 5,377494)
3	Sodium nitrite	Sodium nitrite as anodic corrosion inhibitor
4	Zinc containing corrosion inhibitors	Sodium zincate (Agrawal et al., US Patent 5,342,578) Zinc borate (Guerra, European Patent 1 304 398 A2)
5	Strong alkaline solutions	Sodium hydroxide, potassium hydroxide, lithium hydroxide (Phillips et. al, US Patent 5,811,026) Alkaline solutions (Keller et al., US Patent 5,725,793) Small amounts of alkali hydroxides (Erickson, US-Patent 6,203718 B1)
6	Phosphates and phosphonate compounds	Phosphates as corrosion inhibitors in coatings (Gharbi et al., 2018) Sodium phosphate (Agrawal et al., US Patent 5,342,578)
7	Rare Earth Metal Salts (REMSs)	Cerium nitrate (Hannon et al., 2002)
8	Inhibitor 7	Potentially suitable new inhibitor described in another application (Dometic GmbH) for absorption refrigerators. It is an inorganic salt and a stabilizer, however the exact formulation of this alternative is not known to Ariston Thermo SpA. (Dometic GmbH, 2015)

4.2.2 Alternative 2: Replacement of GAHP technology

The product GAHP is closely connected to the use of sodium chromate. Therefore, besides the check of substance alternatives to the sodium chromate, a change of the complete system needs to be investigated and evaluated in case of analysis of alternatives to GAHP technology. Long listed technical alternatives in the HVAC sector are: condensing gas boiler, electrical heat pump, hybrid heat pump and biomass. Results are presented in the table below. The electrical heat pump and the condensing boiler are assessed further in chapter 4.3.2

Table 18 List of technical alternatives (details on the colour code are available in the last row of the table)

Terminals	Condensing Boiler	Electrical Heat Pump	Hybrid Heat Pump	Biomass
Medium temperature supply				
High temperature supply				
Use of renewable energy				
High energy efficiency				
Low influence to electricity grid networks				
Low emissions (CO_2, PM, NOx; VOCs)				
Heat exchange efficiency at low outside temperatures				
Evaluation on suitability	**Not suitable:** Energy efficiency <100% No use of renewable energy	**Not suitable:** Poor performance at high thermal lift (<0°C and radiators >45°C). High operating cost for end user	**Not suitable:** Linear combination of boiler and electrical heat pump. Depending on requirements on system performance one subsystem will dominate. In total performance of GAHP always better than a	**Not suitable**: Very high emissions of CO_2, PM, NOx, VOCs. Huge environmental impact.

			hybrid independently from the hybrid configuration.	
Suitable	**Suitable but not recommended**	**Not suitable**	**Partly suitable**	**Not applicable**

4.3 Assessment of alternatives

4.3.1 Alternative 1: Substitution of sodium chromate as corrosion inhibitor

The substitution of sodium chromate by another corrosion inhibitor would be the most reasonable and easiest alternative to the use of sodium chromate.

All identified alternatives are evaluated whether they meet the functional requirements defined in chapter 3.1.4 and listed below based on literature information, supported by the information of other Authorisation holders.

Functional requirements:

- Suitable for anaerobic conditions
- Effective in high NH_3 concentrations and high pH levels
- Effective in operating temperature up to 200 °C
- Prevention of gas formation
- Approved suitability for GAHP
- Long lifetime service tested

Only if all points mentioned above are fulfilled, an evaluation of the overall corrosion resistance for the GAHP can be evaluated.

4.3.1.1 Technical feasibility of substance alternatives

Soluble silicon compounds

Soluble silicon compounds, as silicates and water glass, were proposed as corrosion inhibitor in ammonia gas absorption machines in several patents (Agrawal et al., US Patent 5,342,578; Keller, US Patent 9,644,143 B2).

Suitable for anaerobic conditions

According to Asrar et al., oxygen is an essential part for sodium silicate to provide a maximum corrosion protection. As the GAHP works in a complete closed system, no oxygen will be present in the system.

Keller claims in his US Patent for the use of basic water glass good corrosion inhibiting effects in laboratory tests in air-sealed absorption machines without inert gas filling and in the temperature range -35 to 200 °C.

Effective in high NH_3 concentrations and high pH levels

Basic water glass was tested in absorption cooling systems (using ammonia, methylamine or dimethylamine as working agent in a range of 25-50% by weight) with good inhibition results (Keller, US Patent 9,644,143 B2). Agrawal et al. stated in their patent tests with an ammonia water solution, having fifteen or more weight percent of ammonia. Highest tested concentration in the coupon immersion test was 45% w/w. ammonia solution. The requirements for GAHP estimate a weight percent of ammonia of at least 40% in aqueous solution.

Effective in operating temperature >200 °C

Agrawal performed coupon immersion tests with different silicate solutions up to a temperature of 260 °C. Furthermore, sodium silicate and sodium zincate were tested as corrosions inhibitors in chillers for 60 days at an ambient temperature range (27 °C and 35 °C). The data indicated that the sodium silicate inhibited chiller generated no greater amounts of hydrogen than a chromate-inhibited chiller (Agrawal et al., US Patent 5,342,578).

Keller described in his patent under laboratory conditions in air-sealed absorption machines temperature ranges from -35 to 200 °C. However, detailed description of tests cannot be taken from the paper. (Keller, US Patent 9,644,143 B2)

Approved suitability for GAHP (industrial application)

Soluble silicon compounds show good corrosion inhibitor properties under laboratory scale. An industrial scale testing in GAHP with high operating temperature was to the knowledge of Ariston Thermo SpA not performed yet. Only small scale testing within chillers have been performed.

Long lifetime service tested

No long term testing with the requirements for GAHP have been performed yet.

Conclusion on corrosion resistance

Soluble silicon compounds, especially basic water glass, show within the laboratory scale some potential in the function as corrosion inhibitor. To evaluate the suitability for GAHP further long term testing under real conditions needs to be performed. A corrosion inhibition of an equipment lifetime is necessary to prove the suitability of the alternative.

Molybdate

Molybdates are well known for their corrosion inhibition function and they have been used as an anodic corrosion inhibitor for carbon steel for many years.

Suitable for anaerobic conditions

Shams El Din and Wang examined the mechanism of corrosion inhibition by sodium molybdate in general (e.g. in tap water as well as in NaCl and Na_2SO_4 solutions) and showed that the use of molybdate as corrosion inhibitor requires the presence of oxygen. (Shams El Din and Wang, 1996)

Takagi et al. found good corrosion inhibition effect by ammonium molybdate in a test vessel up to 170 °C and proposed molybdate as an inhibitor for heat exchanging apparatus. However, the described method includes dissolved oxygen. (Takagi et al., US Patent 5,377,494)

Effective in high NH_3 concentrations and high pH levels

Downey US Patent 5,547,600 claims the use of a complex mixture (molybdate, borate, silicate) as corrosion inhibitor in refrigeration systems, which use an aqueous solution of a halogen salt of lithium or ammonia. However only lithium bromide working fluids, and not ammonia, were tested under laboratory conditions and in an operating refrigeration system (Downey, US Patent 5,547,600). Ideal pH range for the function of molybdate is considered to be between 6-10.

Effective in operating temperature >200 °C

From the literature no information could be derived that molybdates have been tested on high temperature levels. Only Takaki et al stated in their patent a temperature up to 170°C. (Takagi et al., US Patent 5,377,494)

Approved suitability for GAHP (industrial application)

Tests have been mainly performed under laboratory scale.

Long lifetime service tested

Long term testing was not considered so far, as the inhibitor works only with the presence of oxygen (Shams El Din, 1996; Takagi et al. US Patent 5,377,494).

Conclusion on corrosion resistance

Molybdates cannot be considered as suitable alternatives for GAHP.

Nitrite

First Patents on nitrite as corrosion inhibitors have been published in 1948 by Electrolux (Widell, US Patent 2457334A). Since then nitrite is used as corrosion inhibitor for carbon steel.

Suitable for anaerobic conditions

Compared to molybdate nitrite does not need the presence of oxygen to form the passivating very thin layer. It can be considered as suitable for anaerobic conditions.

Effective in high NH_3 concentrations and high pH levels

Nitrite is good soluble in pure NH_3 and in water solutions with high NH_3 concentrations (Widell, US Patent 2457334A). Best performance pH range is between 8 and10. Within the GAHP system even higher pH values within the pure ammonia are possible.

Effective in operating temperature >200 °C

Based on information from Dometic GmbH (2015) nitrite is rapidly consumed at high temperatures and the thin protective layer will not be present after short period of time.

Approved suitability for GAHP (industrial application)

Tests have been performed on industrial scale in refrigerant units. According the results of Dometic (2015) the service life of a unit was only 1 year.

Long lifetime service tested

Long term testing was not possible. System already broke down after the first year of testing with lower temperatures than the requirements of GHAP.

Conclusion on corrosion resistance

Nitrite cannot be considered as suitable alternatives for GAHP.

Zinc containing corrosion inhibitors

Guerra and Agrawal et al. mention in their patents the use of zinc mixtures as potential corrosion inhibitors in absorption systems (Agrawal et al., US Patent 5,342,578 and Guerra, European Patent 1 304 398 A2).

Suitable for anaerobic conditions

None of the literature references give indication that zinc mixtures have different corrosion inhibition properties based on the presence or absence of oxygen.

Effective in high NH_3 concentrations and high pH levels

Solubility of zinc highly depends on the pH value of the medium.

Effective in operating temperature >200°C

From the literature, no information could be derived that phosphates have been tested on high temperature levels.

Approved suitability for GAHP (industrial application)

Guerra and Agrawal et al. show in their patents during testing generation of high amounts (up to ten times greater amounts) of non-condensable gases within low temperature appliances.

Long lifetime service tested

No long-term testing on real GAHP conditions has been performed so far.

Conclusion on corrosion resistance

Zinc mixtures show within low temperature appliances already a generation of non-condensable gases. Therefore, it can be considered that under high temperature conditions the amounts will be even higher and consequently zinc containing corrosion inhibitors are not a suitable alternative.

Strong alkaline solutions

Strong bases such as sodium hydroxide, potassium hydroxide, caesium hydroxide or lithium hydroxide were proposed to be used as corrosion inhibitors for aqueous ammonia systems by several patents (Phillips et al., US Patent 5,811,026; Keller et al., US Patent 5,725,793; Erickson, US Patent 6,203,718 B1).

Suitable for anaerobic conditions

Phillips et al. stated suitability in anaerobic systems during their test on laboratory scale (Phillips et al., US Patent 5,811,026).

Effective in high NH_3 concentrations and high pH levels

Phillips et al. claims in their patent concentrations of ammonia in water from 1-50%. Test have been mainly performed with a low concentration of 10% NH_3/H_2O.

Within another patent a pH range of 10.5 to 11.8 is given as suitable to establish maximum corrosion inhibition (Erickson, US Patent 6,203,718 B1)

Effective in operating temperature >200 °C

Phillips et al. tested in their patent temperatures up to more than 200°C, but the clearly indicated a significant higher hydrogen generation in case of temperatures above 200°C.

Approved suitability for GAHP (industrial application)

So far no information is available from literature that any of the alkaline solutions are tested under real GAHP conditions.

Long lifetime service tested

Most tests have been only performed under laboratory conditions for periods less than 5 years.

Conclusion on corrosion resistance

Strong alkaline solutions are considered as not suitable as on high temperature conditions significant hydrogen formation can be seen.

Phosphates and phosphonate compounds

Phosphates coatings were widely used to protect metals as carbon steel. Usually, a metal phosphate surface layer is precipitated onto the metal.

Suitable for anaerobic conditions

Oxygen is needed to form the passivation layer in a phosphate inhibited system which consists of a Fe_2O_3/phosphate film.

Effective in high NH_3 concentrations and high pH levels

Phosphates have limited pH stability in aqueous solutions (pH5-10) and therefore are not feasible to substitute chromate. (Gharbi et al., 2018)

Agrawal et al. describe in their patent the electrochemical testing of several substances in 15% ammonia solution and found sodium phosphate to have a lower worse inhibition efficiency than other substances. (Agrawal et al., US Patent 5,342,578)

Effective in operating temperature >200°C

From the literature, no information could be derived that phosphates have been tested on high temperature levels.

Approved suitability for GAHP (industrial application)

As Agrawal et al. found in their patent insufficient inhibition efficiency already in the electrochemical screening testing, no tests with phosphate were performed in a ammonia-water absorption chiller. (Agrawal et al., US Patent 5,342,578)

Long lifetime service tested

No long-term testing on real GAHP conditions has been performed so far.

Conclusion on corrosion resistance

Phosphates cannot be considered as suitable alternatives for GAHP.

Rare earth metal salts (REMS)

Hannon et al. describe their research on rare earth metals salts (REMS) as corrosion inhibitors for the protection of carbon steel surfaces of ammonia-water absorption heat pumps. They propose pre-treating the carbon steel surface with a cerium oxide/hydroxide layer (cerating) and adding rare earth metals salts to the solution as corrosion inhibitor. (Hannon et al., 2002)

Suitable for anaerobic conditions

No indication is given that oxygen is needed in the working fluid for corrosion inhibition.

Effective in high NH_3 concentrations and high pH levels

They performed the testing at temperatures over a period of 1 to 2 weeks in test apparatus that simulated a range of temperatures, ammonia concentrations and phases typically found in ammonia-water absorption system. Hannon's results for the system of cerated surfaces and cerium nitrate as drop-in inhibitor, based on the generation rate of non-condensable gases and corrosion rates, were comparable to or even better than that of chromate.

Effective in operating temperature >200 °C

Good results were achieved for cerated surfaces systems even at high temperature levels between 205 and 245 °C.

Approved suitability for GAHP (industrial application)

So far only laboratory experiments in test rigs up to ten weeks were performed. So the suitability for industrial scale is not known.

Long lifetime service tested

No long term testing was performed.

Conclusion on corrosion resistance

In laboratory scaled tests rare earth metal salts as drop-in inhibitor showed some potential for corrosion inhibition in combination with prior cerating of the inner metal surfaces. To evaluate the technical suitability of this method for GAHPs further investigation and long term testing under real use conditions would need to be performed. Currently rare earth metal salts cannot be considered as suitable alternatives for use in GAHP.

Inhibitor 7

A potentially suitable new inhibitor, 'Inhibitor 7', is described in another application (Dometic GmbH, 2015) for absorption refrigerators. The "Inhibitor 7" is an inorganic salt and a stabilizer, however the exact composition of this alternative is not known and further information are not available to Ariston Thermo SpA.

Effective in operating temperature >200°C

Corrosion protection of "Inhibitor 7" was described to be reduced at high temperatures (>180 °C) (Dometic GmbH, 2015). It needs to be pointed out that absorption cycle for refrigeration system has the same nature of the absorption cycle for GAHP systems, but is less demanding in terms of corrosion than due to the higher thermal lift associated with GAHP applications.

Conclusion on corrosion resistance

Information on inhibitor 7 is not available for Ariston Thermo SpA. Based on the information provided by Dometic GmbH (2015) the alternative can be considered as unsuitable for the use in GAHP.

4.3.1.2 Economic feasibility and economic impacts of substance alternatives

There is no indication that the alternative corrosion inhibitor substances are not economically feasible. However as none of the assessed drop-in alternatives are technically feasible currently, it is not known which additional costs may arise by a potential substance alternative, e.g. for adaptations in the construction of the ammonia absorption heat pump.

4.3.1.3 Availability of substance alternatives

The composition of Inhibitor 7 which is mentioned in the Application for Authorisation of Dometic GmbH as a potential corrosion inhibitor, is not known to Ariston Thermo SpA, and therefore not available.

There is no indication that the other alternative corrosion inhibitor substances discussed in section 4.3.1 are available on the market.

4.3.1.4 Hazard and risk of substance alternatives

The classification and labelling information according to CLP (EG) 1272/2008 of the assessed alternative inhibitors are outlined in Appendix 1. None of the alternative substances is classified as carcinogenic, mutagenic or toxic for reproduction. Therefore, all alternative corrosion inhibitors mentioned in Table 2 are less hazardous compared to sodium chromate. However, a reduction of the overall risk by applying an alternative inhibitor can only be achieved if uncontrolled corrosion can be excluded. Any corrosion, which may occur in the ammonia absorption heat pump, increases the risk of uncontrolled ammonia exposure and hazard due to hydrogen gas formation.

As outlined in chapter 4.3.1, currently none of the potential drop-in alternatives fulfil the technical requirements to exclude corrosion and non-condensable gas formation with sufficient extent to ensure safe work of ammonia absorption heat pumps for the whole lifetime. Therefore, currently no alternative corrosion inhibitor is known which can reduce the overall risk.

4.3.1.5 Conclusions on substance alternatives

Within the assessment of technical feasibility of potential substance alternatives, Ariston Thermo SpA comes to the same conclusion as all other authorisation holders that no drop-in alternative to sodium chromate for the use as a corrosion inhibitor in ammonia absorption systems is currently available.

None of the potential drop-in alternatives fulfils the technical requirements to exclude corrosion and non-condensable gas formation with sufficient extend to ensure safe work of ammonia absorption heat pumps for the whole lifetime of 24 years. Therefore, currently no alternative corrosion inhibitor is known which can reduce the overall risk.

Table 19: Conclusion on assessment of substance alternatives (details on the colour code are available in the last row of the table)

	Suitable for anaerobe conditions	Effective in high NH_3 concentrations and high pH levels	Proven Effectivity in operating temperature >200 °C	Approved suitability for GAHP (industrial application)	Long lifetime service tested	Overall Suitability as corrosion inhibitor
Soluble silicon compounds						
Molybdate						
Nitrite						
Zinc containing corrosion inhibitors						
Strong alkaline solutions		**Pre-treatment needed**				

Phosphates and phosphonate compounds						
Rare earth metal salts (REMS)						
Inhibitor 7						

Suitable	**Suitable but not recommended**	**Not suitable**	**Not applicable**

4.3.2 Alternative 2: Replacement of GAHP technology

As stated above, no current alternative can replace the functions of sodium chromate as corrosion inhibitor. Consequently, the product gas absorption heat pump is closely connected to the use of sodium chromate as anticorrosion inhibitor. To make the function of sodium chromate redundant the entire absorption technology needs to be replaced. The most common technical alternatives are condensing boilers and electrical heat pumps. These two technologies are evaluated in the next chapter.

4.3.2.1 Technical Alternative 2.1: Electrical heat pump

As discussed above, the electrically driven compression heat pump (in the following “electrical heat pump” or “EHP”) employs the same physical principle as the gas absorption heat pump: it works by extracting heat from one “source” at low temperature and transfer it to a “well” at high temperature, therefore reversing the natural flow of heat that spontaneously moves from high to low temperatures. In an electrical heat pump, heat is transferred by circulation of the refrigerant through a cycle of evaporation and condensation. On one side, the refrigerator is evaporated at low pressure and therefore, it can absorb heat from its surroundings. In the cycle the refrigerant is afterwards raised to high pressure where it condenses and the up-taken heat is released. The high pressure level is gained by a compressor and not by heating the refrigerant (Figure 12).

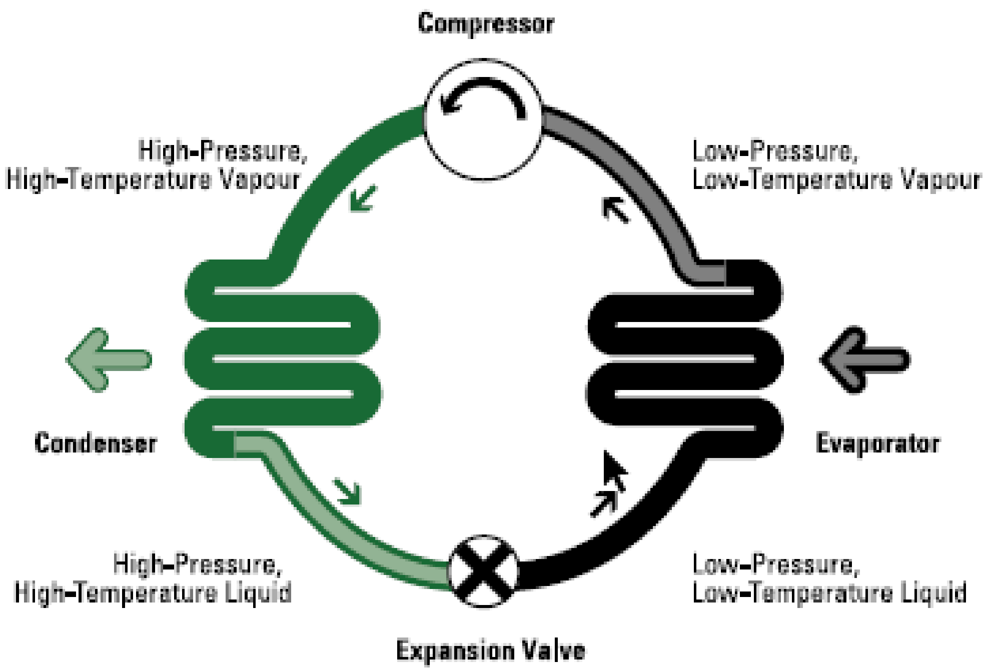

Figure 12 compressor driven heat pump (Natural Resources Canada's Office of Energy Efficiency 2004)

Electrical heat pumps show the highest efficiency in the low temperature sector like for floor heating. For medium and high temperature differences between the condenser (radiators) and evaporator (outdoor) the efficiency rapidly decreases. For the high temperature applications (radiators) electrical heat pumps are absolutely not recommended because of reduced energy performance (even lower than a condensing boiler) and increased operating cost.

Electrical heat pumps instead are very successful in new buildings (where underfloor heating is possible/available and ground source drilling are often used to minimize thermal lift). Using electrical heat pumps in retrofit (where radiators are the dominant emission technology in Europe and ground source drilling is unlikely) results in poor energy efficiency, disproportionate installation and operating costs. GAHP focuses on the retrofit segment, which is a complete different target market compared to EHP.

The most common refrigerant of heat pumps, which are sold today, is fluorinated hydrocarbons. According to the European fluorocarbons manufacturers association the most common refrigerant used in electrical heat pumps is HFC-410A. This refrigerant has a GWP index of 2088 which shows a significant environmental concern (British Department of Energy & Climate change 2014a). New refrigerants in EHPs with lower GWP and ODP will reduce such environmental issue, but will not completely avoid the use of F-Gas.

Depending on the electrical energy source mix, electrical heat pumps show also lower carbon savings than the GAHP. Another limitation of the electrical heat pump is the high operation noise of the compressor. EHP have to use a compressor and use an airflow at the evaporator that is approximately double compared to an GAHP of the same power.

Even though the electrical heat pump shows higher efficiency in the low temperature sector the GAHP has lower running costs in the main European market countries. A rational end-costumer would always be attracted by the most costs-effective technology. When projecting running costs between electrical heat pumps and the GAHP in the future, on the basis of the British Department of Energy & Climate change 2014b, it is expected that electricity prices will rise faster than gas prices in most countries. This market trend will further strengthen the appeal of gas absorption heat pumps.

4.3.2.1.1 Conclusions on technical Alternative 2.1

According to the points mentioned above and the fact that the electrical heat pump technology is not applicable for retrofit and for high or medium temperature sectors as well as the use of fluorocarbons-containing refrigerant makes the electrical heat pump an unsuitable alternative for the GAHP. The Figure 13 below illustrates the advantages of the GAHP technology compared to the electrical heat pump technology.

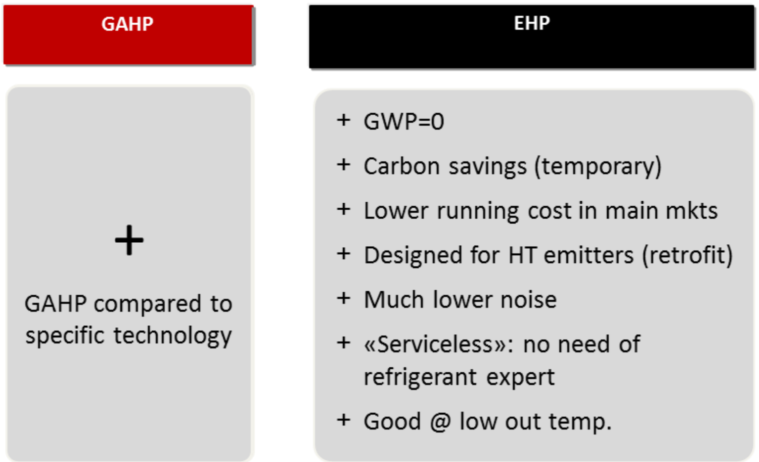

Figure 13 Advantages GAHP compared to EHP

4.3.2.2 Technical Alternative 2.2: Condensing boiler

Boilers use controlled combustion of fuel, either gas or oil, to heat water. In the burner fuel and oxygen are mixed and combusted. Generated heat is transferred to water by heat exchangers. The heated water is then pumped through pipes to the radiators. After the heat exchange at the radiators the cooled water returns to the burner where it is heated again.

In the traditional conventional boilers, the hot gases from the combustion process are passed through the heat exchanger and led directly out through a flue conduit. This waste of heat equals in low efficiency of 60-84% and high energy consumption by the system. The efficiency can be described by energy equivalent output per energy input.

Condensing boilers are enhancements of the conventional boiler. The technology is fully developed and already implemented in the market. Compared to the non-condensing boiler the condensing boiler utilises the latent heat of water to increase the efficiency of the whole system. The hot gases from the combustion are passed through a second heat exchanger where the produced water vapour condenses. By condensing the vapour, heat is transferred back to the returning cold water in the system. This pre-heating lowers the combustion temperature gradient. The use the exhaust air in a condensing boiler can improve the efficiency of the system to 85-97%. The system is mostly beneficial to new construction but it is also applicable for retrofits (Figure 14).

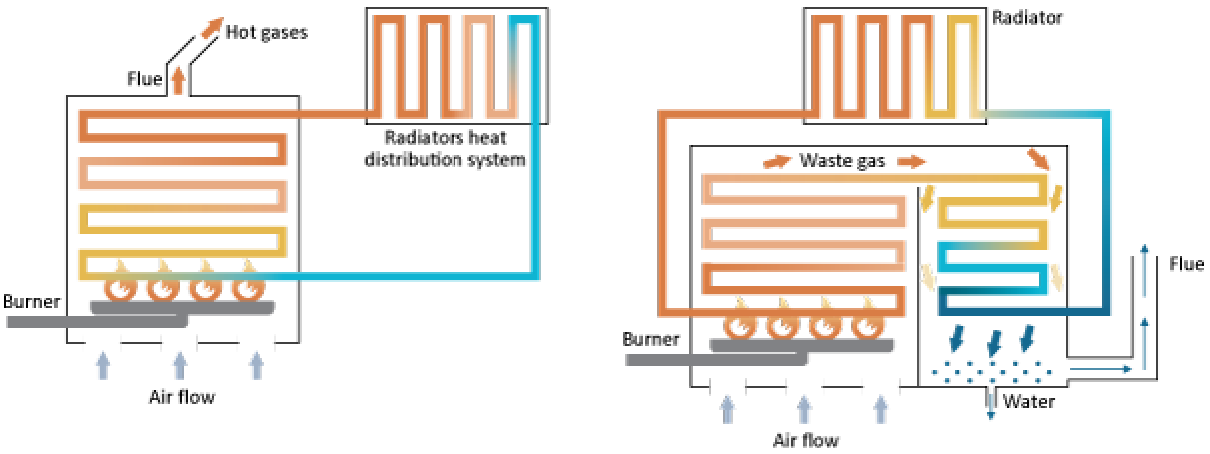

Figure 14 Conventional and condensing boiler (International Energy Agency)

4.3.2.2.1 Conclusions on technical alternative 2.2

Boilers dominate currently the heating market due to relatively low capital costs and low operating costs in the past. However, the design and function have already achieved the theoretically maximum energy efficiency. The main disadvantage compared the GAHPs is the lower efficiency and higher energy consumption. The higher energy consumption leads to higher emissions of greenhouse gases (CO_2, NOx, etc.). This technology can only partially contribute to the decarbonising aims (replacing old standard efficiency boilers with latest generation condensing boilers). Another disadvantage compared to GAHP is the higher running costs due to lower efficiency. Relying only on the boiler technology would prevent Europe from accelerating the decarbonisation process of existing buildings. The figure below illustrates the advantages of the GAHP technology compared to the boiler technology (Figure 15).

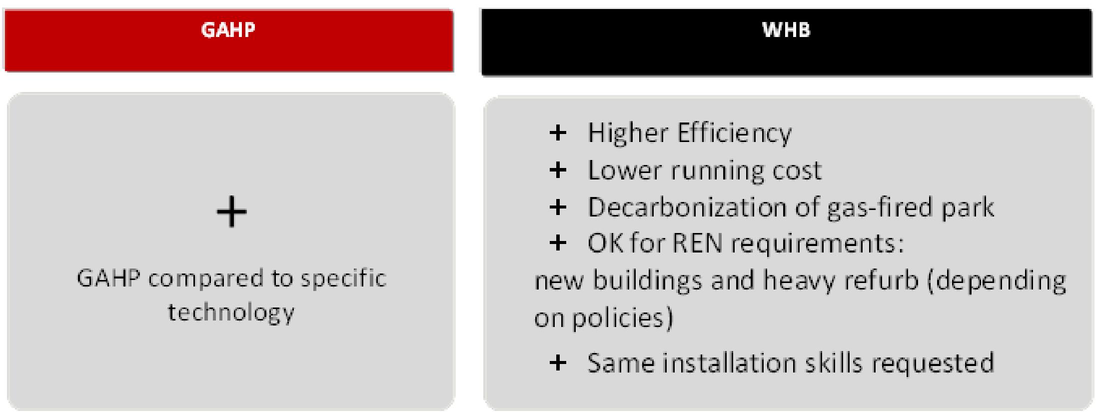

Figure 15 Advantages GAHP compared to boiler

4.4 The most likely non-use scenario

Should the authorisation not be granted, the most likely "non-use scenario" is that Ariston Thermo SpA will suspend the entire GAHP development and manufacturing program in the EU. It is very possible that Research and development (R&D) program and manufacturing program will be moved to Far-East. Most likely to Far-East where Ariston Thermo SpA is present since the 1990s. The high level of innovation of the product and custom developed manufacturing processes will impose that R&D department is in close proximity of the manufacturing facilities.
The products will then be manufactured and sold under a legal entity of Ariston Thermo in Asia (example: Ariston Thermo China Co Ltd).

With shifting of the production to Far-East, Ariston Thermo SpA will need to build a new production site. Due to the product structure, a vertical integration will be mandatory in Far-East, too. The weight and size of components will not allow for insourcing material/components from Europe while managing low inventories to guarantee high quality levels and reduced costs in the introductory phase. Therefore the non-use scenario will involve the entire GAHP value chain.

The move of the entire value chain will result into a substantial delay of the launch program. The main factors affecting the delay will be:

- Hiring new stuff
- Training
- Equipment move
- Supply chain redefinition

Delay in market launch of GAHP

Hiring:

Most of R&D and Operation personnel currently involved in the GAHP program are based in Europe. A relocation program of these senior and highly skilled personnel into Far-East is not expected to attract large number of volunteers. Therefore, a Far-East hiring program will need to be put in place for several tens of engineers that will need to be fluent in English.

In the experience of AristonThermo SpA with more than ten years of business and thousands of employees in the Far-East, this hiring process of this specialized personnel might take up to 12 months.

Training:

Once technical employees are available, these personnel could receive training on the specifics of Gas Absorption Heat Pump technology at European R&D center of AristonThermo.

Both thermodynamics of the absorption cycle, design criteria and manufacturing technologies will need to be transferred. During the time of writing this process in Europe close collaboration between R&D Center (ATIT) and AristonThermo organization in Far-East is required. Until completion of this training, personnel currently engaged with the program will need to remain active on the program and repeat the know-how transfer, which will result in a doubling of the required resources. This process is currently planned to last 24 months.

Equipment move:

All equipment for the Albacina plant is currently already delivered or on order. Therefore, with regard of the non-use scenario a complete equipment move from Europe to Far-East would be needed. An international move of the equipment will imply a redefinition of specification for the Far -east manufacturing location. The requirements for Far-East will demand different certifications and approvals. Once documentation is ready all custom documents can be prepared and definition of logistic move can be started. The process is expected to take approximately 6 month. This process will happen in parallel to other activities.

Supply chain redefinition:

Once training activity is at least half the way through, the team of partially trained engineers will be able to identify Far-East suppliers to replace the currently identified European suppliers. Suppliers will need to comply with PPAP (ProductionPartApprovalProcess) as quality process commonly used in consumer good and automotive industries.

This process, which is already ongoing and nearly finished for the European suppliers, will need to be repeated with supply of new sample and new tooling. Supply Chain redefinition is currently planned to last 24 months. This timeframe includes all process from identification to approval for production of the materials and suppliers. Qualification and approval process is an essential task as the GAHP includes hundreds of “critical-to-safety” or “critical-to-function” parts.

All in all, the non-use scenario will end-up in a delay of product launch of at least 48 months.

Besides the delay of the product launch the non-use scenario will show several more negative effects for Ariston Thermo SpA and the HVAC sector.

Ariston Thermo SpA will lose their time advantage about GAHP technology and a shift to Far-East will open the opportunity for competitors outside the EU to gain knowledge on this European based technology. This will open also the opportunity for Non-EU producers to enter the European market in a second step. Nevertheless, Ariston Thermo SpA still sees themselves in advance of all other competitors. Other European players developing the GAHP will face the same non-use scenario and they will very likely follow the approach of Ariston Thermo SpA. This will bring the current European leadership in GAHP technology to an end.

The current market opportunity for GAHP product lies in particular in Europe. Companies settled in Europe will then import GAHP products from Far-East as it happened already with many other technologies.

Indeed, there is also a great potential of the product in the Far-East in particular in China as they are moving progressively toward such new technologies for space heating. China is currently facing the “coal-to-gas” transition. But this is considered to be a slow process and therefore, in the first years, sales to Chinese market will substantially be lower than toward Europe.

Overall, there will be extra costs associated with transportation and duties to import products from Far-East to Europe.

Besides the timely delay, such a move to Far-East is also related to high costs for the company Ariston Thermo SpA.

All costs related to the non-use scenario will be presented under chapter 5.

4.4.1 Summary of effects of non-use scenario

All effects of the non-use scenario are summarised in Table 20 below.

Table 20 Non-use scenario conclusion

Effected of non-use scenario:	Effects

Ariston Thermo SpA	- Move of R&D and manufacturing to Far-East
	- Costs for new production site in Far-East
	- Hiring and training costs
	- Additional shipping costs to export to the EU market
	- Delay of product launch at least 4 years
	- Weaken of market position
	  o Loss of economic dominating position for GAHP product
	  o Loss of market share
	  o Loss of sales/revenue

GAHP Technology	- End of European leadership on GAHP technology - Slowdown of technology implementation
Non-EU competitors	- Easy access to the market - Will be the first to enter the market
EU competitors	- Following Ariston Thermo SpA approach to move outside EU
Public	- Lack of trust in technology - Jobs will be lost in Europe - Less Research fundings regarding GAHP for European universities

5 IMPACTS OF GRANTING AUTHORISATION

The following chapters present cost-benefit comparison between the continued used and the described non-use scenario in chapter 4.4. As far as possible, all impacts are provided as monetised values to simplify the comparison between the cost and benefits of the continued use. If quantification was not possible, the impacts are described in a qualitative manner. The cost-benefit analysis (CBA) investigates the economic, wider economic, social, environmental and human health impacts. The benefits of the continued use are compared to the costs due to the human health impacts to show that the benefits outweigh the risk.

All impacts are presented in costs of the non-use scenario.

5.1 Economic impacts

Ariston Thermo SpA considers for the valuing the economic impacts of granting authorisation in a quantitative manner only for the years of transition till the supply chain in Far-East is set up. Within the transition time Ariston Thermo SpA does not expect that anyone else could close the GAHP-gap.

Based on company knowledge, Ariston Thermo SpA is by far the closest to launch a GAHP product on the market. There is a well-established network between the few experts with competence on the thermodynamic cycle of gas absorption heat pumps. Most of these experts are located in the EU. All competitors located in the EU would require an authorisation, too. So it would be very likely that they would follow the approach of Ariston Thermo SpA with a move to Far-East.

Competitors from outside the EU will face significant higher market entry barriers simply based on the market structure, since the whole heating market in the retrofit sector is dominated by only a few companies (the top five companies hold more than 60% of the total market). Penetrating EU heating market without the support of these companies is unlikely.

European competitors would need similarly authorization for use of Sodium Chromate; at time of submission of AristonThermo request, no evidence of additional requests is known. Therefore, it is very unlikely that any other company could launch a GAHP on the market in advance of Ariston Thermo SpA.

As consequence Ariston Thermo SpA sees it as reasonable to consider the whole transition period of 4 years for valuing the economic impacts.

Economic impacts will arise for Ariston Thermo SpA and for the public by the implementation of the non-use scenario as described in chapter 4.4. With non-granting of authorisation for the use of sodium chromate as corrosion inhibitor in GAHP, the whole program will be moved to Far-East. Impacts related to the move of production to Far-East and the resulting delay for the product implementation will be presented. Impacts of the company profit are adopted by a discount rate.

As recommended in the European Commission's impact Assessment Guideline, a discount rate of 4% is used for the monetisation of the impacts. All costs for the non-use scenario reflect the benefit of continued use. 2019 is taken as basis year for the discount rate.

5.1.1 Ariston Thermo SpA

As described in the non-use scenario in chapter 4.4, a move to Far-East will be related to costs and profit loss for Ariston Thermo SpA.

Hiring:

Establishing a hiring program for high skilled engineers with fluent English speaking skills will result in extra costs of Blank #22 within the first year of the transition phase.

Training:

Once the technical personnel is available, they will need to be trained. Such a training on the thermodynamics, the design criteria, and the manufacturing will require a doubling of resources and will take around 24 months. Ariston Thermo SpA expects costs of more than Blank #23. Therefore, respectively Blank #24are considered for the 2nd and 3rd year of the transition time.

Equipment move:

Equipment will be moved to Far-East after finalisation of the training. It will take place in parallel of other activities. It does not affect the product launch directly. Costs for the equipment move are set for the 4th year of the transition time with an amount of Blank #25.

Supply chain redefinition:

One of the most critical points during the shift to Far-East. Redefinition will take place once the training is at least half way through. This process is planned to last 24 months. Such a PPAP will drive extra costs of approximately Blank #26 . A clear split within this 24 months cannot be made to the current time. Therefore Blank #27 are taken into account as additional costs for the 3rd and the 4th year of the transition phase.

Summary of moving costs:

Table 21 below summarises the costs related to the move to Far-East within the years of transition period. The total impact on the moving costs with a discount rate of 4% is 2,729,635€.

Table 21 Moving costs

Year	2020	2021	2022	2023	
Cost of non-use scenario					Total
Hiring program	Blank #28	[redacted]	[redacted]	[redacted]	[redacted]
Training	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Equipment move	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Supply chain redefinition	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Total costs (without discount)	[redacted]	[redacted]	[redacted]	[redacted]	3,100,000
Total costs (with discount 4%)	[redacted]	[redacted]	[redacted]	[redacted]	2,729,635

Profit loss

The postponement of product launch on the market for 4 years is the most significant effect for Ariston Thermo SpA. This delay of market launch is associated with high profit losses.

Within the transition phase, Ariston Thermo SpA will gain no profit with the GAHP and also in the following years after the transition phase Ariston Thermo SpA will have reduced sales. For evaluation of these impacts, Ariston Thermo SpA considers the same business case for the shift to Far-East as for the production in Italy as shown in chapter 3.2.3, but with a 4 years delay of product implementation.

It is anticipated that the non-use scenario will reach the same sales number as the use scenario not before 2035. The adapted business case for the non-use scenario as presented in Table 22 results in total in a total profit loss for Ariston Thermo SpA in 100,038,756€ (4% discount rate).

Table 22 Profit loss non-use scenario

Blank #29

[redacted]

As already explained in the business case for the use scenario it is extremely difficult to establish a robust quantitative analysis for a time period of 20 years. This makes it even harder to present any robust results over a longer time period for the non-use scenario as this scenario is connected to even higher uncertainties. An evaluation of the profit loss and the impacts for Ariston Thermo SpA should consequently only be considered for the first 4 years.

Considering the time of transition, Ariston Thermo SpA will face a profit loss of 16,016,249€ (4%). (Table 23).

Table 23 Profit loss non-use scenario transition period

Year	2020	2021	2022	2023	Total
Costs of non-use scenario					
GAHP sold in the EU (use scenario)	Blank #30 [redacted]	[redacted]	[redacted]	[redacted]	[redacted]
GAHP sold in the EU (non use scenario)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Profit per unit; €	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Profit loss; €	[redacted]	[redacted]	[redacted]	[redacted]	18,083,977
Profit loss (4% discount); €	[redacted]	[redacted]	[redacted]	[redacted]	16,016,249

Logistic costs

Current market opportunity for GAHP lies in particular in Europe. Production of GAHP in Far-East would require transportation to Europe, which would result in a poor ecological footprint for the GAHP.

Such transportation of the final products to Europe would also result in additional shipping costs for Ariston Thermo SpA. Based on company and market knowledge the transportation costs from Far-East to Europe for an insured 40 feet container is around 5000$ (http://worldfreightrates.com/de/freight). Based on GAHP unit size 48 units can be shipped within one container. Therefore, transportation costs per unit are estimated to be 104 $. As such shipping costs are always counted in $, the current exchange rate average USD/Euro of 0.875 (04.02.2019) is used for the conversion from USD to Euro. Shipping costs per unit are therefore, 91€.

It is not unlikely that such costs will be passed to the end-user. Nevertheless as described in the beginning of chapter 5.1 the quantification of impacts is only considered for the transition period. Consequently these costs are presented here in Table 24 for completeness reasons, but they will not be further taken into account for the comparison of the use and non-use scenario. Total transportation costs for the complete review period add up to 24,568,692€ (4% discount rate).

Table 24 Transportation costs

Blank #31

[redacted]

Total economic impact of non-use scenario for Ariston Thermo SpA

A move to Far-East results in a total loss of 21,183,977 (18,745,883€ (4% discount)) for Ariston Thermo SpA as shown in Table 25.

Table 25 Total costs of transition phase related to Ariston Thermo SpA

Year	2020	2021	2022	2023	
Cost of non-use scenario					Total
Hiring program	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Training	Blank #32 [redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Equipment move	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Supply chain redefinition	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Profit loss	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Total costs (without discount), €	[redacted]	[redacted]	[redacted]	[redacted]	21,183,977
Total costs (with discount 4%), €	[redacted]	[redacted]	[redacted]	[redacted]	18,745,883

Besides the quantitative impacts for Ariston Thermo SpA, the non-use scenario involve several qualitative impacts.

With a move to Far-East, a knowledge transfer of the complete GAHP technology would be needed, too. Such a knowledge transfer to Far-East could result in a loss of the European leadership position in the GAHP technology. It cannot be ruled out that after the implementation of the technology in Far-East, Far-East companies will adopt the technology know-how and sell GAHP in Europe with potentially much higher concentrations of sodium chromate in the refrigerant solution. Additionally the non-use scenario could disentitle Ariston Thermo SpA's leading position in the GAHP technology, as it gives all competitors time to catch up the know-how gap.

All this impacts cannot be monetised and therefore, it will not be considered any further in the quantified CBA.

5.1.2 Public

The GAHP offers not only positive effects for Ariston Thermo SpA but also for the public. End-users of the GAHP technology can gain an economic value out of the use of this new technology in the form of energy cost savings. The average European end-users can save up to 700€/unit/year on heating costs compared to a condensing boiler technology based on a building heat demand of 25,000kWh and an average gas price of 0.07€/kWh.

Values for the end-user are calculated by the following equation:

$$\frac{Heat\ demand\ x\ Gas\ price\ x\ Savings\ on\ primary\ energy}{100} = \frac{25{,}000kWh\ x\ 0{,}07€/kWh\ x\ 40}{100} = 700€$$

Without a doubt, GAHP appliance will feature an higher acquisition costs than a normal condensing boiler. But comparing the use - and non-use scenario the payback and the savings on heating costs starts 4 years earlier and thus Ariston Thermo SpA sees the savings on heating costs as a reasonable point for the CBA. As for the economic impacts for Ariston Thermo SpA only the transition period of 4 years is considered as quantitative input for the cost-benefit analysis.

Within the first year, based on the business case, end-users can save in total Blank #33 (4% discount) on heating costs. At the end of the review period in 2039, #34 GAHPs could by installed within Europe. This would produce yearly savings on heating costs of Blank #35 (4% discount).

At the end of the transition period in 2023, the total cumulative savings in the transition period amount 34,055,000€. (29,912,696€ (4% discount) These costs are taken into account for the CBA.

Blank#36

[redacted]

Table 26 Energy cost savings

Blank #37

[redacted]

5.1.3 Conclusion on economic impacts

As described under 7.1 only the period of transition which reflects the delay of product launch is considered in der economic impacts. After this transition period it can be concluded as described in chapter 4.4 that another competitor or another technology can close the generated gap. Table 27 reflects the total economic impacts raised from the non-use scenario for the transition time from 2020-2023.

Table 27 Economic impacts of non-use scenario

	2020	2021	2022	2023	
Cost of non-use scenario					**Total**
Ariston					
Hiring program	Blank #38 [redacted]				
Training					
Equipment move					
Supply chain redefinition					
Profit loss					
Total costs Ariston:	[redacted]				21,183,977
Public					
Savings heating costs	[redacted]				34,055,000
Total costs (without discount), €	[redacted]				**55,238,977**
Total costs (with discount 4%), €	[redacted]				**48,658,579**

5.2 Human Health or Environmental Impact

5.2.1 Human Health

Derivation of costs for Human Health in relation to a granted authorisation is derived in detail in chapter 3.5.3.

In total costs for continued use for Human Health are considered as 216€ to 362€.

5.2.2 Environment

Besides the negative Human Health impacts, granting authorisation for the “Use of sodium chromate as an anticorrosion agent of the carbon steel in sealed circuit of gas absorption appliances up to 0.70% by weight (as $Cr6+$) in the refrigerant solution” shows also benefits for the environment.

Ammonium-water solution is the most environmentally friendly refrigerant solution featuring a Global warming potential (GWP) of zero and an Ozone Depletion Potential (ODP) of zero.

Gas absorption heat pumps are rated with energy label (ErP-Label) A^{++} which is the highest efficiency class for thermal heating appliances.

In addition, GAHP achieve the lowest amount of NOx emissions since high efficiency is combined with very low pollution specific emission (Figure 16).

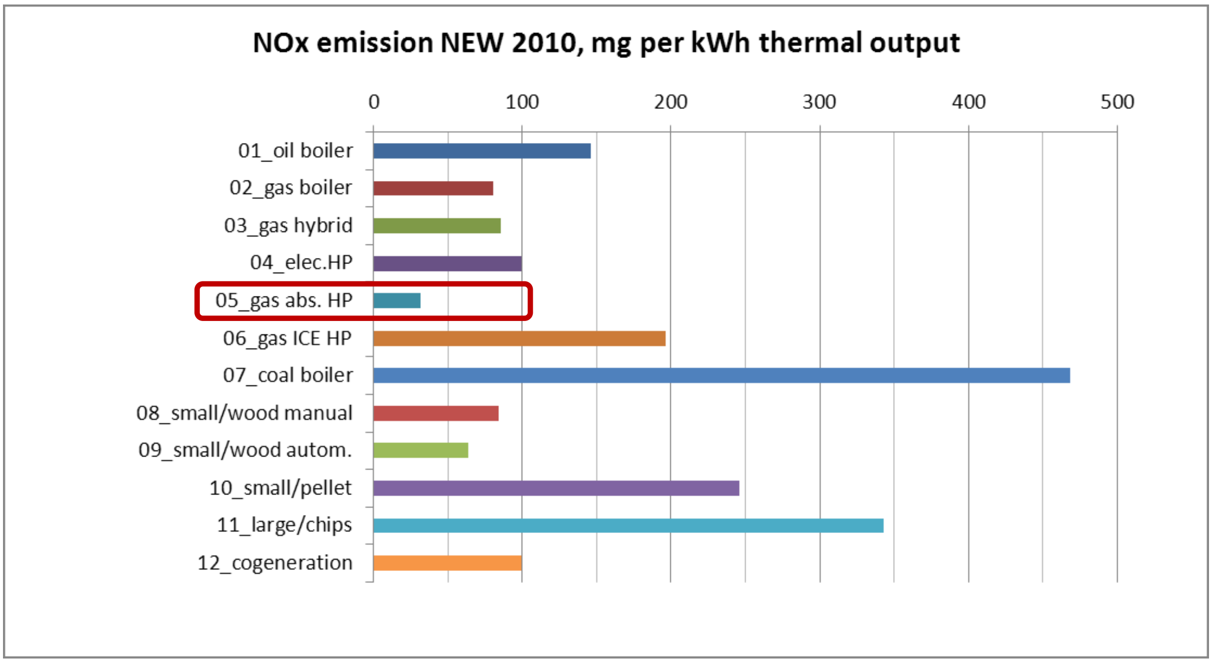

Figure 16 NOx emissions in mg per kWh thermal output for 12 base cases (VHK, 2011 for Depart of Environment of EU Commission)

Moreover, the Figure 17 below shows that GAHP have one of the lowest CO_2 emission (except biomass based solution).

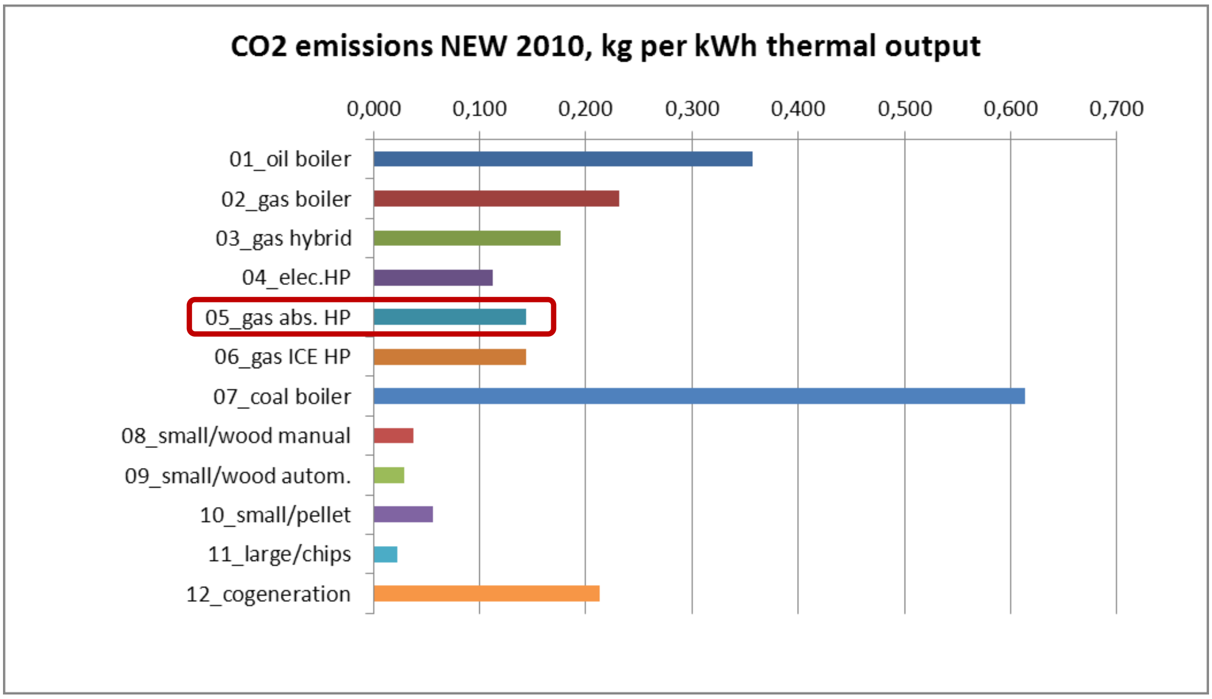

Figure 17 CO_2 emissions per kWh thermal output (VHK, 2011 for Depart of Environment of EU Commission)

The following Table 28 reports the total value of CO_2 savings, calculated for the authorization period. A value of more Blank #39 Euro/year at the end of the review period on CO_2 savings can be estimated with the use of GAHP. Such CO_2 savings can be established with the defined non-use scenario, after the transition period, too. Consequently, the monetised values of CO_2 savings are only taken into account for the four years of transition period from 2020-2023. Over this period the savings compared to a conventional boiler in form of CO_2 certificates amounts 1,792,266€ (1,574,262€ (4% discount)).

Table 28 Monetised CO_2 savings of GAHP

Average CO2 emissions per household (Heat demand: 25,000kWh/year)	4.61	t/household/year
CO2 savings	40%	Compared to regular boiler
Savings on CO2 emissions	1.842	t/unit/year
Costs of CO2 emissions (CO2 certificates)	20	Euro/t
Economic Value of CO2 saving	36.84	Euro/year/unit

Blank #40

[redacted]

All in all, gas absorption heat pumps are the technology with the lowest output of any emission and therefore it can be seen currently as the cleanest way of heating residential buildings.

5.3 Social impacts

The Marche region has an unemployment rate of 10.6% (European Commission, 2018) which is slightly below the general unemployment of Italy with a rate of 10.85% (Statista, 2018). The overall unemployment rate in Italy is at the moment above the average unemployment rate of the Euro-zone.

Ariston Thermo SpA as a local and historical company takes its responsibility to support the development of economics in the Marche region.

With the new manufacturing site dedicated to renewable energy technologies and the already existing headquarter in Fabriano, Ariston Thermo is by far the largest employers in the Marche region. By end of 2019, #41 employees in the high tech qualified industry of renewable energy, which is an important quantity in particular in Marche region, are expected to be recruited. These numbers are expected to grow continually over the following#42years. Currently the GAHP division will represent only a small percentage on the new employees, but the total number of people involved on the GAHP production will be growing and will depends upon volumes and levels of automation implemented. As rule of thumb, #43 units/year will imply a manufacturing organisation of approx. #44 people. At least a similar number could be anticipated in the presale, sales, marketing and installation, service organisations through Europe.

In case of the non-use scenario none of the mentioned employees will be hired in Italy.

Only the experts already working on the GAHP will remain during the transition period. During this period Ariston Thermo SpA will require to work with double of resources. Local experts need to train the colleagues from Far-East. After this training phase the experts in Italy will get unemployed. As these are highly skilled experts it is very unlikely that they will remain unemployed over a longer period. Consequently the unemployment of these experts will not count any further in the CBA.

5.4 Wider economic impacts

Granting authorisation for GAHP could reduce the pressure on the upgrade of the electrical grid resulting from the pressure on electrification of heating (and electrical mobility). Additionally, with a successful market implementation, several competitors would follow and further developments on this technology would raise the importance of the product category.

This would result in a change of the supply chain from a vertical integrated one to a more traditional supply chain. Such improved manufacturing environment will in the end lead to lower end prices for the end-consumer.

Savings on heating costs as described under 5.1.2 for the end-user of yearly approximately 700€ and the fast increase of awareness for the GAHP technology, will open the opportunity for parallel market for distributors, retailer and installers.

The non-use scenario with the production of GAHP in Far-East and the import to Europe will allow all of the above described wider economic impacts, but with a delay of several years. The non-use scenario would significantly reduce the ability for Ariston Thermo SpA to lead the technology introduction.

5.5 Distributional impacts

The socio-economic analysis does not only affect Ariston Thermo SpA. To emphasise the points mentioned above, the distributional effects on the costs and benefits of continued use are presented in Table 29.

Table 29 Distributional impacts for continued use

Distributional effects on supply chain	Costs of continued use	Benefits of continued use	Explanations
Supplier	/	/	Ariston Thermo SpA would buy only very small amounts sodium chromate within the first 3 years (less than 1t/y). Reaching the total production amount, the tonnage remains still under 10t/y.
Ariston Thermo SpA	/	18,745,883 (4%discount)	Shifting the production to Far-East would

			result in a delay of product implementation of at least 4 years. Therefore, the 4 years of transitions phase are considered in the use-/ non-use scenario comparison. A total loss of 18,745,883 (4% discount) to 21,183,977 (without discount is estimated. Additionally Ariston Thermo SpA will lose probably the advantage of being first on the market.
Wider economic actors	/	(+)	Installers and retailers will be minor affected by the non-use scenario. A Product delay would slow down the market implementation and simultaneous the opportunity on sales. Granting authorisation could reduce the pressure on the update of the electrical grid
Public	216€ (4% lower bound)€ up to 362€ (2% higher bound)		Cost for continued use could be estimated as relatively low due to high containment of

			the whole process and the low amounts of used sodium chromate. The total costs of continued used assessed via the Willingness to pay approach are 216 to 362€
	/	29,912,695€ (4% discount) #45 (4% discount) per unit	Savings on heating costs with GAHP technology is around 40% per unit per year, which is anticipated to be 700€ for an everage European family. Therefore, on single unit will save heating costs of #46 during the transition phase
	/	+	With an estimated amount of #47 units/year around #48 new jobs will be created for the GAHP manufacturing.
	/	1,574,262€ (4% discount)	GAHP could be one important jigsaw piece to fulfil the target aims on CO2 reduction. The value of the carbon saving for the transition period

			exceeds 1.5 million €

5.6 Uncertainty analysis

The analysis on the costs and benefits are based on assumptions and the presented business case. As the implementation of new products is affected by a lot of external effects of which some are unforeseen an uncertainty analysis is indispensable. The main concrete uncertainties are the development of the sales of GAHP after the product launch. It is nearly impossible to forecast the sales over the complete review period. Even for the transition period of 4 years it is hard to predict the developments of the different scenarios. Additionally, the current market prices for gas and the price for CO_2 certificates will not remain the same over the transition period. Although it is unlikely that these prices will be reduced, Ariston Thermo SpA will allocate a higher discount rate on these two points, too.

For the uncertainty analysis a, a sensitive value discount rate of 15% is considered Table 30 shows in summaries the values taken into account for the uncertainty analysis. Discount rates are applied on the combined costs for the non-use scenario.

Table 30 Uncertainty analysis

Uncertainties	*Basic assumption*	*Sensitive values*
Discount rates	*4%*	*15%*

Table 31 Outcome uncertainty assessment

	2020	2021	2022	2023	
Cost of non-use scenario					**Total**
Ariston					
Hiring program	Blank #49 [redacted]				
Training					
Equipment move					
Supply chain redefinition					
Profit loss					
Total costs Ariston					21,183,977
Public					
Savings heating costs	[redacted]				34,055,000
Environment					
CO2 savings	[redacted]				1,792,266
Total costs (without discount), €					**57,031,243**
Total costs (with discount 4%), €					**50,232,841**
Total costs (with discount 15%), €					**36,489,490**

The sensitivity analysis as presented in Table 31 estimates as an upper value 50,232,841 (4% discount) and a sensitive value of 36,489,490 (15% discount) for the impacts for the transition phase of the non-use scenario. Conclusions on the impact analysis including the upper and lower bound are presented under chapter 6.1.

6 CONCLUSIONS

Aim of this socio-economic analysis was to show that there are no suitable alternatives currently available and that the benefit of the use of sodium chromate as corrosion inhibitor outweighs the risk to Human Health.

The analysis of alternative concluded that there at present no suitable alternatives available which fulfil the requirement determined by GAHP. In addition, a replacement of the technology by already known heating appliances like boilers would put on hold improvement in terms of energy efficiency and CO_2 Emissions. Ariston Thermo SpA applies the highest technology and safety standards for the mixing and filling equipment in the new production line in Albacina. A further assessment on alternatives is planned with long term testing under real conditions. Only if such a long term testing is performed a conclusion on the suitability for the alternative can be made. A corrosion resistance must be established for at least 24 years, which reflects the lifetime of a boiler. As the process is very closely connected to other already authorised uses like for the use in refrigerators, Ariston Thermo SpA is confident to establish a communication network with the other authorisation holders and to work out a replacement of sodium chromate as corrosion inhibitor in 2039.

Table 32 shows the qualitative and quantitative outcome of the cost-benefit analysis. Based on the outcome of the chemical safety assessment, Ariston Thermo SpA estimates the human health costs for the continued use to be 216€ - 362€. Compared to the benefits between 36,489,490€ (15%) and 50,232,841€ (4%)

Another point, which could be considered in the comparison, is the cost-benefit comparison per unit. One unit per year will save the end-consumer around 700€ on heating costs and around 36€ on CO_2 emission expressed in CO_2 certification compared to a conventional boiler. The yearly savings for on single end-consumer overweight the risk of the human health impacts for the whole program for the entire review period of 20 years.

6.1 Comparison of the benefits and risk

Table 32 Comparison of costs for continued use and costs for the non-use scenario

Conclusion of Socio economic analysis	Investigation	Type of assessment	Monetised impacts
Costs continued use			
Human health impacts	Monetised damage of human health	Quantitative	216 € up to 362€
Costs of non-use scenario			
Economic impacts	Ariston Thermo	Quantitative	18,745,883€ (4%)
	Public	Quantitative	29,912,695€ (4%)
Social impacts	No new jobs, already hired experts will lose their job	Qualitative	
Environmental impacts	CO_2 savings	Quantitative	1,574,262€ (4%)
Wider economic impacts	Requirements on updated of the electrical grid	Qualitative	
	Less opportunities for energy savings for the customer	Qualitative	
	Loss of market share and competiveness	Qualitative	
Total costs considering uncertainty analysis		Quantitative	36,489,490 (15%) up to 50,232,841 (4%)
Total costs for non-use scenario		total costs non-use scenario (15%)- costs continued use = 36,489,128 €up to 36,489,274 € total costs non-use scenario (4%)- costs continued use = 50,232,625 € up to 50,232,479 € Additionally losses which are assessed qualitatively	

6.2 Information for the length of the review period

As already concluded by other applicants and agreed by ECHA, with granting authorisations for these applications, currently no drop-in alternative is either technically available or feasible. Within the assessment of alternatives in this report, Ariston Thermo SpA comes to the same conclusion.

The absorption refrigerator was already invented in the early twentieth century, but it took almost 100 years to find a solution to use this technology in an efficient way for space heating. This difficulty results from the more challenging environment for space heating applications compared to cooling applications. Absorption heat appliances require delivering very high water temperatures to heat radiators even in case of very cold outside conditions in winter. The difference in temperature (thermal lift) between the sink (radiator) and the source (outdoor air) side can easily reach temperature differences of 80°C or even more. To achieve such high thermal lifts with a good thermal efficiency the product design demands very high requirements on the system and consequently for the inhibitor. Temperature inside the appliance can reach 200°C and it frequently will operate in excess of 20 bars. Compared to the GAHP the absorption refrigerator works normally with a temperature lift of 40°C and an inner temperature of the appliance can be limited to 150°C-160°C. Cooling cycles consequently will feature lower maximum pressures of 10-15 bars.

The high requirements for a corrosion inhibitor set by the GAHP makes it even more difficult to identify a suitable alternative as shown in chapter 4.3.1.5. The identification of a potential alternative will therefore take very long. The substitution roadmap under chapter 2.4.1 shows the anticipated procedure for evaluating and testing of possible alternatives after the indication.

Due to the fact that corrosion is a very slow process and the challenging environment with the high requirements on the product design make a test under real conditions indispensable.

Furthermore, the long lifetime of such technologies of at least 24 years require a testing over a longer period to reflect the complete life expectancy of a GAHP. Even a testing under HALT conditions would require a period of 5 years to draw conclusive results.

Therefore, the whole process as described in the roadmap for substitution including monitoring/Research, Identification, Validation, Product development and Market implementation will take around 20 years.

Next to that, the GAHP is seen, not only by Ariston Thermo SpA, as one of the key enablers to achieve ambitious aims on CO_2 reduction, however, it will take time to establish the GAHP in such an economically slow market.

Ariston Thermo SpA is very aware of the health and environmental issues of sodium chromate. Therefore, all possible precaution measures within the new production facilities will be applied to reduce the risk for the workers and the general population, while minimising the concentrations of used sodium chromate with further technological developments of the product.

Ariston Thermo SpA feels that the benefits of the GAHP for the environment by CO_2 emission reduction and for the society highly overweigh the risk of the usage of sodium chromate.

In conclusion, Ariston Thermo SpA sees all points given to apply for a review period of 20 years based on the outcome presented in the socio-economic analysis.

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

Once granted the authorisation, Ariston Thermo SpA will start to implement and perform the processes described in the substitution strategy under chapter 2.4. Resources from the product development will start focusing on the development of alternatives.

Furthermore as described under chapter 2.4 the company will invest in two directions. On the one hand, technological developments on the GAHP product itself which will result in further decrease of Sodium Chromate to the very minimum possible concentration compatible with the GAHP requirements. On the other hand, real conditions and long term testing on identified possible alternatives will be established and performed.

Indeed, Ariston Thermo SpA is already currently defining a long term agreement with the local university Blank #50 for support and research of possible alternatives to substitute sodium chromate in the near future. Blank #51 was already involved in the development of GAHP and in the Heat4U project. Therefore, Ariston Thermo SpA considers this university as perfect strategic partner.

Additionally, Ariston Thermo Innovative Technologies (R&D Center of Aristonthermo for innovative/renewable technologies) is investing in creating an endurance test area where the above mentioned validation tests will be performed.

7 REFERENCES

Agrawal, Arun K. Hindin, Barry, US Patent 5,342,578, 1994-08-30

Keller, Jürgen US Patent 9,644,143 B2, 2017-05-09

Shams el Din, A.M. and Wang, L., Desalination 107, 29-43 (1996)

Downey, Sandra J., US Patent 5,547,600, 1996-08-20

Takagi, S.; Minato, K.; Satomura, M., US patent 5,377,494, 1995-01-03

Phillips, B.A.; Whitlow, E.P., US Patent 5,811,026, 1998-09-22

Keller, J. and Peters, R., US Patent 5,725,793, 1998-05-10

Erickson, D.c., US Patent 6,203718 B1, 2001-03-20

Gharbi O.; Thomas, S.; Smith, C; Birbilis, N., Chromate replacement: what does the future hold, npj Materials Degradation (2018)2:12; doi:10.1038/s41529-018-0034-5

Hannon C.L.; Mansfeld, F.B.; Gerstmann, J.; Sun, Z., Development of Corrosion Inhibitors for Absorption Heat Pumps, Proceedings of 2002 ASME International Mechanical Engineering Congress and Exposition, Nov 17-22, 2002, New Orleans, LA

Moser, H.; Zotter, G.; Kotenko, O.; Rieberer, R., The Formation of non-condensable Gases in Ammonia/Water Absorption Heat Pumps made of Stainless Steel - Literature Review and experimental Investigation; 4th IIR International Conference on Ammonia Regrigeration Technology, Ohrid, April 14-16, 2011 (www.iifiir.org)

Anna Alberini; Milan Ščasný (2014): Stated-preference study to examine the economic value of benefits of avoiding selected adverse human health outcomes due to exposure to chemicals in the European Union.

British Department of Energy & Climate change (2014a): Impacts of Leakage from Refrigerants in Heat Pumps. With assistance of Eunomia Research & Consulting Ltd, the Centre for Air Conditioning and Refrigeration Research (London Southbank University).

British Department of Energy & Climate change (2014b): RHI Evidence Report: Gas Driven Heat Pumps. Assessment of the Market, Renewable Heat Potential, Cost, Performance and Characteristics of Non-Domestic Gas Driven Heat Pumps (GDHPs). With assistance of Delta Energy & Environment Ltd. and David Strong Consulting Ltd.

Delta Energy & Environment (2012): The Delta-ee Heat Study Report.

Ecoheatcool and Euroheat & Power (2006): ECOHEATCOOL Work package 1. The European Heat Market. With assistance of Sven Werner, Norela Constantinescu.

European Chemicals Agency (2011): Guidance on the preparation of socio-economic analysis as part of an application for authorisation.

European Chemicals Agency (2013): Application for Authorisation: Establishing a reference dose response relationship for Carcinogenicity of hexavalent chromium.

European Chemicals Agency (2016): Valuing selected health impacts of chemicals. Summary of the Results and a Critical Review of the ECHA study.

European Chemicals Bureau (2005): European Union Risk Assessment Report. chromium trioxide, sodium chromate, sodium dichromate, ammonium dichromate and potassium dichromate

European Commission (2009): IMPACT ASSESSMENT GUIDELINES SEC(2009) 92.

European Commission JRC (2013): Development of European Ecolabel Criteria for Water-based Heaters. TECHNICAL REPORT.

European Union (2015): Final Report Summary - HEAT4U (Gas Absorption Heat Pump solution for existing residential buildings) | HEAT4U | FP7 | CORDIS | European Commission.

Eurostat (2014), Consumption of energy. Available online at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:Consumption_of_energy, checked 12/12/2018

Fraunhofer IWES/IBP (2017): Heat Transition 2030. Key technologies for reaching the intermediate and long-term climate targets in the building sector. Study commissioned by Agora Energiewende.

Gharbi, Oumaïma; Thomas, Sebastian; Smith, Craig; Birbilis, Nick (2018): Chromate replacement. What does the future hold? In npj Mater Degrad 2 (1), p. A402. DOI: 10.1038/s41529-018-0034-5.

Harald Moser; Gerald Zotter; Oleksandr Kotenko; René Rieberer (2013): The formation of non-condensable gases in ammonia/ water absorption heat pumps made of stainless steel - literature review and experimental investigation.

International Agency for Research on Cancer (IARC): Cancer FACT Sheets. Available online at http://globocan.iarc.fr/Pages/fact_sheets_cancer.aspx, checked on 9/12/2018.

Kemna, René; van Elburg, Martijn; Corso, Andrea (2017): CH Boilers Ecodesign and Energy Label. Task 2 (DRAFT) Market Analysis. 2nd ed. With assistance of BRG Building Solutions. Edited by VHK for the European Commission. European Commission, Directorate-.

Nadler, Diana L.; Zurbenko, Igor G. (2014): Estimating Cancer Latency Times Using a Weibull Model. In Advances in Epidemiology 2014 (1), pp. 1–8. DOI: 10.1155/2014/746769.
Natural Resources Canada’s Office of Energy Efficiency (2004): Heating and cooling with a heat pump. Rev. ed. [Ottawa]: Office of Energy Efficiency (Home heating and cooling series).

Nausha Asrar, Anees U. Malik, Shahreer Ahmed (n/a): CORROSION PREVENTION WITH SODIUM SILICATE.

Teel, R. B. (1980): The stress-corrosion cracking of steels in ammonia. -A survey- with consideration given to OTEC design. Argonne, Illinois. Available online at https://www.osti.gov, checked on 8/24/2018.

Terry Brown, John Cherrie, Martie Van Tongeren, Léa Fortunato, Sally Hutchings, Lesley Rushton (2012): The burden of occupational cancer in Great Britain – Lung cancer. (Research report 858).

The European Heat Pump Association EEIG (EHPA) (2010): EHPA Outlook 2010. European Heat Pump Statistics.

Treasury, H. M. (2018): The Green Book. CENTRAL GOVERNMENT GUIDANCE ON APPRAISAL AND EVALUATION.

Dometic GmbH, Analysis of Alternatives and Socio-economic Analysis, Sodium chromate, EC 231-889-5, CAS 7775-11-3, 2015-05-18 as published on https://echa.europa.eu/applications-for-authorisation-previous-consultations

Arlanxeo Netherlands B.V. , (application transfereed from original Applicant Lanxess Elastomers B.V.), Analysis of Alternatives, Sodium dichromate, CAS No. 10588-01-9, 7789-12-0, EC No. 234-190-3, 2015-11-10 as published on https://echa.europa.eu/applications-for-authorisation-previous-consultations

H&R Ölwerke Schindler GmbH, Analysis of Alternatives, Sodium dichromate CAS No. 10588-01-9, 7789-12-0, EC No. 234-190-3, 2017-11-20 as published on https://echa.europa.eu/applications-for-authorisation-previous-consultations

TOTAL Raffinerie Mitteldeutschland GmbH, Analysis of Alternatives, Sodium dichromate CAS No. 10588-01-9, 7789-12-0, EC no. 234-190-3, 2016-02-22 as published on https://echa.europa.eu/applications-for-authorisation-previous-consultations

Borealis Plastomers BV, Analsisis of Alternatives (AoA) and Socio-economic Analysis (SEA), Sodium dichromate, CAS No. 10588-01-9, 7789-12-0, EC No. 234-190-3, 2016-02-

15 as published on https://echa.europa.eu/applications-for-authorisation-previous-consultations

Jacobs Douwe Egberts DE GmbH, Analysis of Alternatives, Sodium dichromate CAS No. 10588-01-9, 7789-12-0, EC no. 234-190-3, 2016-02-10 as published on https://echa.europa.eu/applications-for-authorisation-previous-consultations

European Energy Exchange AG, European Emission Allowances (EUA), https://www.eex.com/de/marktdaten/umweltprodukte/spotmarkt/european-emission-allowances#!/2018/11/20, access date, 13.11.2018

APPENDIXES

1 Appendix: Classification of assessed drop-in inhibitors according to (EG) Nr. 1272/2008

Table 33 Classification of assessed inhibitors

No	Name	CAS	Classification
-	Sodium chromate	7775-11-3 (sodium chromate)	Acute tox 2* (inh.) Acute Tox. 3* (oral) Acute Tox. 4* (dermal) Skin corr. 1B Skins sens. 1 Resp. Sens. 1 Muta. 1B Carc. 1B Repr. 1B STOT RE 1 Aquatic Acute 1 Aquatic Chronic 1 (harmonised classification)
1	Soluble silicon compounds	6834-92-0 (sodium silicate)	Skin Corr. 1B STOT SE 3 (resp. irrit.) (harmonised classification) Eye Dam. 1 Met. Corr. 1 (additionally in REACH registration dossiers)
		various soluble sodium silicates, water glass 1344-09-8 (sodium silicate) 6834-92-0, 13517-24-3 (disodium metasilicate)	Skin Corr. 1B Eye Dam 1 STOT SE 3 (resp. irrit.) Met. Corr. 1 (REACH registration dossiers)
		1312-76-1 (potassium silicate)	
		13870-28-5 (disodium disilicate)	Eye Dam. 1 (REACH registration dossiers)
		12627-14-4 (lithium silicate)	Eye Dam. 1 STOT SE 3 (resp. irrit.) (REACH registration dossiers)

2	Molybdates	7631-95-0 (sodium molybdate)	not classified (REACH registration dossiers)
3	Sodium nitrite	7632-00-0 (sodium nitrite)	Ox. Sol. 3 Acute Tox. 3* (oral) Aquatic Acute 1 (harmonised classification)
4	Zinc containing corrosion inhibitors	7646-85-7 (zinc chloride)	Acute Tox. 4* (oral) Skin Corr. 1B Aquatic Acute 1 Aquatic Chronic 1 (harmonised classification)
5	Strong alkaline solutions	1310-73-2 (sodium hydroxide)	Skin Corr. 1A (harmonised classification) Met. Corr. 1 Eye Dam. 1 (additionally in REACH registration dossiers)
		1310-58-3 (potassium hydroxide)	Acute Tox. 4* (oral) Skin Corr. 1A (harmonised classification) Met. Corr. 1 (additionally in REACH registration dossiers)
		21351-79-1 (caesium hydroxide)	Acute Tox. 4 (oral) Skin Corr. 1A Eye Dam. 1 Repr. 2 STOT RE 2 (REACH registration dossiers)
		1310-65-2 (lithium hydroxide)	Acute Tox. 4 (oral) Skin Corr. 1B Eye Dam. 1 Repr. 2 (REACH registration dossiers)
6	Phosphates and phosphonate compounds	7601-54-9, 10101-89-0, 56802-99-4 (trisodium orthophosphate)	Skin Irrit. 2 Eye Irrit. 2 STOT SE 3 (resp. irrit.) (REACH registration dossiers)

7	Rare Earth Metal Salts (REMSs)	10108-73-3, 10294-41-4 (cerium nitrate)	Eye Dam. 1 Aquatic Acute 1 Aquatic Chronic 1 (REACH registration dossiers)
8	Inhibitor 7	not known	Eye Irrit. 2A Acute Tox. 3 Aquatic Acute 1 (Dometic GmbH, 2015)