

Final Report
on the

**Costs and the impact on emissions of potential
regulatory framework for reducing emissions of
hydrofluorocarbons, perfluorocarbons and
sulphur hexafluoride
(B4-3040/2002/336380/MAR/E1)**

Prepared on behalf of the
European Commission (DG ENV)

by

Jochen Harnisch (Ecofys) & Winfried Schwarz (Öko-Recherche)

Contact:

Ecofys GmbH
Jochen Harnisch
Landgrabenstr. 94
90443 Nürnberg
Germany
phone: +49 911 9944677
j.harnisch@ecofys.de

February 4, 2003

Content

| | | |
|-----------------|---|-----------|
| <u>1</u> | <u>INTRODUCTION</u> | 3 |
| <u>2</u> | <u>METHODS</u> | 4 |
| 2.1 | <u>SCOPE OF THE MONITORING SYSTEM</u> | 4 |
| 2.2 | <u>SELECTION OF APPLICATIONS FOR PROHIBITIONS</u> | 5 |
| 2.3 | <u>INFORMATION COLLECTION</u> | 7 |
| 2.4 | <u>EMISSION ESTIMATES AND PROJECTIONS</u> | 7 |
| 2.5 | <u>SELECTION OF EMISSION REDUCTION OPTIONS</u> | 8 |
| 2.6 | <u>COST ESTIMATES</u> | 8 |
| <u>3</u> | <u>MONITORING</u> | 9 |
| 3.1 | <u>SCOPE AND BENEFITS</u> | 9 |
| 3.2 | <u>COSTS OF THE SYSTEM</u> | 10 |
| 3.3 | <u>CONFIDENTIALITY ISSUES</u> | 11 |
| 3.4 | <u>ORGANISATIONS CONSULTED</u> | 11 |
| <u>4</u> | <u>MARKETING AND USE RESTRICTIONS</u> | 12 |
| 4.1 | <u>APPLICATION: SF₆ IN CAR TYRES</u> | 12 |
| 4.2 | <u>SF₆ IN SOUND INSULATING GLAZING</u> | 15 |
| 4.3 | <u>SF₆ IN SPORT SHOES</u> | 22 |
| 4.4 | <u>SF₆ IN MAGNESIUM DIE CASTING</u> | 24 |
| 4.5 | <u>HFCs IN SELF-CHILLING BEVERAGE CONTAINERS</u> | 32 |
| 4.6 | <u>HFCs IN ONE COMPONENT FOAMS</u> | 34 |
| 4.7 | <u>HFCs IN NOVELTY AEROSOLS</u> | 40 |
| 4.8 | <u>HFCs AS SURFACE CLEANING SOLVENTS</u> | 45 |
| 4.9 | <u>PFC AS FIRE FIGHTING AGENTS</u> | 49 |
| <u>5</u> | <u>SUMMARY OF QUANTITATIVE RESULTS</u> | 52 |
| <u>6</u> | <u>REFERENCES</u> | 55 |
| <u>7</u> | <u>GLOSSARY</u> | 57 |

1 Introduction

The final report of the European Climate Change Programme (ECCP, 2001a) recommended a number of dedicated actions to limit emission of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF₆) in Europe:

Recommendation 1: Make a clear political statement on the importance of reducing fluorinated gas emissions

Recommendation 2: Establish a regulatory framework in a “Community Directive on Fluorinated Gases”

The key objectives of such a Directive would be:

- Improved monitoring and verification of emissions of fluorinated gases.
- Improved containment of fluorinated gases.
- Marketing and use restrictions in certain applications, such as SF₆ in tyres and windows.

Recommendation 3: Use existing or planned EU legislation to the extent possible for the reduction of fluorinated gases

Recommendation 4: Examine the appropriateness of selected voluntary agreements primarily in the semi-conductor, switchgear and foam sector

Recommendation 5: Carry out integrated, independent assessments of relevant technologies in order to facilitate a comparison between the use of fluorinated gases and alternatives

Recommendation 6: Promote the development and appropriate use of alternative fluids and not in kind (NIK) technologies

This analysis explicitly addresses items one (“Improved monitoring and verification of emissions of fluorinated gases”) and three (“Marketing and use restrictions in certain applications”) of the ECCP’s recommendation 2 on the a regulatory framework on fluorinated gases. Item two of (“Improved containment of fluorinated gases”) has been addressed by a separate study.

Our report is structured in a way to permit an optimal accessibility of information required in the legislative process. It is strongly recommended that readers also consult the final report of the ECCP on fluorinated gases (ECCP, 2001b) which gives an overview of all relevant sectors affected and the perspectives beyond the measures addressed here.

The report represents the views of its authors and not necessarily those of the Commission.

2 Methods

In this chapter an overview is given over the key methodological issues relevant for this analysis. As pointed out for the whole report it is structured in a way to permit an optimal accessibility of information required in the legislative process.

2.1 Scope of the monitoring system

The ECCP working group had concluded in 2001 that in only very few sectors an effective monitoring system for emissions of HFCs, PFCs and SF₆ was operational (Table 1). For the legislation under development the Commission has concluded not to impose comprehensive obligations on businesses to estimate and report their emissions at this stage.

Table 1 Existence of emission monitoring systems in key market sectors - after ECCP (2001b)

| SECTOR | MONITORING SYSTEM |
|--|---|
| Refrigeration & Stationary Air Conditioning | not existing* |
| Mobile Air Conditioning | not existing* |
| Technical Aerosols | being set up by FEA for the consumption of HFCs |
| Metered Dose Inhalers | not existing |
| Solvents | not existing |
| Fire-Fighting | not existing |
| SF ₆ in Tyres & Windows | not existing |
| Aluminium Production | operated by EEA |
| Semiconductor Production | operated by EECA |
| Emissions of HFC-23 | operated by EFCTC |
| Magnesium Production | not existing |
| Production & Use of SF ₆ switchgear | being set up by CAPIEL / EURELECTRIC |
| Foams: PU, PIR, Phenolics | not existing |
| Foams: XPS | not existing |
| One Component Foams | not existing |
| Others (Misc. and M&D losses) | not existing |

* Monitoring systems exist for systems with more than 3 kg of refrigerant in at least one Member State

Instead the Commission is considering to request a reporting of production and sales into broad categories, as well as export and import of HFCs, PFCs and SF₆ analogous to those in place for ozone depleting substances under EC Regulation 2037/2000. It is envisioned that this information will provide a valuable cross-check of emissions estimates at low costs.

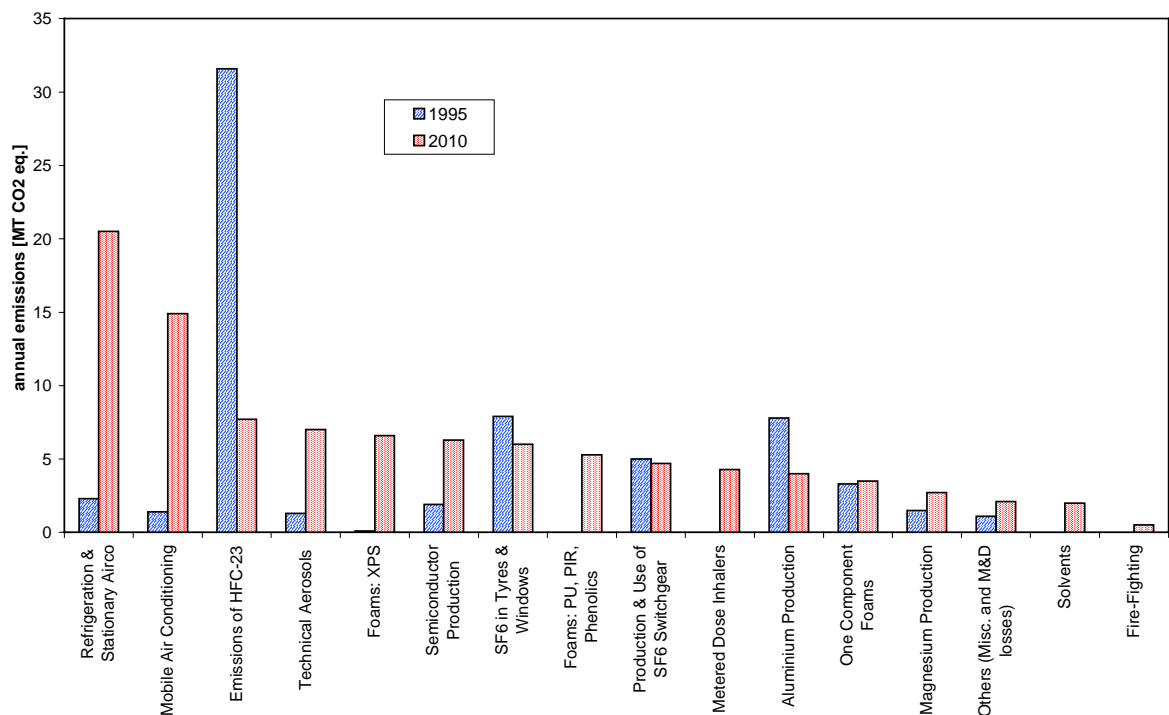
2.2 Selection of applications for prohibitions

2.2.1 Introduction

The selection of candidate sectors for use restrictions has been the result of an iterative process. At the inception of the project the following classification had been proposed by the consultants based on the criteria of

- technical availability of alternative,
- acceptable overall health, safety and environmental performance of the alternative,
- acceptable cost effectiveness of the alternative,
- likely ineffectiveness of other instruments to control emissions and
- no tangible effects on international trade.

These criteria were applied to the different sectors covered by the working group on the



fluorinated gases of the European Climate Change Programme (Figure 1).

Figure 1 Overview of estimated and projected emissions of fluorinated gases from different applications for 1996 and 2010 – after ECCP (2001b).

2.2.2 Candidate applications

Subsequent analyses have led to the selection of the following nine candidate application – substance combinations¹:

¹ Some reviewers of the draft report have remarked that additional applications should be added to the list. However, limited resources and the advanced state of the process precluded its amendment.

- SF₆ in car tyres
- SF₆ in sound insulating glazing
- SF₆ in sport shoes
- SF₆ in magnesium casting
- HFCs in self-chilling beverage containers
- HFCs in one component foams
- HFCs in novelty aerosols
- HFCs for surface cleaning
- PFCs in fire-fighting

2.2.3 Criterion on health, safety and environment

In considering the available alternative technologies it is important to determine whether these are acceptable in respect to health, safety and the environment. Minimum acceptability requires compliance with Community and Member State legislation.

It is important to recognise, however, that there are practical limitations on what can be achieved within the scope of this study. Within the community developing and applying life cycle assessments (LCA) of products it is generally recognised that an integrated quantitative analysis of environmental, health and safety issues is not possible for the foreseeable future. Even for a selection of major environmental issues the same limitations are widely accepted to apply.

To avoid significant environmental disbenefits as a consequence of the implementation of climate policies, several criteria can be envisioned to compare an alternative technology to the respective technology employing fluorinated fluids. In principle the preferred technology could be required to demonstrate, e.g.

- a) superiority in all major environmental aspects,
- b) net environmental superiority across environmental aspects by means of an LCA,
- c) optimum environmental cost effectiveness across environmental aspects, or
- d) dominant impact on greenhouse gas emissions relative to other environmental aspects.

Criterion a) will obviously not often be met by any real technology and would thus impede innovation. Criterion b) can only be checked as part of a resource intensive process involving a number of critical assumptions and value judgements. It is thus regarded as inappropriate for this exercise. Criterion c) while theoretically attractive is methodologically still underdeveloped and too data-intensive to be practical for this exercise. The conceptually least demanding criterion d) solely requires that the proposed measures has greatest specific impact on greenhouse gas emission in comparison to potential draw-backs in other environmental dimensions (e.g. measure A leads to a reduction of EU ghg-emissions by 0.5% but increases EU VOC-emissions by 0.02%). In the context of this study, the application of criterion d) was the only practicable approach.

2.2.4 Greenhouse gas vs. VOC emissions

The comparison of greenhouse gas emission reductions greatly relies on the availability of accepted standard metrics for weighing the different substances according to their environmental impact within the dimension in question. For greenhouse gases this metric is the global warming potential (GWP) over a 100 year period as reported by

IPCC (1996). For volatile organic compounds (VOC) a widely accepted metric is not available due to the regional differences in terms of background air pollution and the many non-linearities of tropospheric ozone chemistry. Annex IV to the 1991 Protocol to the 1979 Convention on long-range trans-boundary air pollution, however, gives an overview of the resulting weighting factors obtained for different VOC species in different regions. Apart from CO₂ the typical HFC replacement compounds like propane, n-butane, n-pentane and dimethylether exhibit weighting factors in a range of 10-60% of the reference compound ethylene, corresponding quite well to the range of values found for the most common VOCs like toluene, benzene or xylene. In comparison HFCs have much lower values typically in the range of 0.1 to 1% (Hayman and Derwent, 1997). Due to a lack of better data on emissions and appropriate weighting factors we here use mass-fluxes of VOCs without weighting for our comparison. For the sake of simplicity we consider HFCs as fully ozone-neutral.

EU-wide emissions of greenhouse gases in the year 1999 amounted to 3836 MT CO₂ eq. (EC, 2001). The respective EU VOC anthropogenic emissions are estimated to be 12 MT of non-methane VOCs (EC, 2001). If say 10 KT of HFC emissions such as 134a is reduced by the same volume of a non-methane VOC such as butane (corresponding to 5 KT) the respective effects are found to be: 0.3 % in terms of CO₂ eq. and 0.04 % in mass terms of non-methane VOCs. The same calculation for HFC-152a results in 0.04 % for both climate change and VOCs. Based on these calculations and taking into account the fact that anthropogenic VOCs are not the only drivers of tropospheric ozone formation, it can be concluded that the relative contribution to ozone formation through HFC-alternatives is generally overcompensated by the relative contribution which emission reduction of HFCs make to mitigate climate change.

2.3 Information collection

For this study ECOFYS and Öko-Recherche have applied their well established investigative method of collecting information. This mainly involves interviews with individual company representatives. In the past it has been demonstrated that this approach yields very up-to-date information on available and evolving technologies, their performance and costs (e.g. Öko-Recherche 1996 and 1999; ECOFYS, 1999 and 2000).

2.4 Emission estimates and projections

It is important to note that on the required level of technical detail virtually no reliable and up-to-date emissions data are available for HFCs, PFCs and SF₆ for any of the EU Member States. For each of the applications it was therefore necessary to collect the required activity and sales data from the affected industries involving a number of extrapolations and generalisations. The level of accuracy and degree of completeness achievable within the timeframe of this project unavoidably results in certain limitations.

For the projection of emissions in 2010 the “frozen-technology” approach was chosen. Accordingly, consumption and technology pattern are assumed to remain constant from today to the end of the first commitment period of the Kyoto Protocol. Deviating from this, emission reductions resulting from policies and measures already implemented are also included. It is important to note that “frozen-technology” does not imply constant emissions. The delayed effect on emissions from past actions is captured as well as

future sector growth. Sector specific growth rates are applied, a value of +3% per annum is used as the default².

2.5 Selection of emission reduction options

Emission reduction options selected for this analysis had to meet the criterion of commercial availability in the EU in the year 2002 including a sufficient number of references well beyond prototype applications. This included the implicit pre-requisite of compliance with current health, safety and environmental regulation on the community level and in the affected Member States.

2.6 Cost estimates

The emission reductions are calculated on an annual basis. All cost data of this report are calculated as 2000 Euros. Abatement costs were calculated from the sum of annualised investment costs and annual operating and maintenance costs divided by mean annual emission savings:

$$\text{Specific costs} = \frac{\text{Annualised capital costs} + \text{annual O \& M}}{\text{Annual abated CO}_2\text{emission}}$$

The annual operation and maintenance costs were assumed to remain fixed over the depreciation period. The annualised capital costs are calculated by multiplying the total investment with the annuity factor, where d = the discount rate ($100\%=1$) and n is the depreciation period of the measure in years:

$$\text{Annuity Factor} = \frac{d}{(1 - (1 + d)^{-n})}$$

Investment costs were annualised over a depreciation period in a manner specific to the affected sector. Here 10 years are used as default value with discount rates of 10 % p.a. to conservatively resemble industrial procedures on investment decisions. Only for stationary applications in the building sector (sound-insulating glazing, fire fighting installations) a default depreciation period of 15 years was used. Moreover, in case of investments in the building sector a macro-economic discount rate of 4% p.a. instead of 10% was used.

² Taking into account the current global economic slowdown this value potentially over-estimates actual growth in most relevant sectors.

3 Monitoring

3.1 Scope and benefits

3.1.1 Application fields

The ECCP Working Group in 2001 considered that measures should be put in place to improve the coverage and accuracy of emissions monitoring in order to support Member States to comply with their obligations under the Framework Convention on Climate Change (UNFCCC). During the work of the ECCP it became clear that during a starting phase this endeavour could at least partly rely on voluntary reporting by industry associations.

To complement these industry actions it was proposed by members of the ECCP Working Group to create a monitoring structure for HFCs, PFCs and SF₆ similar to the one laid out in EC legislation 2000/2037 for ozone depleting substances. This approach monitors sales (analogous to the requirements under the Montreal Protocol) but does not aim to directly estimate emissions (as required under the UN Framework Convention on Climate Change). To monitor sales of HFCs, PFCs and SF₆ a differentiation into the application fields as used for the global AFEAS reporting has been proposed. AFEAS companies report their global sales of ozone depleting substances and HFC-134a into the application fields of:

- Refrigeration and Air Conditioning,
- Closed Cell Foams,
- Medical Aerosols
- Solvent Applications,
- Other Short-Term Uses.

Due to the wider application of the whole group of HFCs, PFCs and SF₆ we have assumed a modified classification for reporting:

- a Refrigeration and air conditioning (HFCs and PFCs)
- b Closed cell foams (HFCs)
- c Medical aerosols (HFCs)
- d One component foams and non-medical aerosol products (HFCs)
- e Semiconductor industry (HFCs, PFCs and SF₆)
- f Magnesium casting (SF₆ and HFCs)
- g Switchgear manufacture and use (PFCs and SF₆)
- h Other mid- to long term uses (HFCs, PFCs and SF₆), e.g. fire-fighting or glazing
- i Other short-term uses (HFCs, PFCs & SF₆), e.g. solvents, car tyres, sport shoes

It is recognised that producers, importers and exporters will often find it difficult to report an accurate break-up of sales into these end-use categories due to the important role of gas distributors for many applications. Based on their knowledge of the respective markets we have assumed that sufficiently reliable estimates could be produced.

3.1.2 Expected benefits

It is expected that the reported market data in combination with a suitable European emission model will allow emission estimates reported by the Member States to be validated by the Commission.

3.2 Costs of the system

We here differentiate between three different groups of organisations affected by a new monitoring system: enterprises with reporting obligations under EC Regulation 2037/2000 (Group A), those without such obligations under 2037/2000 (Group B) and the European Commission.

3.2.1 Setting up the system

It can be assumed that the setting-up of the monitoring system will be a straight-forward procedure duplicating what is already taking place under 2037/2000. No methodological developments will be required.

Based on information obtained from EFCTC it is estimated that the following costs will arise from setting up the monitoring system in each of the mentioned categories of organisations:

- Group A: 5 days per enterprise – defining the appropriate calculation procedures
- Group B: 15 days per enterprise – defining the appropriate calculation procedures
- EC: 2 days – Climate Change unit of DG Environment

3.2.2 Operating the system

Based on information obtained from EFCTC it is estimated that once the system has been established, annual requirements arise for each of the organisations:

- Group A: additional 10 days – data mining and conversion, liason with external auditors and environmental enforcement agencies
- Group B: 15 day – data mining and conversion, liason with external auditors and environmental enforcement agencies
- EC: €2000 p.a. supplementary funding of auditor of 2037/2000 data
2 days for evaluation of data

3.2.3 Number of affected businesses

Based on information provided by EFCTC, the European Commission and our own research we estimate that the following number of enterprises will have reporting requirements:

- Group A: An estimated 40% of the 150 big or specialised enterprises with reporting obligations under 2037/2000: 60 enterprises
- Group B: A number of suppliers and of technical gases (e.g. Linde), exporters of equipment e.g. containing SF₆ (e.g. ABB or Siemens) or specialised suppliers e.g. to the semiconductor industry: 30 enterprises

3.2.4 Total costs

Using the estimates made above and applying a uniform value for labour costs of €375 a day for each of the organisations we calculate the total cost data as given in Table 2.

Table 2 Initial and recurring costs for the monitoring system

| | Affected Organisations | Labour Costs p.e. | Other costs p. | Total |
|--------------------------------------|-------------------------------|--------------------------|-----------------------|-----------------|
| Initial | | | | |
| Enterprises reporting under 2037 | 60 | € 1,875 | - | €112,500 |
| Enterprises not reporting under 2037 | 30 | €5,625 | - | €168,750 |
| Commission | 1 | € 750 | - | € 750 |
| TOTAL | - | - | | €282,000 |
| | | | | |
| Annual | | | | |
| Enterprises reporting under 2037 | 60 | €3,750 | - | €225,000 |
| Enterprises not reporting under 2037 | 30 | €5,625 | - | €168,750 |
| Commission | 1 | €750 | €2,000 | € 2,750 |
| TOTAL | | | | €396,500 |

3.3 Confidentiality issues

The commercially most relevant compound HFC-134a (and its blends) has a number of different producers, importers and exporters within the EU lending it an exceptional position in terms of confidentiality requirements for reporting. For most other fluorinated gases involved there seem to be too few participants to exclude a back-calculation of individual companies' sales of a specific compound into a specific application field.

A way to avoid this problem could be an aggregated disclosure of sales data by the Commission for each of the sectors listing data for HFC-134a and a group of all other HFCs. The reported raw data per application, compound and organisation could be retained by auditors appointed by the Commission as currently happens for the data reported on ozone depleting substances.

3.4 Organisations consulted

EFCTC was consulted regarding its views on a monitoring of the production, import and export of HFCs, PFCs and SF₆. It expressed a strong preference for a monitoring of emissions on an EU level. EFCTC also provided information on the likely number of businesses getting reporting obligations under a monitoring system of the production, import and export of fluorinated gases.

Linde Technical Gases was contacted to get an understanding of the differentiation of sales data available to a major gas distributor.

DG Environment of the European Commission has provided the necessary information to estimate incurring costs.

4 Marketing and use restrictions

4.1 Application: SF₆ in car tyres

4.1.1 Description of application

The concept of filling car tyres with SF₆ instead of air goes back to 1984 when Germany's leading car-tyre company Continental invented the "Air Safe" system. The SF₆ molecules, being larger than those of air, diffuse more slowly through the rubber. That should guarantee "stable tyre pressure for 1 year and longer".

4.1.2 Evolution of emissions

To fill the four tyres of a passenger car (spare tyres are not filled so) about 1 kg SF₆ is necessary. In the mid-1990's any interested car-owner in Germany could have filled his car tyres in one of 500 retail outlets of the German tyre trade for a price of about 50 Euro. Because of the influence of Continental (the inventor) on markets next to Germany, customers there were also occasionally offered to buy SF₆ in car garages and tyre outlets. This was especially the case in Austria and to some degree also in the eastern areas of France, Belgium and the Netherlands. By far the biggest single SF₆ market for car tyre filling has been Germany. According to gas vendors the EU market size for this application can be approximated by adding 20% to the German consumption. Accordingly, SF₆ consumption for this application rose in the EU to more than 100 t/a and peaked in 1995 at 150 t. As the emissions follow consumption with a delay of approx. 3 years when tyres need to be changed the emissions peaked at 150 t 1998 (Table 3).

Around the summer of 1996, Continental ceased to directly supply the tyre trade with SF₆, but left it up to the tyre traders to continue to satisfy customer demand. Other tyre trade chains, up to then not involved in SF₆ filling, started to offer nitrogen as the "green" alternative and also the two main trade chains formerly in the SF₆ business ceased offering SF₆ and/or began to offer nitrogen.

The SF₆ consumption within EU-15 dropped significantly since 1996 to a level of 5 t in 2001. (Numbers in the following table are communicated by the only relevant gas traders for this application [Linde/Chemogas 50%, Messer 50%], in tonnes).

Table 3 Car tyres: 1996-2010 SF₆ consumption and emissions in t SF₆ in the EU - Scenario "frozen technology"

| | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2010 |
|-----------------------------|------|------|------|------|------|------|------|------|------|------|
| SF ₆ consumption | 80 | 60 | 35 | 11 | 7 | 5 | 5 | 5 | 5 | 5 |
| SF ₆ emission* | 140 | 144 | 150 | 80 | 60 | 35 | 11 | 7 | 5 | 5 |

* Emissions follow consumption with a delay of approx. 3 years when tyres are changed.

If the consumption level of 2001 remained constant until 2007, namely 5 t per annum ("frozen technology"), emissions would follow by 2004 down to this value, where they would remain until 2010.

4.1.3 Available emission reduction options

Meanwhile, the SF₆ filling of car-tyres is requested only occasionally. The customers are only a few (some 5,000) people, believing in the advantage of that system. The big majority of the car holders use air to fill the tyres as they did always before. Most former users of SF₆ have either switched to nitrogen offered by some tyre traders and garages as the more eco-friendly alternative or have reverted back to using air.

4.1.4 Achievable emission reductions

The emissions dropped from 1998 to 2004 by a considerable 96 %, as a result of voluntary actions, or – in absolute numbers – from 3.6 MT to 0.120 MT CO₂-eq. A – technically seen – unproblematic general prohibition of SF₆ filling into car tyres would lead to zero emissions three years after the prohibition of consumption has entered in force, saving 0.120 MT CO₂-eq.

4.1.5 Specific costs of reduction options

A general prohibition of SF₆ filling into car tyres would result in net savings to customers and society as to inflate the cars by air is much less expensive. Taken the EU wide 2001 consumption of 5 tonnes as constant, the saving of the customers would amount to (50 €/per kg) 250,000 € annually. The calculated cost-effectiveness is –2 € per ton of CO₂ eq. for the end user who moves back to filling his tyres with air.

4.1.6 Affected economic sectors and impact of measures

The effect of a prohibition of SF₆ in this application would be limited to the private sector. Mild impacts would be seen in the affected garages (service sector) and by the limited number of private consumers who continue to request SF₆. For the manufacturer of SF₆ and the respective distributors this part of their sales has declined rapidly and must be considered as insignificant.

Peaking in 1995 about 600 medium sized shops and garages had been involved in selling SF₆ to about 150,000 car holders. Roughly 80 % of the shops and garages involved were (are) situated in Germany, the others in Austria, Belgium, the Netherlands, and France.

The shops' and garages' extra earnings from the filling service had peaked at overall € 7.5 million, meanwhile having dropped to just € 0.25 million. The net earnings, of course, were and are only about half as much as the producers and distributors of the gas had and have to be paid and labour costs have to be considered.

4.1.7 Recommendations

It is recommended to immediately prohibit the use of SF₆ to inflate tyres.

4.1.8 Organisations consulted

The inventor of the SF₆ filling of car tyres, the German tyre company Continental, has issued an official statement to the consultants explaining the reasons for introducing that system (keeping the tyre pressure a longer time constant permitting optimum rolling resistance) as well as the reasons for ceasing (environmental and safety aspects, the latter neglecting the regular pressure monitoring on customers' side).

The tyre dealers and garages formerly selling SF₆ (e.g. Stinnes Reifendienst) and further tyre chains (point S, Reifenring) are focussing on nitrogen as a filling gas for clients who are looking for a less ordinary solution than air.

None of consulted organisations continued to defend the use of SF₆ as a tyre gas any longer.

Referring to the main SF₆ distributors (Linde, Messer), SF₆ for the tyre application represents only a marginal part of their entire gas business, whose elimination would not have any significant effect on their total turnover.

Apparently these companies as well as the only remaining producer of SF₆ within the EU have accepted the decline of demand for SF₆ for "open" applications and are in the process of concentrating their business on "closed" applications which they consider more secure markets in the long-term.

4.2 SF₆ in sound insulating glazing

4.2.1 Description of application

In the 1970s, single glazing in windows and glass facades was superseded by double glazing. Since 1975, occasionally SF₆ has been filled into the space between the panes in order to improve the sound-insulating effect in Central Europe. Compared to glazing filled with air or noble gases, SF₆ enhances the sound insulating value by additional 2 decibel (dB) in the relevant range to building acoustics of 35-50 dB⁴. 5 dB is perceived by people as a halving of noise.

The sound-insulating effect results from the reduced velocity of sound in heavy gases by some threefold compared to air. SF₆, being a very heavy gas, is therefore suited for sound insulation - but not for thermal insulation. In the latter function, SF₆ is poorer than air. Argon is the gas used for thermal insulation in glazing.

The function and lifetime of all insulating glazing depends decisively upon the gas-tightness of the edge seal design. The outer sealing of the glazing rim must prevent both outward gas losses and the inward penetration of water vapour for as long as possible. Depending upon geography and climate, the normal lifetime of soundproof windows is between 15 and 30 years, averaging in Central Europe at 25 years. The most important limiting factor is the diffusion of water vapour, which gradually exceeds the capacity of the desiccant inside the space to bind it and to maintain a moisture balance in the interspace, with the result of inside condensation at lower temperatures.

4.2.2 Three different emission categories

SF₆ emissions from soundproof windows must be distinguished according to three different categories of filling losses, use phase emissions and disposal losses. Their respective quantitative impact changes over time.

A. Filling Losses (Overfilling)

Of the annual SF₆ consumption for soundproof windows, roughly 33% arise as filling emissions in the year of fabrication of the glazing (IPCC 2000). Both in hand-held equipment and in automatic gas filling presses, turbulence in the interior is unavoidable, so that not only residual air but also an air-SF₆ mixture escapes. The resultant gas loss, the overfilling, ranges from 30 to 60% of the fill, averaging 50% of the effectively filled quantity. Filling losses occur exclusively in the year of fabrication and are directly proportional to annual SF₆ consumption.

B. Use Phase Emissions

Use phase emissions are the gas losses from the filled glazing throughout its entire lifetime, which averages 25 years. Use phase emissions are assumed to be 1% per annum (IPCC loc. cit.). This contains both continuous gas losses through the edge seal and gas losses through glass breakage before and during use.

⁴ The sound reduction values of different glazing systems expressed by dB as used in this study are equivalent to the Weighed Sound Reduction Indices R_w according to ISO 717-1:1996.

C. Disposal Losses

The emissions of the third category, disposal losses, only occur at the end of the use phase of the glazing – usually about 25 years after the filling emissions. While a reprocessing concept for disposal of filled equipment is already introduced for SF₆ in electrical equipment, in the soundproof window sub-sector are no plans for a scheme to recover SF₆ from end-of-life glazing, and this is not considered technically feasible. It thus must be expected that at the end of the lifetime of the soundproof glazing or of the window frame the filling gas escapes to the atmosphere. These are major emissions, as of the initial SF₆ filling only the stock leakage losses of 1% per annum over the 25-year lifetime are absent, and thus approx. 78% are still present. As the first SF₆ soundproof windows were installed in 1975, the disposal and resultant gas losses began from the year 2000 onwards. These will then increase from year to year, peaking in 2020 as 1995 was the peak in filling.

4.2.3 Evolution of consumption and emissions

Similar to SF₆ for car tyres, by far the biggest single SF₆ market for soundproof glazing is Germany. In the past considerable markets have also been Austria (prohibition in 2003) and Switzerland (prohibition in 2000) and to some degree Denmark (prohibition in 2002), Benelux and the eastern areas of France. According to gas vendors and leading producers of insulating glass the EU market size for this application can be approximated by adding 20% to the German consumption. Accordingly, SF₆ consumption for this application in the EU peaked in 1995 at 300 t and dropped afterwards to some 90 t in 2001. Apart from a generally decreasing demand for insulating glazing from the construction industry starting in 1997, this was chiefly a result of soundproof windows no longer being filled exclusively with SF₆ but with blends of argon and SF₆ in order to meet the rising requirements of thermal insulation. Over the 1995-2001 period, the average proportion of SF₆ to argon dropped to some 30% in 2001. In the scenario "frozen technology" a gas composition of 30% SF₆/70% argon is assumed as a longer-term compromise between acoustic and thermal insulation.

The overall SF₆ emissions from soundproof glazing in 1995 had a different composition of source types (see above) from the pattern 2001, and the composition in 2010 will be different again. It should be kept in mind that only the filling losses occur exclusively in the year of fabrication and are directly proportional to annual SF₆ consumption. Differently, use phase emissions and disposal losses are determined by gas consumption over the past 25 years being only weakly affected by short-term changes as the declining consumption since 1995.

Under these conditions, the emissions shown in Table 4 result for the 1995-2010 period:

- From 1995 to 2001, total emissions drop from 129 to 62 tons of SF₆ due to the decline of filling emissions.
- Disposal losses arose for the first time in 2000. These then become the largest emissions item, growing to 80 t by 2010. As assumed, filling emissions remain constant from 2001 onwards, namely at 30 t. Stock leakage emissions remain relatively stable at 25 t.
- In this scenario, total emissions forecast for the year 2010 figure approx. 135 t⁵ or 3.2 MT CO₂ eq.

⁵ The peak in the year 2020 figures 218 t total emissions, of which 171 t are from disposal.

Table 4 SF₆ emissions (1995-2010) from soundproof glazing in scenario "frozen technology" in t/a and MT CO₂ eq.

| | 1995 | 2001 | 2010 |
|---|------------|------------|------------|
| 1. Filling losses | 110 | 30 | 30 |
| 2. Stock leakage losses | 19 | 25 | 25 |
| 3. Disposal losses | - | 7 | 80 |
| Total emissions in t/a | 129 | 62 | 135 |
| Total emissions in MT CO₂ eq. | 3.1 | 1.5 | 3.2 |

4.2.4 Emission reduction option

A number of suppliers of soundproof glazing within the EU no longer use SF₆ for their glazing. Since 2002, three of the eight large supplier-chains of insulating glazing, comprising about 100 of the overall 350 companies in that business, fully avoid SF₆. To achieve the same level of sound reduction as before they basically offer an improved glazing structure in comparison to using SF₆.

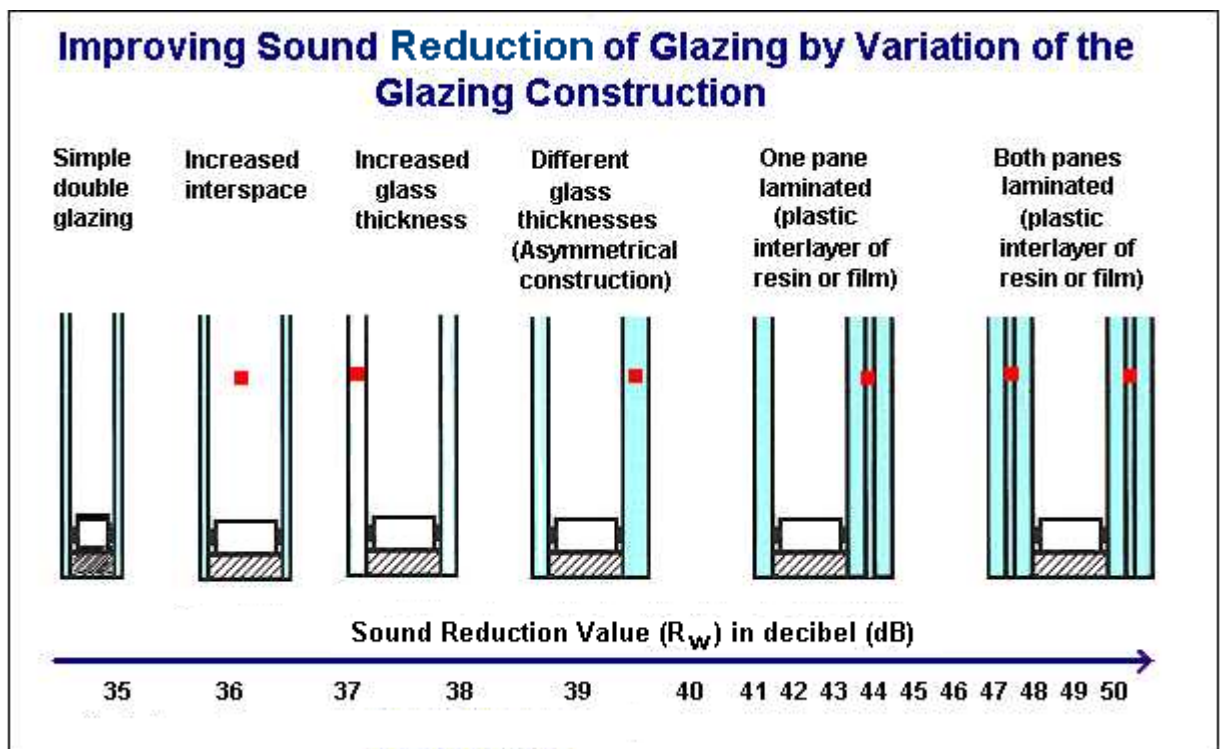


Figure 2 Improving sound reduction quality by variation of the glazing construction. Stepwise, in the picture from left to right, more advanced glazing constructions and thus higher sound reduction values can be achieved by consecutive use of different technologies, beginning with relatively simple enlarging the cavity and ending with laminated glasses at both sides of the glazing. In this picture gas filling is not considered. (Red points mark the parts of a glazing where the indicated modifications are made.)

To recall, sound reduction is not brought about primarily by SF₆, but by overall glazing construction. The factors here are increased space or glass thickness, different glass thickness (asymmetrical glazing structure), or the use of laminated panes with cast resin or plastic film as inner layers. This achieves sound reduction values of 35 to 50 dB (see

Figure 2). SF₆ can enhance sound reduction by an additional 2 dB, but is not a substitute for advanced glazing design.

As shown in Figure 2, a wide range of structural technologies is available to enhance the soundproofness of glazing from 35 dB to 50 dB and more. Avoiding SF₆ here implies, that one technological option is no longer available, and has to be replaced by use of structural technologies alone. Generally speaking, a given structure with SF₆ filling achieves a 2 dB higher sound reduction value or, that comes to the same, to achieve an additional sound reduction of 2 dB without SF₆, the glazing structure has to be adjusted to a higher technological level.

For example, the sound reduction value of 38 dB can be achieved by the glazing structure "pane – space – pane" with the measures 8 mm – 12 mm – 4 mm (total 24 mm), if the space is filled with 70% argon and 30% SF₆. To achieve the same reduction value of 38 dB only by argon as gas filling, the glazing structure "pane – space – pane" has to change to 10 mm – 16 mm – 4 mm (total 30 mm). The thickness of one pane increases by 2 mm, the space increases by 4 mm.

If SF₆ would be no longer used for sound insulating glazing from 2004 onwards, the SF₆ emissions from this application would not stop immediately. As shown above only the filling emissions would be cut at once whereas use phase emissions would decrease just slightly, and end-of-life emissions would be the same for the next 25 years. Owing to a potential prohibition from 2004 onwards SF₆ emissions by 2010 would drop against the scenario "frozen technology" by 34 t or 0.81 MT CO₂ eq. as shown in Table 5. (It should be kept in mind that over the next 25 years, after 2010, additional emissions of 56 t or 1.338 MT CO₂ eq. will be avoided).

Table 5 Projected SF₆ emissions in 2010 from sound insulating glazing as a result of an EU wide prohibition on SF₆ usage in 2004

| | Reduction scenario | Scenario "Frozen technology" |
|---|--------------------|------------------------------|
| Filling emissions | 0 | 30 |
| Stock leakage emissions | 21 | 25 |
| Disposal losses | 80 | 80 |
| Total emissions in t | 101 | 135 |
| Total emissions in MT CO₂ eq. | 2.4 | 3.2 |

4.2.5 Investment cost of the reduction option

To achieve the same sound reduction values without SF₆ basically more material is required (larger spacer, thicker glass), and therefore costs rise, which are not compensated by smaller expenses for SF₆. This is true for values below 40 dB which are typical for the residential sector. Expansion of glass thickness and of the space between the panes mostly are sufficient to achieve the desired sound reduction performance. When higher values of sound reduction, beyond 40 dB, are demanded (as typical for the office-sector), with argon alone the step to the very cost-intensive laminate technology must be taken one or two dB sooner than with adding SF₆. Therefore, in the upper range of sound reduction performance the costs of SF₆-free glazing are also expected to be higher as they are likely in the lower range.

To find the additional investment costs for building owners who want to achieve the same sound reduction with argon as with SF₆, for every single sound reduction value in the market-relevant range between 37 dB and 45 dB the market prices of the glazing are compared two by two. That means, price-quotations of such suppliers are compared, who offer in 2002 (or did it in 2001) for the same sound reduction value an SF₆ containing as well as an SF₆-free solution. The prices refer to 1 m² of glazing with standard measures of 1.20 m length and 0.84 m width. Discounts on the list-prices are considered to the extent usually allowed to window-makers by the suppliers (60%).

As Figure 3 shows, prices of argon-filled glazing are at each sound reduction value higher than those with SF₆ filling. Below 40 dB the price-difference is very small as the technologies used are simple. From the transition point to cost-intensive laminate technology the cost difference moves between €7 and €29.⁶

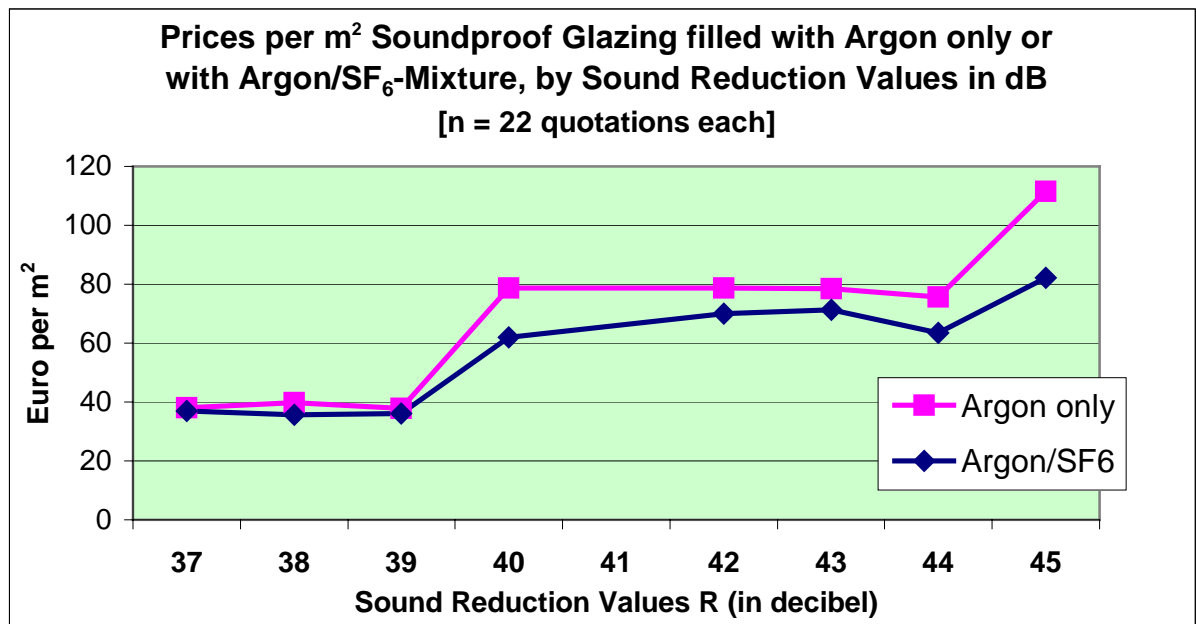


Figure 3 Prices per m² soundproof glazing filled with argon alone or with argon/SF₆ mixture, by sound reduction values in dB. The curve of the argon-filled glazing constantly runs above the SF₆ curve, indicating higher prices over the whole range of interest. Below 40 dB the price-difference is very small as the technologies used are simple. At 40 dB a bigger difference of some €20 is shown reflecting the sooner transition to cost-intensive laminate technology when using argon alone. For 41 dB a glazing with and without SF₆ from one and the same supplier could not be found. Soundproof glazing beyond 45 dB is not considered as it is too rarely sold (less than 1 %, according to the suppliers). By the way, in this price-comparison six of the eight large supplier-chains are represented by at least one quotation.

⁶ These findings more or less agree with a cost analysis in the report "Reduction of Additional (Non-CO₂) Greenhouse Gases; Consequences of using SF₆-free sound-proofing glass", performed by the Dutch Adviesbureau Peutz on behalf of Novem, published on 1 May 2002. The authors claim, based on "a survey of several suppliers", additional costs of SF₆-free constructions for glazing with higher sound insulation levels from €9 to €23. On the other hand, below the laminate technology the prices of glazing are significantly lower for SF₆-free glass-compositions, according to that study, different from our findings

Over the whole range of relevance from 37 to 45 dB the mean price with Argon only is €7.37, with SF₆ it is €7.19. This is a mean cost difference of €0.18 or of 17.8%. If the additional investment cost of €0.18 per m² glazing are annualised (15 years depreciation period, 4% discount rate), the mean annual additional cost per m² soundproof glazing filled with 100% argon instead of a mixture 70% argon/30% SF₆ amount to €0.92.

In 2001, some 2.28 million m² soundproof glazing were installed EU-wide. This quantity is expected to be constant until 2010. Therefore additional annual costs of € 2.092 million will arise from investment in argon-filled and SF₆-free soundproof glazing. The SF₆ emissions avoided by 2010 as a result of a prohibition from 2004 onwards (see Table 5) amount to 34 t or 0.81 MT CO₂ eq. Therefore, the specific reduction cost of 1 t CO₂ eq. comes to €2.59. (The SF₆ emissions per m² glazing amount to 0.36 t CO₂ eq.)

4.2.6 Balanced annual cost of reduction option

As initially mentioned, thermal insulation of insulating glazing is poorer if SF₆ is applied in comparison to argon. That is the reason why the share of SF₆ in argon has been reduced in the recent years to some 30% of the overall gas filling. That proportion is a compromise as the U-value (expressing the unit's thermal conductivity) of SF₆ containing soundproof glazing usually is 1.5 W/m²K. On the other hand the U-value of the same type of glazing filled with argon is better by 0.4 W/m²K around 1.1, according to the technical information data provided by the suppliers.

A difference in thermal insulation of 0.4 W/m²K has significant impacts on the heating demand, the heating costs and the CO₂ emissions connected with heating.

Based on simulations in a study, conducted in 1995 on behalf of the DG XVII of the European Commission, a 0.4 W/m²K lower U-value results in a reduced heating demand by 0.1 GJ per m² and year, in Central Europe. On the base of € 11 per GJ natural gas for heating, annual cost of €1.10 per m² glazing are saved if the glazing does contain argon only instead of a blend with SF₆.

This savings of €1.10 balanced against the additional annualised investment cost per m² argon-filled soundproof glazing of €0.92 turn the additional annual costs of SF₆ free soundproof glazing negative, to a gain of €0.18 per m² or of €10,400 per 2.28 million m² glazing. Consequently, the specific reduction cost for 1 T CO₂ eq. would turn negative, too, being €-0.50 (€10,400/807,000 t CO₂ eq.).

4.2.7 Outlook: Reductions after 2010

It should be noted, that the emissions avoided by 2010, caused by the investment in argon-filled soundproof glazing, are only the smaller part of the overall emissions avoided. Leaving the time frame 2010 for a while in favour of a longer-term view, SF₆ emissions, chiefly disposal losses, in the range of 90 t/a or 2.15 MT CO₂ eq. will not occur due to the switch to SF₆ free soundproof glazing. Seen with these eyes, the specific reduction costs of 1 t CO₂ eq before balancing with gains from less heating costs would drop from €2.59 to €0.97.

4.2.8 Number, size and geographical distribution of businesses affected

The structure of the manufacturers of insulating glazings capable of filling SF₆ into them, is determined by some 350 small and medium sized enterprises, 80% of whom are sited in Germany, the rest in Benelux, the eastern parts of France and before 2002

also in Denmark and Austria. Roughly a half of these companies form eight different networks or supplier-groups (often with special purchase conditions from of glass works), producing more or less uniform ranges and using a common glazing brand name.

It is assumed that in case of a general prohibition of SF₆ higher investment prices would be passed on to the customers, namely the window makers, who would in turn pass this higher cost on to their customers, the building owners. It should be noted, that in the normal case as a result of enhanced glazing construction due to absence of SF₆ the usual window frames will not have to be changed. Thus, on this stage of processing additional cost will not arise. This is confirmed by the interviewed window makers who claim the margins of the standard frame profiles to be wide enough to receive glazing having become some millimetres thicker.

4.2.9 Recommendations

It is recommended to prohibit the use of SF₆ for soundproof glazing from 2004 onwards without a transition period. Small and medium-sized enterprises should be allowed a transitional period until 2006.

4.2.10 Organisations consulted and their main views

The "Bundesverband Flachglas", the German association of traders of flat glass and producers of insulating glazing, as represented by Mr Graap provided information on the annual sales of insulating glazing for Germany. The association confirmed the standpoint released in 2001 the consumers should decide for "glazing without SF₆ which shows nevertheless high values of sound reduction".

Apart from some technical information, the price data were provided by companies belonging to the overall eight leading networks with a combined market share in soundproof glazing far over 50% within the EU: Saint-Gobain Glass (formerly VEGLA), Markenkreis Flachglas (formerly Pilkington), Interpane, Sanco-Glas Trösch, Semco, Uniglas, Isolar, Consafis. Three of these "groups" offer their 2002 range solely with SF₆-free soundproof glazing. The latter, not surprisingly, support an EU-wide legislation prohibiting the use of SF₆.

The data on SF₆ consumption for soundproof glazing were provided by the four gas vendors covering almost 100% of the market: Linde, Messer, Air-Liquide, Air Products.

4.3 SF₆ in sport shoes

4.3.1 Description of application

NIKE introduced its “air” series of sport shoes using soles containing gas cushions filled with SF₆ in the early 1990’s. The use of these cushions is one possible technological approach to ensure an elastic attenuation of shocks while combining appropriate support to the foot with wear comfort. Often NIKE visibly integrates these cushions into the soles of its shoes. The resulting requirements for the cushion material are numerous: sufficient gas retention, robustness, elasticity, transparency, weldability, compatibility of surface with other sole materials and acceptable costs. The “air” product series since its peak in the 1990’s has maintained a significant share of total NIKE footwear. The “air” technology is protected through a series of different patents. Some of Nike’s US and international patents have recently expired thus making it possible in principle for other shoe manufacturers to apply the technology.

4.3.2 Evolution of Emissions

Nike has reduced its global SF₆ usage annually since the 1997 calendar year high of 277 T. The actual global SF₆ reductions as a percentage of the 1997 baseline are as follows: 1998 reduction was 46.4%; 1999 reduction was 62.0%; 2000 reduction was 68.7%; 2001 reduction was 81.0%; 2002 reduction in SF₆ is estimated to have been 83.6% if SF₆ had been used the entire year.

The actual usage of SF₆ in the production of pressurized cushioning units at Nike’s US manufacturing facility was discontinued on September 3, 2002. At that time Nike began using PFP (perfluoropropane) in place of SF₆ in the production of its cushioning systems. This means all Nike footwear product imported into Europe after June 30, 2003 will be SF₆ free.

PFP was selected as the gas to be used during the transition to complete elimination of greenhouse gases in Nike products imported into Europe by June 30, 2006 because it had the lowest GWP of any gas that would enable Nike to maintain product performance during the transition period. PFP has a GWP of 7,000, as compared to 23,900 for SF₆, representing a 70% reduction in GWP. However, Nike recognizes that PFP is 36% heavier than SF₆ so the effective reduction in global warming potential as a result of this change in gas is 60%.

Based on current marketing projections and conversion by Nike to new technology utilizing nitrogen, the estimated metric tons of PFP in Nike footwear imported into the European market during the transition period by calendar year is as follows: 2003 estimated at 8.25 T; 2004 estimated at 6.7 T; 2005 estimated at 4.23 T. These estimates are based on Nike’s conversion program to the new technology and future market conditions, therefore they are potentially subject to change.

4.3.3 Emission reduction options, potentials and costs

According to information provided by NIKE, the company has investigated different options to use the gas cushion in the respective shoes without using SF₆. The main problem encountered is to keep gas losses at sufficiently low levels while meeting the

above mentioned performance criteria at acceptable costs. In some of its products NIKE is using nitrogen, for the rest of its products it has announced to complete a switch to the PFC perfluoropropane (C_3F_8) by June 2003 – reducing GWP of the filling gas by 60%. The completion of a SF_6 phase-out had already been announced for the year 2001 in 1997. Due to a number of unexpected technical problems NIKE has been forced to postpone it to ensure product performance during the phase-out transition. All other producers of sport shoes produce their shoes without relying on the patented gas cushions. Though high performance sport shoes can certainly be produced without gas cushions, it needs to be acknowledged that these patented cushions are apparently well appreciated by a large number of consumers and provide a unique selling point to NIKE.

4.3.4 Affected economic sectors and impact of measures

NIKE is the only manufacturer applying gas cushions in part of its product range. An early phase-out of fluorinated gases in their products could have a significant impact on NIKE's sales into the sector.

4.3.5 Recommendations

Define a phase-out schedule for SF_6 (by June 2003) and other fluorinated gases in cushions of sport shoes soles (by June 2006 latest). This schedule follows the latest commitment by NIKE.

4.3.6 Organisations consulted

The European representation of NIKE has been contacted and it supplied Nike's position paper on SF_6 /PFP in footwear.

4.4 *SF₆ in magnesium die casting*

4.4.1 Description of application

In magnesium die casting⁷, SF₆ is used as a protective cover gas over the molten metal in order to prevent slow oxidation or violent ignition. It is distributed at concentrations of 0.2-3 vol.-% in blends with carrier gases such as dried air, nitrogen or CO₂ over the surface of the more than 650°C hot molten metal, which would otherwise ignite at temperatures over 500°C. Only a small fraction of the SF₆ supplied undergoes a chemical conversion, so that consumption and emissions can be equated.

SF₆ has been used in this application since the mid 1970s, then competing with SO₂, which in concentrations of 0.5-2% over the melt forms a protective layer of MgSO₄. As SF₆ is simpler to handle than the toxic SO₂, it became the cover gas of choice in many new casting companies, set up at the end of the nineties especially in Germany when the Volkswagen group decided to increase the use of lighter metals to save car weight.

Today SF₆ is used in the EU only to process magnesium which is imported as ingots. Elsewhere, when casting the primary metal into ingots, SF₆ cover gas is also used, and in larger amounts than in the casting companies. As the only EU primary producer has closed in 2000, SF₆ emissions from that plant which in 1995 still had amounted to some 30 t/y were cut down, at once. European secondary smelters and alloyers have also started to use SO₂ instead of SF₆ for cost reasons in all but very few specialised applications. In the following we are dealing exclusively with some 60 die casting companies across the EU, basically melting ingots for the production of magnesium parts by means of SF₆ or SO₂ as cover gas. By far the most magnesium parts are produced by die casting, i.e. by high pressure in either cold or hot chamber machines. Smaller series are cast by pressure-less or low-pressure methods like sand casting.

4.4.2 Evolution of emissions

From 1995 to 2001 SF₆-emissions from die-casting have risen from some 20 t/y to some 22 t/y within the EU. Emissions of 50 t/y or 1.20 MT CO₂ eq. are projected for 2010 as a result of the following two opposing trends:

On the one hand, most of the then existing plants have decreased their absolute 1995 emissions by reducing the specific SF₆-emissions per tonne of magnesium die casting⁸

⁷ Different parties involved in reviewing the draft report had opposing views on whether or not the scope of this potential use restriction should be widened to all types of magnesium casting or even the smelting and refining of all non-ferrous metals. Due to a lack of robust information on these additional applications the consultants at this time have restricted their analysis to the fairly homogenous field of magnesium die-casting. IPPC, however, may offer an alternative route to reduce emissions from enterprises which are above the threshold of 20 t of metal per day.

⁸ Strictly speaking, this emission coefficient is not an adequate indicator for comparing different plants' emissions with each other as it refers the consumed cover gas to the net weight of the casting parts although SF₆ has to protect the gross melt weight. The latter is by 35 to 100 % higher, depending on the geometry of the metal parts intended, as it includes the scrap (sprue and gatings, dross, defective parts) which is not destined for sale but for reuse inside the plant (again needing cover gas) or in specialised secondary plants. Despite its limitations this coefficient is used here, as usually only sales data (net weight of the parts) are available.

from 3 kg to the current average level of less than 1 kg (0.9 kg) by technical measures (improved tightness of the ovens, fully automatic cover gas dosage, electronic control of both gas mix and flow rate, reduction of overdosing etc), and additionally in several plants a conversion to SO₂ has been implemented.

On the other hand a die casting capacity expansion commenced from 1996 onwards with the establishment of new large-scale foundries belonging to the car manufacturing or car component supplier industry, especially in Germany, which exclusively use SF₆ as cover gas as its handling by non-specialized workers is seen easier and safer. This second tendency is so strong that the SF₆ savings through improved technology and conversion to SO₂ have been overcompensated by the SF₆ consumption of those new foundries, since 2000 at the latest. In 2001 the overall EU production of magnesium parts totalled 39,100 tons, 37 % of that were produced with SO₂ and 63 % or 24,500 tons with SF₆ (see Figure 4). The diagram shows the 2001 total of 39,100 tons of die-cast magnesium split into the 10 EU producer countries as well as into the sort of cover gas used for its production – SO₂ or SF₆. Although the quantities of metal are shown, not of gas, this makes no decisive difference in the relations as the specific emissions in case of SF₆ per t magnesium average at not much less than 1 kg/t. Germany is by far the largest producer of magnesium parts as well as the largest user of SF₆. Though Germany is the largest user of SO₂, too, in Austria, Sweden, Denmark SF₆ is no more used as cover gas. Spain is not far away from that either.

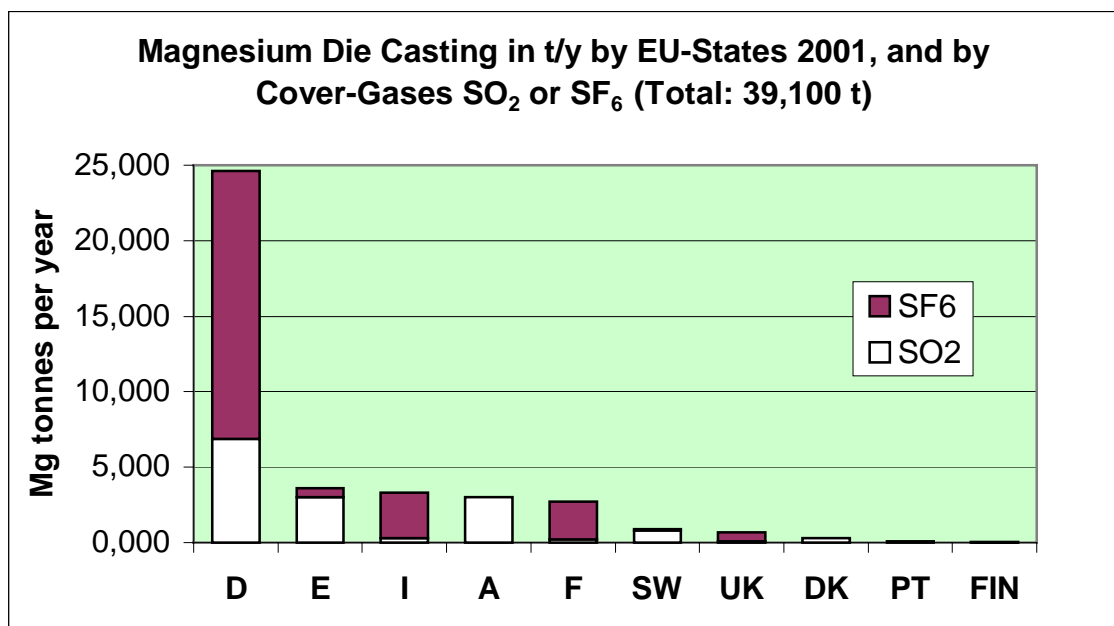


Figure 4 Distribution of magnesium die casting across the EU.

It is assumed in our 2010-scenario that production capacities grow to 2010 by almost 15%, annually. In first line new, modern, large-scale plants using SF₆ increase the production from 24,500 tons to some 79,000 tons over the 2001-2010 period. This mainly results from an increased use in car manufacturing. Emissions of SF₆ are not expected to grow proportionally as new plants should achieve emission coefficients not much higher than 0.5 kg SF₆/t Mg-casting. Thus SF₆-emissions are forecast to grow from 22,000 kg to 50,000 kg by 2010, in terms of global warming from 0.53 MT CO₂ eq. to 1.20 MT CO₂ eq.

4.4.3 Available emission reduction options

Technical improvements have contributed a lot to emission reduction of the magnesium die casting plants over recent years *cutting the specific SF₆ consumption* per tonne magnesium produced from over 3 kg to under 1 kg (0.9 kg). From a large plant even an emission coefficient of 0.43 kg/ t Mg is reported, benefiting of three-shift operation, which minimizes warm-up and cooling losses. In plants erected from 2003 onwards 0.5 kg/t Mg should be generally be achievable. Further reduction beyond this point will be difficult due to technical reasons.

Therefore a *conversion to a different cover gas* is the option of choice if further emission reductions are to be achieved. A number of different alternatives are currently under examination, including HFC-134a and the fluoro-ketone C₆F₁₂O. Preliminary test results suggest that degradation products of these compounds forming at the hot metal interface can be handled in normal working conditions. Major suppliers of HFC-134a and fluoro-ketones claim that the overall economics of the use of these compounds will be favourable in comparison to SF₆.

At the time of writing, however, SO₂ was still the only commercially available alternative to using SF₆ in as a cover gas in a broad range of applications in magnesium die casting. The following economic analysis was therefore limited to the option of converting SF₆ to SO₂ technology. The reader should take note that it is likely that additional reduction options will become available over the next few years – potentially exhibiting even better economics.

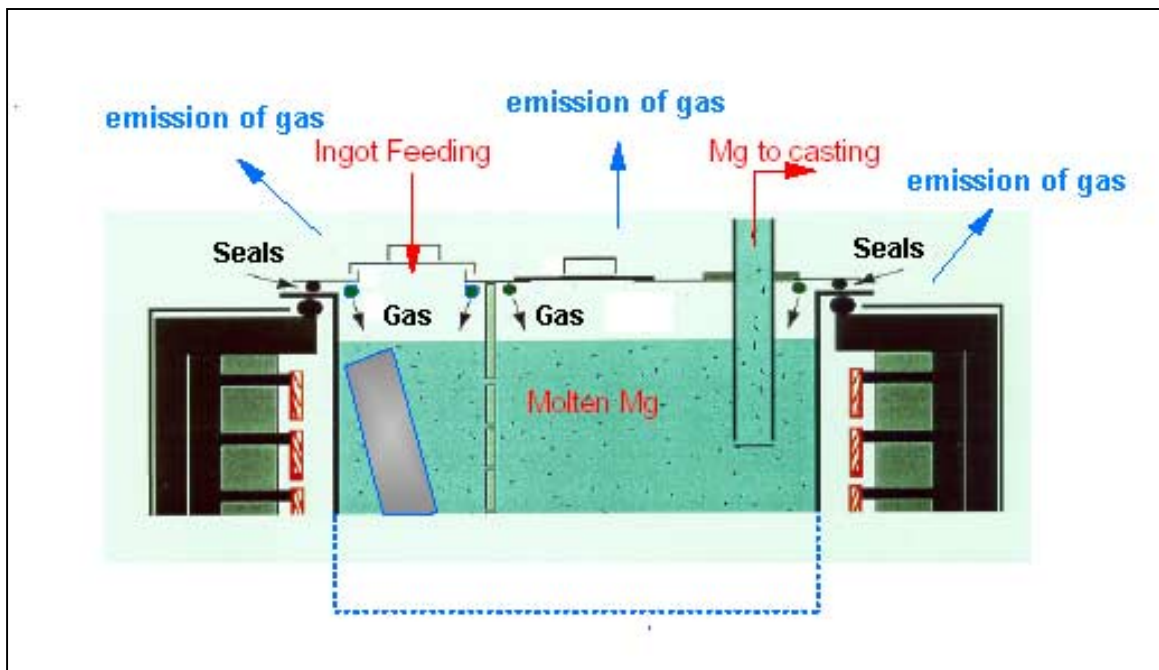


Figure 5 Application of Cover Gas in Magnesium Die Casting. Source: Hydro-Magnesium.

Figure 5 gives an overview of the casting equipment in which SF₆ or SO₂ are used. Different from SF₆, which can be transferred from gas mixers (often next to the oven) to melting ovens and casting machines through usual steel pipes, the use of SO₂ requires (1) piping of stainless steel with special seals and fittings, (2) gas detectors and flow

meters for each oven/machine, (3) an alarm system for the centralized gas mixing station. The latter should be ventilated and its alarm system must be activated in case of leakages or deviations from the desired gas composition. The suited carrier gas to be mixed with in concentrations of about 1-2 vol. % is because of its inertness solely nitrogen (no CO₂ or dried air).

4.4.4 Achievable emission reductions

Basically every plant today running with SF₆ cover gas could be converted to SO₂. The installation of SO₂ gas supplying systems in new plants or when modern plants expand their casting capacity is economically more favourable. A barrier worth mentioning is the additional investment cost (see Table 6) which in reality restricts conversions to SO₂ to plants of a capacity over 500 t/y Mg parts or – that comes approximately to the same - of an SF₆ consumption more than 500 kg/y.

Currently, within the EU some 25 small and middle-sized plants run with less than 500 t/y Mg output each, altogether producing just 3,500 t/a Mg parts and emitting a little more than 3,000 kg SF₆ (0.08 MT CO₂ eq.). On the other hand the 8 largest SF₆ using plants with capacities over 500 t/a account for an annual output of 21,000 t Mg parts and SF₆ emissions of 19,000 kg (0.45 MT CO₂ eq.). This is 86 % of the overall Mg output from plants using SF₆ and correspondingly 86 % of the EU wide SF₆ emissions from magnesium casting. (Apart from those plants 16 other die-casting and sand-casting plants without SF₆ are known with an overall capacity of 14,600 t/y).

The achievable SF₆ 2010 emission reduction by retrofitting these 8 bigger plants to SO₂, totals some 19,000 kg or in terms of global warming 0.454 MT CO₂ eq.

If also all the forecast growth of new capacities for magnesium casting would take place with solely SO₂ as cover gas, by 2010 additional emissions of 26,500 kg SF₆ or in terms of global warming 0.63 MT CO₂ eq. could be saved, leaving over just 4,500 kg SF₆ or emissions of 0.11 MT CO₂ eq. from the smaller plants which are assumed to grow annually just by 4% (from 3,500 t in 2001 to 5,000 tons in 2010).

The overall emissions reduction by 2010 is estimated at 45,500 kg SF₆ or 1.09 MT CO₂ eq., against forecast 1.20 MT CO₂ eq. according to scenario "frozen technology".

4.4.5 Cost of the reduction option

A. Cost comparison of new capacities, with SF₆ and SO₂

It seems unlikely the envisaged capacity expansion from 24,500 t/y to some 79,000 t/y could be realized by the existing small-scaled casting companies. The investors will most likely come from the automotive business sphere as they did in recent years. Therefore large-scale producers are expected to either enlarge their existing or establish new plants, sizing from 500 t/y to over 4,000 t/y magnesium die-casting capacity each. Such new plants alone should grow the overall casting output by 53,000 t/y, by 2010.

- If the "automotive die casters" go on using SF₆ they will save investment costs but will spend more on operating costs. Typical cover-gas systems for a modern 1,000 t/y plant cost some €23,300, which are annualised to roughly €3,800 (based on a 10 years depreciation period and a 10 % discount rate). Annual expenses for SF₆, being dosed in a 0.2% concentration with the carrier-gas nitrogen, come to €10,300, as 514 kg SF₆ at €20 per kg are needed under the

assumption that the emission coefficient will be 0.5 kg/t Mg, constantly. Annual costs total to €14,072 (see Table 6).

- If instead SO₂ is used, the gas system meeting all modern safety and dosage requirements costs €70,000, three times as much as a modern SF₆ system. The annualised investment costs are roughly €1,400. The cover-gas being dosed in 1.5 vol. % concentration with the same quantity of nitrogen as in the case of SF₆, costs €4,000 (1,350 kg at €3.00 per kg). The total annual costs are €16,457, €2,385 more than in case of using SF₆ (see Table 6).

Table 6 Basic Data of a Modern Die-Casting Plant of 1,000 t Magnesium Output

| General Casting Data | | |
|--|------------------------------------|-------------------------------|
| Capacity of the ovens | 2,000 kg | |
| Maximum smelting performance | 1,000 kg/h | |
| Casting time per day (Cold chamber) | 13.2 h | |
| Working days | 250/y | |
| Utilisation | 76 % | |
| Gross melting weight (shot weight) | 2,000 t/y | |
| Scrap factor | 50 % | |
| Net weight of the Mg parts | 1,000 t/y | |
| Sales per year (€15.00 per kg) | €15 million | |
| Surface of the Mg baths | 6 m ³ | |
| Gas (carrier + cover gas) per m ² surface | 300 litres per hour, all year long | |
| Extra gas dosage while charging | + 25 % | |
| Gas Data | SF₆ | SO₂ |
| Carrier gas | nitrogen | nitrogen |
| Cover gas concentration in carrier gas | 0.2 vol. % | 1.5 vol. % |
| Cover gas dosage per hour | 46,9 g | 154,2 g |
| Cover gas dosage per year | 514 kg | 1,688 kg |
| Coefficient cover gas/net Mg output | 0.51 kg/t | 1.69 kg/t |
| Emissions in T CO ₂ equivalent | 12.278 | - |
| Cost Data | SF₆ | SO₂ |
| 1 kg cover gas | €20.00 | €3.00 |
| 1 m ³ carrier gas (nitrogen) | € 0.20 | €0.20 |
| Invest-cost of new gas equipment | €23,333 | €70,000 |
| Discount rate per year | 10 % | 10 % |
| Depreciation period | 10 y | 10 y |
| Annualised invest cost of equipment | € 3,797 | €11,392 |
| Operating cost of cover gas | €10,274 | € 5,065 |
| Annual running cost (without nitrogen) | €14,072 | €16,457 |
| Additional total cost of using SO ₂ | - | € 2,385 |
| Specific emissions reduction cost | - | €0.19 / t CO ₂ eq. |
| Share of additional cost in sales | | 0.02 % |

Please note: Most data are only valid for this 1,000 t/y plant and change with the plant's size.

The annual costs of using SO₂ instead of SF₆ in a modern 1,000 t/y plant are €2,385 higher. Using SO₂, emissions of 514 kg SF₆ or 12,300 tons of CO₂ eq. are avoided. The specific reduction cost of 1 t CO₂ eq. is €0.19 in a new 1,000 t/y plant (see Table 6).

The costs of using SO₂ in new plants are still higher, if the output is smaller than 1,000 t/y. Given an output of 500 t/y, the additional annual costs in case of SO₂ are €3,905 (investment costs are assumed to amount to €60,000 [SO₂] against €20,000 [SF₆]), SF₆ emissions of 257 kg are avoided or 6,100 t CO₂ eq. The specific reduction cost of 1 t CO₂ eq. rises to €0.64.

It is found that the bigger the plant, the less differ the annual total costs between both systems. At an annual output of some over 1,500 t/y the turning point is passed. From that plant size onwards the costs of the SO₂ usage grow relatively slower than those of using SF₆, even though the investment costs of SO₂ gas systems are assumed to increase by €10,000 with every additional 1,000 t capacity (with the SF₆ investment costs remaining a third of the SO₂ system's cost). At 1,500 t/y plant size the reduction cost of 1 t CO₂ will have become negative, having turned at 2,000 t/y to €- 0.07, which is a gain instead of cost.

B. Costs of retrofitting existing capacities from SF₆ to SO₂

The cost calculations above are valid for newly erected plants, where no SF₆ gas system has existed before. When converting existing plants currently using SF₆ to SO₂ it should be clear that the investment cost-calculation for a new SO₂ system is not limited to the cost-difference between new SO₂- and new SF₆-system which might be purchased alternatively. As a cover gas system is already installed which cannot be used further but has to be exchanged completely to suit SO₂, the calculated investment has to cover the entire cost of the new SO₂ gas system replacing the older one. Therefore, conversion of existing plants from SF₆ to SO₂ is, relatively, more expensive regarding the investment than setting up an SO₂ system from the beginning. This refers to eight running large-scale plants in the automotive sector in different EU countries with output of more than 500 t/y each, producing together some 21,000 t/y averaging to 2,750 t/y per plant. For instance, the annualised investment costs of an SO₂ gas system for a new 1,000 t/y output plant come to additional €7,595 measured against the investment cost of a new SF₆ gas system, which virtually could be installed as an alternative. If in a same sized plant the still existing SF₆ gas system was exchanged by a new SO₂ system, the annualised investment costs were €1,392 as well, which are, however, all additional, as measured against no costs at all. Thus, the cost-difference is €3,797 in favor of an SF₆ system.

Nevertheless, at an output of 2,800 t/y the break even point would be reached and the additional costs of the SO₂ system grew negative, as the costs of SF₆ cover gas alone would exceed the sum of annualised investment costs and running SO₂ gas costs. In reality the break even point is reached at a far lower level of plant output. Though investment costs have to be calculated higher in case of converting existing plants, operating gas costs become much lower compared to the costs of the replaced SF₆. Today existing plants, even the bigger ones, do not consume just 0.5 kg per t magnesium parts, but, on an average, 0.9 kg as shown above.

Substituting SO₂ for SF₆ in old plants therefore reduces the running costs nearly twice as much as in case of establishing new plants with SO₂. The turning point at which the total costs of using SO₂ get lower than the comparable cost of using SF₆ is below 900 t/y output, based on an SF₆ consumption coefficient of 0.9 kg/t Mg, when the payments for 800 kg SF₆ exceed the total of annualised SO₂ investment costs and running SO₂ gas costs.

At 500 t/y output the use of SO₂ still is more expensive than using SF₆, namely by €3,297 annually. But at this plant size using SO₂ avoids SF₆ emissions of 450 kg or 10,755 tons of CO₂ eq. The specific reduction cost of 1 t CO₂ eq. amounts to €0.31. (For comparison, the respective reduction cost in same-sized new plants were shown to be €0.64). By the way, the share of the additional costs in the plants sales comes to 0.04%.

To sum up, it is found to be economic to use SO₂ instead of SF₆ as cover gas in magnesium die casting at least in plants with an annual metal output of 500 tons and more, regardless whether a plant is to be freshly erected or still runs with SF₆. Below 500 t/y replacing or preventing SF₆ by SO₂ should be considered, too. However, as 95% of the present-day and probably a still larger share of the future casting will take place in plants over 500 t/y minimum output, from the standpoint of effectiveness (controlling, emission reduction potential) and economics (annualised investment costs below €4,000, making a share of less than 0.05% of the plant's turnover) it is obviously advisable to bring the larger plants into focus, at first.

4.4.6 Number, size and geographical distribution of businesses affected

Currently, within the EU run eight plants using SF₆ with annual casting output (net weight of the parts) exceeding 500 tons, each. Four are sited in Germany, two in France and another two in Italy, countries with strong automotive industrial background. It is fair to assume the expected capacity expansion largely to be borne by companies of these countries, too, supplemented by Spain. Without exception the eight SF₆ using large-scale foundries belong to the car manufacturing or car component supplier industry, being either parts or affiliates of big companies.

4.4.7 Recommendations

It is recommended to prohibit the use of SF₆ as a protective gas in magnesium casting with the exception of die casters producing less than 500 tons magnesium parts (net weight) or - alternatively - using less than 500 kg cover gas. A transition time until the end of 2006 should be granted to existing die casters. The IPPC Directive exhibits only limited applicability to die casting with only one large magnesium die caster exceeding the threshold of 20 tons of metal per day. Secondary smelters which do not belong to the group of die casters will often exceed this threshold.

4.4.8 Organisations consulted and their main views

The European section of IMA (International Magnesium Association), represented by Mr Closset, provided data on magnesium die-casting for specific EU countries. Presently the IMA has no explicit position in favour of or against a specific cover gas. Although in the course of the ECCP process SO₂ had been recommended by the biggest European magnesium supplier and primary producer (Hydro-Magnesium), which is trying other cover gases as well, at the moment. As far as the consultants interviewed personnel of plants using SO₂ a uniform picture was not obtained. While the majority of SO₂ users denied corrosion owing to acidic gas emissions or troubles resulting from the toxicity of SO₂, in some cases complaints arose about the need for more carefulness than before, and in one case (Spain) quality problems were mentioned in connection with humid air inside the casting hall.

The country specific production data from IMA were refined by the consultants by means of telephone interviews with some 40 single casting companies all over the EU to find out plant specific metal output and cover gas usage. These findings were

crosschecked with help of leading European industrial suppliers of casting equipment and its periphery devices (Bühler AG, Switzerland; Rauch, Austria; Striko-Westofen, Germany; Frech, Germany). The equipment suppliers also gave detailed information on costs of cover gas systems for new plants, while the cost data on SF₆ replacement in already existing plants were found out by evaluation of three real life conversions with plant outputs of 500, 1,000 and 2,000 tons, carried out in Germany and Austria (Zitzmann, Georg Fischer-Mössner, TCG Unitech).

4.5 HFCs in self-chilling beverage containers

4.5.1 Description of application

Over decades the concept of self-chilling beverage cans has attracted considerable attention from packaging engineers. The largest potential for this applications is likely to be found in the sports and outdoor sector in developed countries. One promising solution involved the use of HFC-134a as developed in the mid-1990's by Joseph Company of California and the BOC Group of UK. For standard can sizes between 60 and 110 grams of HFC-134a are required to achieve sufficient cooling. Before being marketed in 1996 and 1997 the product encountered a wave of environmental concerns expressed by green NGOs like WWF and Greenpeace. The application was raised and discussed in the EU Council of Ministers. After failure to find acceptance for the product through emission compensation by means of a re-forestation project proposed under the umbrella of the Environmental Defense Fund (EDF) Joseph and the BOC group agreed to stop the project in 1997. A prohibition of the use of HFC-134a and HFC-152a in this application was issued by US-EPA in 1999.

4.5.2 Evolution of emissions

Currently there is no evidence that HFCs are used for this application in Europe or elsewhere. It is not anticipated that this application of HFC-134a will become relevant to end-consumers in the near or mid-term. If only 0.1% of the EU beverage can market of 38 billion cans in 2001 had applied self-chilling based on HFC-134a, emissions of 3200 t of HFC-134a or 4.2 MT CO₂ eq. would have occurred. It is however worth noting that the concept of self-chilling beverage containers is attracting increasing commercial interest, e.g. self-chilling beer-barrels (Tucher CoolKeg[®] - based on zeolith/water absorption) are now available in Germany. The same applies to self-heating cans (e.g. Nestlé Thermotic Can-TDL[®] - quicklime/water).

4.5.3 Available emission reduction options

Conventional solutions avoiding HFCs involve refrigeration of cans, thermal insulation of chilled cans and as a means of last resort the consumption of unchilled drinks. In the United States the patented product ChillCan[®] (under involvement of Joseph Company) utilising the cold generated from CO₂-desorption from a pressurized charcoal cartridge is being marketed to fillers and beverage companies since early 2002. US-EPA has awarded its Stratospheric Ozone Protection Award to the inventors of this Chill-Can[®] MicroCool[™] technology. Comparable products are reported to have been available in Japan and for military applications in the US for some time already.

4.5.4 Achievable emission reductions

Use restrictions in this field would have a solely deterring effect. No immediate emission reductions can be achieved.

4.5.5 Specific costs of reduction options

Not defined for a zero-emission situation.

4.5.6 Affected economic sectors and impact of measures

The main sectors potentially involved are the food and beverage industry and the packaging manufacturers. No meaningful information on the number and size of businesses affected or their geographical distribution can be given. The overall

economic impact of a use prohibition of fluorinated gases in self-chilling beverage containers is estimated to be insignificant.

4.5.7 Recommendations

It is recommended to immediately prohibit the use of HFCs in self-chilling beverage containers.

4.5.8 Organisations consulted and their main views

US-EPA (Sally Rand) on commercial relevance of HFC based self-chilling beverage cans outside of USA: no such use known.

4.6 HFCs in one component foams

4.6.1 Description of application

In can-dispensed polyurethane (PU) one component foam (OCF) is used by professional craftsmen and – to a smaller extent – do-it-yourselfers (DIYers) in order to mount doors and windows and to fill and insulate different kinds of open joints and crevices. One single standardized 750-ml can contains between 180 –240 ml (150-190 g) propellant gas. Different from other rigid PU foam products the propellant does not serve as an insulation agent, but is a solvent, a viscosity reducer, a foaming aid and expels the foam from the can. OCF contributes significantly to reducing heat losses from buildings and thus saves energy, due to the insulating properties of the PU foam and due to the fact that the foam adheres to building materials giving air-tightness. The propellants are either blends, consisting of HFCs (134a, 152a) and flammable gases (propane, butane, dimethyl ether), or flammable gases without HFCs. The propellant escapes from the foam upon application, except for small residues which remain for at most one year in the hardened foam.

4.6.2 Evolution of emissions

Since the switch from HCFC-22 to chlorine-free propellants (initially mainly HFCs), which was completed in 1995, the quantity of HFCs used for OCF has constantly decreased. There are two reasons to name. Firstly, in 2000 only 30 million of the EU-wide sold 55 million cans did contain HFCs at all, namely the 23 million cans sold in Germany and 7 million in other EU-countries. However 25 million cans or about 80% of all the cans sold within the EU-15 (outside Germany), did contain as propellants only flammable gases without halogens. This trend of replacing HFCs by low-cost gases like hydrocarbons has set in soon after the 1996 switch.

Table 7 One Component Foam: 1996, 2000, 2010 emissions of HFCs in t and MT CO₂ eq. in the EU - Scenario "frozen technology"

| | 1996 | 2000 | 2010* |
|------------------------|-------------|-------------|--------------|
| 134a emissions in t | 3,100 | 1,200 | 1,636 |
| 152 a emissions in t | - | 1,000 | 1,364 |
| HFC total in t | 3,100 | 2,200 | 3,000 |
| MT CO ₂ eq. | 4.0 | 1.70 | 2,32 |

* Between 2000 and 2010 an annual growth rate of a little more than 3 % is assumed. Taking into account the current economic slowdown this value possibly over-estimates future growth. On the other hand the growth rate had exceeded 10 % annually over all the nineties.

Secondly, also the 30 million cans with HFC propellants contained less HFCs and more inflammable gases per can than in 1996. In 1996, the HFC quantity in a standardized 750-ml can averaged 100 g, in 2000 it had dropped to 80 g (134a) or 60 g (152a), and this development is still going on. The so called '50-gram rule' established by an agreement of the working group of the leading Central and Western European fillers (AKPU) has not prevent this reduction. This rule permitted from the very beginning only 50 g halogen-free flammable gases (expressed as grams of butane) contained

within the 150-190 g propellant in order to prevent explosions under certain standard conditions.

A further reason for the observed decline of the HFC-content in the average can is a shift away from HFC-134a which at first had been the only HFC in OCF cans, to HFC-152a, meanwhile amounting to a half of the HFCs volume in the cans. The density of 152a is by 25% lower than that of 134a, its GWP is even much more lower with 140 against 1300.

4.6.3 Available emission reduction options

An easy and comparatively safe way to reduce global warming emissions from OCF application is to extend the replacement of HFC-134a by HFC-152a in the formulations. An additional replacement rate of about 10% per year is seen feasible by the AKPU. Although unlike 134a the 152a is flammable, the critical concentration is roughly 3 times higher than in case of hydrocarbons and therefore providing sufficient safety for by far the most cases of using OCF. Exceptions are a few selected applications with very high safety requirements (eg. underground: mines, tunnels) where the nonflammable propellant HFC-134a is necessary. Such underground applications chiefly occur outside the EU-15, but some also within the EU-15 with a market share of much less than 5% at the maximum .

Not intrinsic safe as HFCs but well to handle by professional users are cans with pure hydrocarbon propellants.

Until recently, an obstacle to the OCF industry to widen the use of flammable gases had been the fire safety test requirements of class B 2 valid in Germany, where unlike the other 14 EU States “highly” flammable building products are not permitted. The class B 2 flammability test could not be met by formulations without HFCs, since it is the small HFC residues inside the foam which provides a temporary fire-suppressing effect. This classification refers to the combustibility of the ready and hardened foam, not to the application of the can⁹. This is so important since Germany is the largest single market worldwide with annual sales of more than 23 million cans.

Meanwhile (2002) several companies have succeeded in developing new formulations which meet the test criteria for fire safety class B 2 with pure hydrocarbon propellants – basically by addition of more flame retardants. The AKPU thinks the rest of the OCF industry to possess a pure hydrocarbon solution by 2005 as well and expects that within the next 3 years only about 20% of all OCF products used in the EU would contain HFCs.

A certain part of the OCF cans is not used by professionals but by do-it-yourselfers which buy these products at DIY centres or other retail trade shops. As this user group is not familiar with the fire risks of purely hydrocarbon blown systems, incorrect

⁹ In principle the B 2 or so-called small burner test requires that a flame being in contact with a 14 days old (stored under standardized climate conditions) piece of hardened foam for 15 seconds does not exceed a height of 150 mm – during each of 5 trials. When the European harmonization of standards and authorization procedures for the construction industry will be completed, the German category B 2 will be replaced by the European category E requiring a just slightly modified small burner test. The specifications to be met are however identical to the former B 2 test.

application causing an explosive atmosphere in small rooms with insufficient ventilation and open flames cannot be excluded, e.g. when a whole can is emptied in one go in less than 2 minutes. Indeed, accidents from purely hydrocarbon-blown OCF have occurred during use in small kitchens with pilot-lights in heating systems as typical in the UK. To prevent this type of accidents, the '50 g rule' was originally introduced. To limit these risks, DIYers across Europe should have access only to safer, HFC containing, cans in the future.

4.6.4 Achievable emission reductions

If in the future OCF cans for use within the EU were generally filled with flammable propellant gases alone (from 2005 onwards at the latest) and only those cans destined for the retail trade (and the underground applications) would contain HFCs, the share of HFC containing cans would not exceed 20 % of the EU-wide sales.

Assuming (1) an annual market growth of little more than 3% (from 55 million cans in 2000 to 75 million cans by 2010) and (2) parallel a continuation of the ongoing conversion from the high GWP 134a to the low GWP 152a in an order of magnitude of 100 t/y and (3) a continuation of the reduction of the HFC-fill per can to 60 g (134a) and to 40 g (152a), the total of HFCs used for OCF within the EU-15 could be lowered to a level of less than 650 (metric) tons by 2010 with a global warming impact of 0.14 MT CO₂ eq. – against 2.32 MT CO₂ eq. in the scenario "frozen technology". HFC-filled would be by 2010 some 15 million cans with 40 g 152a and 0.75 million cans (5%) with 60 g 134a. The remaining 50 million OCF cans would be propelled by hydrocarbons alone.

Table 8 Projected emissions in 2010 from One Component Foam as a result of chiefly using HFC-152a in at most 20% of the cans used within the EU, in t and MT CO₂ eq.

| | Reduction scenario | Scenario "Frozen technology" |
|------------------------|--------------------|------------------------------|
| 134a emissions in t | 45 | 1,636 |
| 152 a emissions in t | 600 | 1,364 |
| HFC total in t | 640 | 3,000 |
| MT CO ₂ eq. | 0.14 | 2,32 |

Compared to the scenario "frozen technology" (2.32 MT CO₂ eq.) in this 2010 reduction scenario global warming emissions would drop to 0.14 MT CO₂ eq. This is a reduction by 2.18 MT CO₂ eq./year.

4.6.5 Specific costs of reduction options

There are two kinds of investments to be made. Firstly, about half of the 12 OCF fillers within the EU are not yet ready to meet the fire safety class B 2 without HFCs and hence need time and R&D manpower to adjust their formulations. The envisaged one-off costs for that are estimated at about €1 million. Secondly, the replacement of non-flammable HFC-134a by inflammable gases (hydrocarbons and HFC-152a as well) leads to higher safety requirements on the plant-sited storage tanks which have to be protected by special equipment and installations. This cost (one-off cost as well) to be borne by all the EU fillers is estimated to range between €2 million to €6 million, overall.

Applying the maximum costs (€ 7 million), a discount rate of 10%/year and a depreciation time of 10 years¹⁰ we arrive at annualised investment costs of € 1.14 million.

The new hydrocarbon-based B 2 formulations themselves will not cause higher running costs. Given a cost-price per kg 134a of €4.50 and per kg 152a of €4, the reduction by 80 grams 134a, respective 60 grams 152a, saves €0.36, respective €0.24 per 750-ml can. To compensate the risen fire risk the amount of flame retardants has to be increased in the same order of magnitude. The cost-price per kg of the standard flame retardant TCPP (tris(chloropropyl)-phosphate) is about € 1.50, currently. Thus the additional flame retardants cause expenses of €0.09 to €0.11 per 750-ml can. As the chemical cost price of hydrocarbons is only about 5-10 % of the chemical cost of HFCs, the additional 60 to 80 grams hydrocarbons cause another €0.03 per can. Making a balance of the running costs of the reformulated B 2 products savings of €0.10 to €0.18 per 750-ml OCF can are expected, at the minimum. In the section 4.6.7 we calculate with savings of €0.10.

4.6.6 Structure and geographical distribution of the economic sector affected

The economic sector directly affected is the OCF industry as a small part of the Chemical Industry in general. The typical OCF company in Europe is an independent SME owning one filling plant with 50 to 100 employees. The plant itself mostly is divided in an OCF department and a same sized department for sealing compounds.

Table 9 Geographical Distribution of European OCF Filling Plants Inside and Outside the EU-15, Number, and Production in Million Cans in 2001

| Countries | Number of Plants | Filled Cans per Year |
|---|------------------|----------------------|
| Germany | 5 | 28 |
| Austria | 2 | 3 |
| Belgium/Netherlands | 2 | 34 |
| Italy/France/Portugal | 3 | 1 |
| <i>Plants within the EU</i> | <i>12</i> | <i>66</i> |
| Switzerland/Estonia | 2 | 27 |
| Poland/Russia* | 9 | 10 |
| Czech Republic/Slovakia/ Slovenia/ Yugoslavia/Turkey | 8 | 14 |
| <i>Plants potentially exporting into EU</i> | <i>19</i> | <i>51</i> |
| <i>Total European Plants</i> | <i>31</i> | <i>117</i> |

Source: AKPU. Please note: Filled cans are not recalculated to standard volumes of 750 ml (actual volumes range from 300 ml to 750 ml, averaging approx. 650 ml, per can).

* Although the majority of the East-European plants indeed only sell outside EU, some plants do export into the EU.

¹⁰ Reviewing this draft chapter the OCF industry representatives (AKPU) claimed a depreciation period of just 3 to 5 years. We say: Taking 5 instead of 10 years, the annualised investment costs would increase from 1.14 to 1.85 m€ not substantially changing the final result.

4.6.7 Economic impacts on sector

The economic impact on the OCF sector derives from the specific costs of realized emission reduction options as above presented. To reduce the 2010 global warming emissions by 2.2 MT CO₂ eq. investment costs of about €7 million are to make by the 12 EU plants. These one-off costs annualised into running costs will amount to €1.14 million. The latter split into the current output of 60 million cans per year (alternatively into the expected annual output of 70 million cans by 2010) make additional costs from that investments per 750-ml standard can of € 1.14/60 (€ 1.14/70) or about € 0.02, annually.

These additional annual costs caused by the investment of € 1.14 million will be overcompensated by balanced savings resulting from less running costs of HFCs being not offset by additional running costs of more hydrocarbons and flame retardants in the new B 2 formulations which will be needed for roughly 35 million cans by 2010 within the EU. 35 million reformulated B 2 cans cause less running costs of at least €3.5 million (€0.10 per can), leading to savings of €3.5 million in annual operating costs.

After all, for mid-term the emission reduction of 2.2 MT CO₂ eq. results in net savings, especially due to less and cheaper HFCs used, considering the OCF industry as a whole. From the annual net savings of almost €2.4 million by 2010 (€3.5 million minus €1.14 million) specific reduction reduction costs of 1 t CO₂ eq. turn to be negative, i.e. a specific gain of €1.09 per T CO₂ eq. avoided can be calculated.

4.6.8 Recommendations

Basically the EU internal use of HFCs as propellant for OCF should be limited to cans destined for the retail trade¹¹ and to cans for underground applications. An instrument to achieve this goal could be a general prohibition on the use HFCs with exemptions for DIY and underground applications. The HFC-134a in OCF for exports should remain unrestricted. The use limitation should enter into force not until 2006 in order to allow the OCF industry to adjust their formulations to the fire safety class B 2, without HFCs. A voluntary commitment of the industry to limit greenhouse gas emissions to a level of e.g. 0.15 MT CO₂-eq.) could be seen as an opportunity to re-consider the urgency of respective legislative measures on the European level. Such a limit would encourage the OCF industry to change to alternative propellants and HFC-152a as far as possible and, on the other hand, would permit the use of HFC-134a to the small extent where it may still be necessary.

4.6.9 Organisations consulted and their main views

The AKPU (Working Group of the EU OCF Industry) was contacted represented by P. Geboes (Soudal NV) and A. K. van der Rhee (Autra Den Braven Aerosol GmbH). The data on can sales, on the number and site of companies involved were provided as well as the forecast that within the next 3 ears only about 20 % of all OCF products in the EU will contain HFC's mainly due to the technical progress in the formulation development of purely hydrocarbon blown systems. On the other hand it should be noted that the AKPU representatives have estimated the HFC emission reduction achievable by 2010 at 1.8 MT CO₂ eq., different from the 2.2 MT CO₂ eq. as estimated by the consultants, the latter thinking only 0.14 MT CO₂ eq. instead of 0.5 MT CO₂ eq.

¹¹ It was pointed out by reviewers of the draft report that a selective prohibition of product sales through only of its distribution channels may not be enforceable.

to be necessary, by 2010. This is why the AKPU does not support such a wide replacement of HFC-134a by HFC-152a, claiming a need for the non-flammable propellant 134a higher than the consultants estimate. Furthermore, the AKPU representatives did not speak up for any legal restriction or limitation of the HFC-134a but for voluntary action (including monitoring) to achieve the reduced level of global warming emissions from OCF application.

Further companies contacted by phone and personally are Henkel (Germany), Rathor (Switzerland), Ramsauer (Austria), Hanno (Austria). Especially Mr Kluth of Henkel KGaA provided information on the criteria of the small burner test and on the principles of OCF reformulation to stand that test (HFCs, hydrocarbons, flame retardants).

4.7 HFCs in novelty aerosols

4.7.1 Description of application

The so-called “novelty aerosols” are a small sub-group of the larger category of aerosols. In the scope of this study, the term “novelty products” will only cover the following applications related to the use of HFCs:

- Artificial snow sprays
- Decoration paint sprays
- Silly string for parties
- Signal horns for parties and sport events

In terms of the number of filled cans “novelty aerosols” account for only a few percent of the total aerosol market which is best known for products like deodorant sprays, hair spray, shaving lather or air fresheners. Most of the aerosol sector has converted from CFCs to hydrocarbons in the late 1980’s including part of the product range of novelty aerosols. In cases where the product had to be non-flammable the fillers of novelty aerosols reverted to HFCs as soon as they became available in the early 1990’s. The need for non-flammable products is only partly market driven and results mainly from liability concerns and from legislation.

For the EU Directive 94/48 (which amends the annex of Directive 76/769 “Marketing and use of certain dangerous substances and preparations”) mandates that substances classified as flammable, highly flammable or extremely flammable may not be used in aerosol generators for sale to the general public for entertainment and decorative purposes. The Directive 94/48 is only incompletely implemented and enforced in the majority of Member States because they are waiting for official test methods on aerosol flammability. As a result flammable as well as non-flammable aerosols for decorative and entertainment purposes are sold into the different national markets.

Often, manufacturers make a distinction between aerosol application for entertainment (must be non-flammable) and decoration (can be flammable) because of the difference application pattern. While groups of consumers on parties or sports events tend to have a non-attentive attitude, it is expected that individual consumers in their homes pay due attention to the safety advice printed on the aerosol can – just as they do it for other flammable aerosol products like hair spray or insecticides. It is important to note that in a number of international markets (e.g. the US) the sale of flammable aerosols for decoration applications is permitted.

According to FEA, European aerosol fillers in the field of novelties have a strong competitive position in the other major markets and the US in particular. A very significant fraction of EU production of novelty aerosols is currently exported from the EU. Latin America is also a major market of “carnival products”, covered by local production.

4.7.2 Evolution of emissions

The European Aerosol Federation (FEA) has recently presented HFC emission data for aerosol applications in 2001. The FEA survey included the whole EU-production of aerosol products including the fraction sold outside of the EU. For 2001 FEA reported

5.83 MT CO₂ eq. of HFC from all aerosols applications (mainly technical aerosols). FEA estimates that 1.27 MT CO₂ eq. came from novelty aerosols produced and consumed within the EU. Imported novelty aerosols are believed to be insignificant. According to FEA, one-component foams are generally not included into these numbers though some very limited double-counting could have occurred.

Table 10 Estimated break-up of EU emissions into the four major novelty applications

| | Share of HFC-consumption | Calc. emissions in 1995 [MT CO ₂ eq.] | Emissions in 2001 [MT CO ₂ eq.] | Calc. emissions in 2010 [MT CO ₂ eq.] |
|-------------------------|--------------------------|--|--|--|
| Artificial Snow | 50% | 0.53 | 0.64 | 0.83 |
| Decoration Paint | 20% | 0.21 | 0.25 | 0.33 |
| Silly String | 20% | 0.21 | 0.25 | 0.33 |
| Signal Horns | 10% | 0.11 | 0.13 | 0.17 |
| TOTAL | 100% | 1.06 | 1.27 | 1.66 |

Based on information obtained from the industry a break-up of emissions into the specific novelty aerosol applications as presented in Table 10 is derived. Currently fairly little information is available about emission levels in 1995 and the likely evolution of emissions until 2010. Proxy emissions for 1995 and 2010 are calculated assuming a moderate growth rate of +3% per year throughout the period 1995 to 2010 across all applications, a constant import share of 30% across all applications and a constant mean global warming potential in time.

4.7.3 Emission reduction options, potentials and costs

Three different types of emission reduction are available:

- a) Conversion to flammable propellants where safety permits
- b) Conversion to non-flammable propellants with lower global warming potential
- c) Marketing restrictions for selected products applying HFC propellants

a) Conversion to flammable propellants

Emission reduction potential

This option is feasible for artificial snow spray and decoration paint spray. Flammable propellants are safely used in a number of Member States as well as in the United States. In order to have robust legal position for this option the use of flammable substances in decoration sprays would need to be permitted as part of next periodic amendment to Directive 76/769. About 1.2 MT CO₂ eq. could be saved through this option in 2010.

Specific abatement costs

For a number of national markets artificial snow and decoration paint sprays are sold using hydrocarbon propellant. The formulations for the use of hydrocarbons and the required filling lines are thus available. The use of hydrocarbons propellant would thus result in net savings due to the higher price of HFCs in comparison to hydrocarbons. Applying costs of €4 / kg for HFC-134a and €0.3 / kg of an alternative hydrocarbon propellant, specific reduction costs of – 2.8 €/ T CO₂ can be calculated.

b) Conversion to non-flammable propellants with lower GWP

Emission reduction potential

A number of fillers already apply mixtures of HFC-134a and 152a instead of pure 134a while maintaining the status of non-flammability of their product. Mixtures of 87:13 of HFC-134a and 152a have been shown to show a good performance in different formulations – exhibiting a 12% reduction of the global warming impact. In a number of cases higher shares of 152a may also be feasible. It is estimated that in 2001 HFC-152a had a 5% share of HFC consumption for novelty aerosols with 134a contributing the other 95%. If no other reductions (e.g. under a) und c)) are taken it is estimated that an additional reduction of 7% of projected emissions in 2010 is achievable, corresponding to a reduction of 0.12 MT CO₂ eq. If option a) is fully taken the achievable emission reduction is significantly smaller (0.04 MT CO₂ eq.). This option could either be mandated or be taken voluntarily. It should be noted that a number of ambiguities regarding the definition and testing of flammability need to be resolved.

Specific abatement costs

Based on indicative market data we here assume that the prices for a kilogram HFC-152a and HFC-134a are 3.5 and 4 € per kilogram, respectively. Additional savings to switching to the cheaper 152a result from the fact that not equal masses of different types of propellant are required for a given aerosol product. Equal volumes (density of the liquid 1.2 vs. 0.9 g/cm³) or molar amounts (102 vs 66 g/mol) are probably the more suitable indicators, resulting in about 30% lower mass consumption of HFC-152a in comparison to HFC-134a propellant for the same product. The extended use of HFC-152a thus exhibits a calculated cost effectiveness of –1.3 €/ T CO₂ eq.

c) Marketing restrictions

Emission reduction potential

For certain aerosol products, like signal horns no sufficiently safe drop-in alternatives are available. However, for the use in sport events and parties size and generated volume are not critical. Non-in kind alternatives like squeeze and pneumatic horns can easily be used with little reduction in comfort. Marketing restrictions for these products in their respective sales channels¹² could be considered. The respective emission potential in 2010 is in the order of 0.13 MT CO₂ eq. At a number of sports events, e.g. in the sports stadiums of the German soccer league (“Bundesliga”), the use of signal horns is prohibited already for noise and safety reasons. Signal horns for maritime and on-shore emergency applications are seen as critical uses of HFCs. Their use should not be restricted at this time. Silly string is another entertainment application of HFCs in which flammable drop-in alternative propellants are not seen as safe options.

¹² Two reviewers of the draft report questioned whether a selective prohibition of sales of the product through a specific distribution channel would be enforceable.

Potentially, not-in-kind alternatives like party streamers could be used resulting in only modest reductions of consumer utility. It may be of interest that some US cities like Santa Clara have issued prohibitions on the use of silly string in public festivities because of the high costs of removing the material from public installations. The estimated reduction potential of a prohibition of silly string¹³ use in Europe is 0.33 MT CO₂ eq. in 2010.

Specific abatement costs

Based on prices listed for various types of commercially available squeeze and pneumatic horns we assume that a typical device is available for about €40. Prices for typical HFC signal horns used for sports events are found to in the range of €10 per item or refill cartridge containing about 200 g of HFC-134a. Using a lifetime of typical squeeze and pneumatic horns of 3 years and conservatively applying a use frequency of only one HFC cartridge a year, we arrive at specific abatement costs of - 7 €/ T CO₂ eq. For silly string – available at roughly € 3.5 per can for 300 ft of string – and the alternative a 500 ft flame resistant party streamer available at about €4.5 per roll specific abatement costs of -50 €/ T CO₂ can be calculated based on 20 g of HFC-134a in each can of silly string - not considering public or private costs for removing silly string from surfaces.

4.7.4 Affected economic sectors and impact of measures

According to indicative information provided by FEA, roughly 15 fillers in Europe produce novelty aerosol products. All of these fillers located in Spain, Italy, Belgium, the Netherlands, France and the United Kingdom are SMEs with often strong focus on export. The exact impact on the sector depends on the specific package of measures. If prohibitions are limited to the use of HFCs in decoration aerosols and flammable propellants are legalised for these applications within the EU, no negative impact is foreseeable on the sector. Use restrictions for HFCs in signal horns for entertainment and silly string could have measurable and possibly significant impact on selected fillers. As long as the production and export of novelty aerosols are left unregulated it remains unlikely that significant economic harm will result for any of the EU fillers through the measures outlined above.

4.7.5 Recommendations

Despite the complicated required procedure, it seems justified to re-permit the use of flammable substances in aerosols for decoration purposes through an amendment of Directive 76/769. The use of flammable aerosols for entertainment purpose, however, is clearly not desirable. In these applications, a general prohibition of silly string and the marketing of signal horns for entertainment purposes should be considered – potentially starting in 2005. Clearly the use of HFCs in safety signal horns should remain possible. As a weaker measure, it could also be considered to prohibit the use of pure HFC-134a in novelty aerosols and require a minimum admixture of HFC-152a.

4.7.6 Organisations consulted

In preparation of this paragraph the European Aerosol Federation (FEA), ECE-Goodmark, Volcke Aerosol Company NV and Autra GmbH. For statistical information

¹³ FEA in its comments to the draft final report cautioned that the impact of this measure could have severe effects on specialised fillers and their suppliers.

the websites of BAMA (United Kingdom) and IGA (Germany) were used: <http://www.bama.co.uk> and <http://www.igaerosole.de>

The key message received from the organisations approached was that a prohibition of the production of aerosol products containing HFCs would have disastrous effects on the industry because of varying requirements on export markets. It was perceived as much less critical if marketing and use restrictions were imposed for the EU market. A revision of the marketing and use restrictions of flammable agents in decoration products as imposed through the poorly implemented and enforced Directive 94/48 was seen as an important step to flank HFC emission reductions.

4.8 HFCs as surface cleaning solvents

4.8.1 Description of application

In some industrial sectors such as electronics, precision mechanics, fine optics, jewellery, the surface of product parts being manufactured is not only very sensitive – sometimes even to water – but also requires an extremely high degree of cleanliness. Thus the applied cleaning agent has to be very mild as well as effective in removing relatively small amounts of organic impurities, and must not leave any residues or spots on the parts' surface when drying. A number of organic solvents are sufficiently qualified to meet this objective.

One successfully applied chemical possibility are short-chained hydrocarbons, esters, and ethers. Due to their flammability their use as precision cleaning solvents requires fire-protected equipment and machinery especially if a heating of the solvent bath is required to use the vapour for rinsing the parts.

Compared to flammable organic compounds the chlorofluorocarbon (CFC) 113 show the same excellent solvent properties but facilitates the cleaning in relatively simple installations. The moderate price of both the cleaning facilities and the cleaning agent itself had made CFCs the standard solvent in precision cleaning, for decades. After the EU-wide prohibition of CFCs the liquid HCFC-141b took its place owing to its comparable chemical properties, in the reduced number of cases where such mild organic solvents were still seen necessary (accounting for 12% of the original CFC-113 use volume).

In face of the total ODS-prohibition being on the agenda (in the EU from 2002 onwards, in line with EC 2037/2000) new generation in-kind solvents with similar properties (HFE-449s1 and HFC-43-10mee) have been developed over the last years and have started replacing HCFC-141b in Europe.

It should be added that, according to EFCTC, PFCs like C_6F_{14} are used as dielectric coolant in closed systems, but not for solvent applications.

4.8.2 Evolution of emissions

A. By the year 2001 the annual sales, which in the middle term become emissions of the same size, of HFCs/HFEs into the EU market hardly exceeded 100 tons, with an estimated proportion between HFC-43-10mee and HFE-449s1 of one third/two thirds. At that time the HFC blend 43-10mee/365mfc was not yet on the EU market place.

For 2002, when the EU prohibition of HCFC 141b in solvent applications came into force, a considerable increase of sales was expected by the solvent industry. However, the reported preliminary sales numbers indicate only a slight rise by some 50 tons for both fluorinated solvents. The slow market growth can be interpreted as transitional assuming users and dealers still have enough 141b in reserve. But there is also a concern within the industry that the transition might take until 2009 when the

aerospace/aeronautics industry will ultimately have to replace 141b, and the users in the electronics generally might define themselves to belong to that exempted sector¹⁴.

There is strong evidence that not the technical characteristics of the new solvents are obstacles to a faster conversion but the high prices are. In 2002, one kilogram of 141b costs €6-7 whereas one kilogram of HFC-43-10mee or HFE-449s1 costs more than €40. The industry announced that the prices would not be lowered significantly in the future as there is no cost-saving large-scale production of these new chemicals. However, the cleaning process running cost of HCFC-141b and the new solvents (HFC/HFE) is very comparable as usage emissions are very significantly reduced, mainly due to the difference in physical properties (boiling point / vapour pressure & fluid viscosity (drag-out) driven).

Mainly in order to lower the price-barrier to more sales the HFC-43-10mee producer has developed an HFC blend consisting of 43-10mee and 365mfc. By addition of 40% of HFC-365mfc (€8-10/kg) the solvent price drops below €30/kg. While HFC-365mfc as a pure fluid is flammable and has a different boiling point (41 °C) from 43-10mee (55 °C), the azeotrope like blend is non-flammable.

B. The long-term emissions forecast (2010) is based on the current annual use of 141b amounting to 6,000 tons. The one half of the latter is expected to be replaced by alternative technologies as no-clean, aqueous or semi-aqueous, and fluorine-free organics. Only the other half might be substituted by new fluorinated solvents. Although these, like 141b, are applied in open chambers where emission control is limited to vapour condensation by means of cooling coils around the upper chamber walls, the future annual use to compensate emissions is estimated at less than the half of the remaining 3,000 tons, namely 1,200 tons at the maximum. Due to the higher boiling point of HFC-43-10mee in comparison to 141b (55°C vs. 32°C) and resulting lower vapour pressure (with HFEs having still better values) the loss of solvent per cleaned part will amount to less than the half as in case of 141b.

The EU VOC solvent directive, in force on national levels since 2001, certainly has a further - lowering - impact on the future demand for HFC solvents. From a threshold consumption of 2 (in some Member States 1) tonnes onwards strict emission limitations for each halogenated solvent is valid, creating still another motive to save HFC and HFE solvents apart from their high price. In Germany e.g. the company 3M has agreed to an average upper emission limit of 30 grams HFE per hour (~ 260 kg/y) for standard precision cleaning systems even below the annual consumption threshold value (1 tonne in Germany).

There are a number of uncertainties to make fairly reliable emissions forecasts. But the long-term estimation dating back to 1998 (EnvirosMarch) predicting 1,200 tons/y meanwhile has turned out to be too high calculated. Taking into account the low conversion rate (from 141b to HFC/HFE) of 20 % as well as the EC VOC directive the EFCTC itself has cut the estimated market potential back to the half, i.e. 600 tons/y.

¹⁴ One reviewer of the draft report cautioned that this effect should not be overestimated as exemptions for a continuation of the use of HCFC-141b are generally granted by Member States only to businesses meeting strict criteria.

4.8.3 Available emission reduction options

Considering the special legal and economical conditions it seems rather unlikely that prospective industrial users of fluorinated solvents make a decision to apply them unless they have no alternative. An option to reduce the absolute amount of fluorinated solvents by 2010 significantly under the 600 metric tons is not realistic in our eyes. On the other hand a change from higher GWP solvents (HFC) to lower GWP solvents (HFE) seems worth discussing, the more as there is no technical advantage of HFC- vs. HFE-fluids and the price level is comparable¹⁵.

4.8.4 Achievable emission reductions

If all the forecasted 600 tons fluorinated solvents in 2010 would consist of HFE-449s1 (GWP: 300) the global warming potential of the emissions would be 0.18 MT CO₂ eq. In a scenario with 50 % HFE-449s1 and 50 % HFC-43-10mee (GWP: 1300) the emissions are 0.48 MT CO₂ eq. The emission reduction achievable by this way is 0.3 MT CO₂ eq.

4.8.5 Reduction costs and economic impacts on sectors

As we propose to discuss only an exchange of solvents (HFE-449s1 replacing HFC-43-10mee) with the basically same prices and the same equipment requirements, no additional costs would arise. It must be pointed out, that the costs arising from the replacement of 141b are no costs owing to a specific legislation on fluorinated greenhouse gases but costs of the ODS phase-out according to the Montreal Protocol and its EU wide transposition. Many of the old 141b facilities probably do not satisfy the needs of modern emission control. It is self-evident that all the measures available to reduce solvent emissions (e.g. low temperature cooling coils on the freeboard of the chambers to freeze out the solvent vapour evolved) have to be done before substances potentially damaging the climate are used.

4.8.6 Number, size and geographical distribution of businesses affected

Within the EU about 1,200 companies are affected in that they are prospective users of the new fluorinated solvents for industrial surface cleaning, most of them currently using 141b. More than half the companies are SMEs. The geographical distribution is not uniform across the EU, as by far the most companies are located in Western and Southern Europe where the respective industries are concentrated. The EFCTC has ranked the Member States according to the number of companies affected as follows: UK (300), Belgium (20), Netherlands (40), France (320), Italy (360), Spain (100), Germany (50), and Austria (10).

While in Northern Europe (Scandinavia) only few companies are active in precision cleaning, the small number of affected companies in Germany and Austria results from the strict legislation, which has prohibited the use of 141b as solvent for surface cleaning since many years. Thus the prospective German and Austrian HFC/HFE users

¹⁵ One reviewer of the draft report pointed out that it would be more appropriate to use TEWI (total equivalent warming impact) of the system instead of the GWP of the substance. The authors of this report would like to caution that TEWI cannot easily be operationalised for legislation on a broad range of cleaning applications.

will not have to replace HCFCs but rather halogen-free organic solvents to satisfy the emissions regulations derived from the EU VOC solvent directive.

4.8.7 Recommendations

It is found to be feasible to prohibit the use of HFCs/substances with a GWP higher than 500 for industrial surface cleaning in new installations immediately (2004) – though a number of stakeholders have expressed reservations¹⁶. At the same time the use in existing applications should be permitted as long as HCFC-141b is not totally prohibited or at least a consistent definition of the user-group "aerospace/aeronautics" is across the Member States. This probably precludes a prohibition prior to 2009.

4.8.8 Organisations consulted and their main views

EFCTC – subgroup solvents, represented by P. Breloer. Mr Breloer provided most of the information about products, sales- and emission trends, user groups etc. He suggested to focus the attention on an orderly European transition out of ODS solvents and stressed the point that restrictions on the new HFE- and HFC-based solvent alternatives to HCFC-141b, offering no-ODP and significantly reduced GWP emissions under use conditions, would be absolutely counterproductive and take away the necessary incentive featuring early action programs.

DuPont Europe, Geneva, represented by J. A. Parceiro. Mr Parceiro especially stressed the uncertainties of the market development caused by the coexistence of HFCs/HFEs with the cheap ODS 141b not allowing any reliable quantitative forecasting of the future demand.

¹⁶ E.g. it was pointed out that this threshold could stifle innovation and lead to a monopoly situation with 3M (currently) being the only supplier. However, one Japanese manufacturer is reported to start its production of HFEs. Legislators could consider to use a higher threshold value (e.g. GWP<1000 – permitting non-flammable blends of HFC-43-10mee and HFC-365mfc into the market) if the threat of a monopoly situation is considered problematic.

4.9 PFC as fire fighting agents

4.9.1 Description of application

In some EU Member States to a small extent gaseous PFCs (mostly C₄F₁₀) are used for fire protection in fixed systems for flooding closed rooms (e.g. control rooms). Although the halon replacement (beginning in 1991) has led to an extensive use of inert gases (nitrogen, argon, CO₂) instead of halon-1301, fluorocarbons had come also in use in special installations where extreme safety is required and where halons had been considered non-replaceable for a long time. Though the most common new fluorocarbons used as fire fighting agents became HFCs (227ea, 236fa, 23, and 125), from the mid-nineties to the year 1999 there were also some fire extinguishing PFCs imported from the USA into the EU.

The only importer 3M Company had promoted the C₄F₁₀ under the product code CEA-410. According to its statement 3M has stopped marketing CEA-410 as fire fighting agent within the EU in 1999 due to the absence of agreed upon essential use with regulator agencies, as the company stated. Since that time 3M only supplies quantities for recharge. Up to that time they had sold into the EU not more than 40 tonnes exclusively to suppliers of fire fighting installations – most of them based in the Netherlands, UK, Italy and Germany. A respectable part of that PFCs sold by 3M to its EU customers had been exported by them further to Eastern Europe inside ready filled fire fighting equipment.¹⁷ Another considerable part being tested by the armed forces as possible halon replacement has escaped into the atmosphere.

The liquid PFC C₆F₁₄ for portable extinguishers (CEA-614) has never played more than a marginal role in replacing Halon-1211 within the EU. The most part of the annual 3M sales into Europe ranging from 1.4 t (1999) to 1.2 t (2001) was destined for Eastern Europe and still is.

4.9.2 Evolution of emissions

The 3M company estimates the number of existing fixed fire installations filled with C₄F₁₀ within the EU at some 50 in 2001, containing about 20 tons altogether. As above mentioned some 15-20 tons of the overall sales of 40 tons into the EU had been forwarded by EU based equipment producers to Eastern Europe. To refill losses from EU wide installed systems alone, 3M estimates its sales at 1.4 t in 2001 and – preliminarily - 1.5 t in 2002 going along with an emission rate of existing installations of 7 % per year. In terms of global warming C₄F₁₀ emissions (GWP 7000) amount to 0.01 MT CO₂ eq., in 2001.

Use and emissions of the liquid fire extinguishing PFC C₆F₁₄ in Europe virtually do not occur within the EU-15 but only in Eastern Europe. Sales for charging portable extinguishers show a decreasing tendency from 1.7 tons in 2000 to preliminary 1.0 t in 2002. No emissions of that PFC are here estimated for the EU-15.

¹⁷ In 1999 there were 11 tons sold into the EU (Netherlands, UK, Germany, Italy) and 7 tons directly into Poland. A considerable part of the sales into the EU was forwarded to Eastern Europe inside installations.

4.9.3 Available emission reduction options

For fire extinguishing in critical applications in special indoor areas where people cannot escape from flames, HFCs are established fluids, although in many cases inert gases can achieve comparable effects. The HFCs used today are HFC-227ea (GWP: 2900), HFC-236fa (GWP: 6300), HFC-23 (GWP:11700) and HFC-125 (GWP: 2800).

Fire extinguishing fluids alternative to PFCs and HFCs – where other agents might be unsuitable - recently developed by 3M are fluoro-ketones like $C_6F_{12}O$ which is commercially available since 2002. Their environmental advantage is their low GWP of 1, their technical drawback is the physical state of a liquid. Thus they cannot be applied as simple drop-in fluids in still existing PFC installations as these are designed for gaseous fluids.

4.9.4 Achievable emission reductions

It is assumed that by 2010 PFCs (GWP: 7000) no longer will be in use in fixed fire extinguishing installations as the latter will have been retrofitted to e.g. HFC-227ea by that time. Annual operating emissions (1.4 metric tons PFCs) of 9,800 t CO₂ eq. would be cut by 6,755 t CO₂ eq., dropping to 3,045 t CO₂ eq. (1.05 metric tons HFCs).

4.9.5 Specific costs of reduction options and economic impacts

To complete the picture, the following indicative cost calculations for a conversion from PFCs to HFC-227ea have been added.

On an average, each of the some 50 present-day PFC suited installations contains 400 kg C₄F₁₀ enabling to flood rooms of 470 m³ with a concentration of 8 vol. %. To adjust one installation to HFC-227ea some technical changes have to be made (new nozzles, new extinguishing vessels, the piping system to a large extent), causing costs of about €23,500 (€50 per m³ flooded room). Apart from that the 400 kg PFC must be removed and destructed which costs €600 (€1500/t). Because of its lower molecular mass only 300 kg of HFC-227ea instead of 400 kg PFC must be filled in, forming costs of €9,000 (€30 per kg). The total investment costs for retrofitting one plant come to €33,100, which are annualised (based on a 15 years depreciation period and 10% discount rate) €4,350. Thus, retrofitting all the 50 installations costs annually €217,500.

The running fluid costs would be lowered compared to PFCs (€45/kg) when using fluorinated compounds like HFC-227ea (€30/kg) or fluoro-ketones (€36/kg). In case of HFC-227ea annual cost for compensating emissions of 1,050 kg (despite of the same emission rate of 7%, being less than in case of PFC due to lower fluid weight per installation) come to €31,500, against €63,000 in case of PFCs, causing smaller operating costs for fluids by €31,500.

The total annual costs (annualised investment plus annual fluid costs) amount to €186,000.

The emission reduction of 8,995/6,755 t CO₂ eq. by retrofit from PFC to HFC-227ea, would cost €186,000, annually. The specific reduction costs of 1 t CO₂ eq. can be calculated to €20.67/27.53.

4.9.6 Recommendations

We recommend to prohibit the use of PFCs in new fire fighting installations from 2004 onwards and to allow recharging existing installations only until 2008. Such a measure would legally back and reinforce the sales-stop of PFCs which is currently voluntary and thus reversible.

4.9.7 Organisations consulted and their main views

The organisation chiefly consulted was the 3M company as represented by Mr P. Breloer. He not only gave the sales data as presented above but also confirmed to the company's statement to withdraw its PFCs from the market. As alternative fluid he spoke up for fluoro-ketones. The second consulted company Great Lakes, represented by Mr Bliemeister, favored the HFC-227ea as agent alternative to PFCs. The company Kidde-Deugra provided data on costs of retrofitting existing PFC installations to HFC-227.

5 Summary of quantitative results

This chapter summarises the quantitative key findings of the analysis of the applications in chapter 4. A break-down of the respective contributions coming from the different applications is given in Figure 6. Table 12 gives an overview of the most important results for each of the applications. Clearly all but one application (fire-fighting) fall in the abatement cost range of negative or very low. Table 13 reports the break-up of achievable EU emission reductions into Member State data. The split was derived based on country specific data on:

- SF₆ in car tyres - country specific activity data
- SF₆ in sound insulating glazing - country specific activity data
- SF₆ in sport shoes – not applicable (emissions are assumed to be zero in 2010)
- SF₆ in magnesium casting - country specific activity data
- HFCs in self-chilling beverage containers - not applicable (emissions are assumed to be zero in 2010)
- HFCs in one component foams - country specific activity data
- HFCs in novelty aerosols – national GDP values
- HFCs and PFCs for surface cleaning - country specific activity data
- PFCs in fire-fighting – country specific activity data

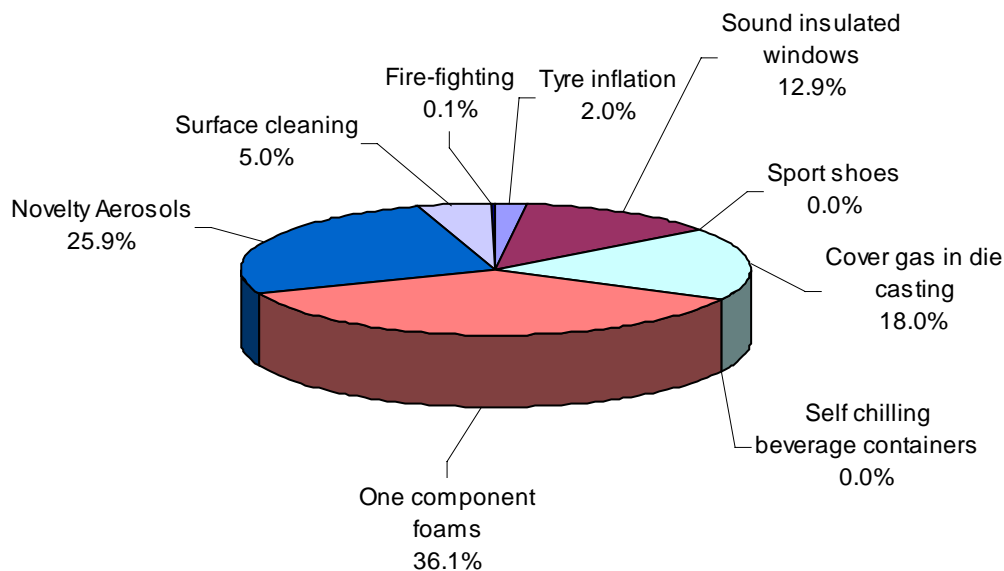


Figure 6 Overview of calculated emission reductions in 2010 through proposed measures for the applications analysed.

Table 12 Overview of characteristics of applications examined for marketing and use restrictions

| Application | Gases Prohibited | Alternative Technologies | Proposed timing of prohibition | Projected Emission in 2010 | Achievable Reduction in 2010 | Abatement Cost – econ. actor | Number of aff. EU businesses | Total investment costs | Exemptions |
|---|---------------------------------|---|--|-----------------------------|------------------------------|---------------------------------|------------------------------|------------------------|--|
| Tyre inflation | SF ₆ | <u>Air</u> | 2004 | 0.12 MT CO ₂ eq. | 0.12 MT CO ₂ eq. | < -2 €/ T CO ₂ eq. | ~ 100 | 0 M€ | None |
| Sound insulated windows | SF ₆ | <u>Argon & modified construction</u> | 2004 | 3.2 MT CO ₂ eq. | 0.8 MT CO ₂ eq. | < -0.5 €/ T CO ₂ eq. | ~ 350 | 23 M€ | None |
| Sport shoes | SF ₆ PFCs HFCs | <u>N₂, PFCs, NIK</u> | 2004: SF ₆ 2006: all | 0 MT CO ₂ eq. | 0 MT CO ₂ eq. | Not defined | 1 | 0 M€ | None |
| Cover gas in magnesium die casting | SF ₆ | <u>SO₂, HFC-134a, Fluoroketone</u> | 2005 | 1.2 MT CO ₂ eq. | 1.1 MT CO ₂ eq. | < 0.7 €/ T CO ₂ eq. | ~25 | 2.0 M€ | Casters with <500 kg annual throughput |
| Self chilling beverage containers | HFCs | <u>CO₂ chill can, NIK</u> | 2004 | 0 MT CO ₂ eq. | 0 MT CO ₂ eq. | Not defined | 0 | 0 M€ | None |
| One component foams | HFC-134a HFC-152a | <u>HFC-152a, HC, ethers</u> | 2006 | 2.3 MT CO ₂ eq. | 2.2 MT CO ₂ eq. | -1.1 €/ T CO ₂ eq. | 12 | 7 M€ | Retail products & Export |
| Novelty aerosols | HFC-134a HFC-152a | <u>HC, ethers, NIK, HFC-152a</u> | 2005 | 1.66 MT CO ₂ eq. | 1.56 MT CO ₂ eq. | < -1.3 €/ T CO ₂ eq. | ~15 | 0 M€ | Safety horns & Exports |
| Surface cleaning | HFCs | <u>HFES, NIK</u> | 2004 in new install./2009 old install. | 0.48 MT CO ₂ eq | 0.3 MT CO ₂ eq | 0 €/ T CO ₂ eq. | 1200 | 0 M€ | None |
| Fire-fighting | PFCs | <u>HFCs, NIK</u> | 2004 in new install./2008 old install. | 0.01 MT CO ₂ eq. | 0.007 MT CO ₂ eq. | 27 €/T CO ₂ eq. | 50 | 1.7 M€ | None |
| TOTAL | | | | 9.1 MT CO ₂ eq. | 6.0 MT CO ₂ eq. | <-0.67 €/ T CO ₂ eq. | ~1750 | 33.7 M€ | |

Table 13 Country data: achievable emission reduction through examined restrictions in each of the Member States in 2010 [MT CO2 eq.]

| Application | Gases Prohibited | AUT | BEL | DEU | DNK | ESP | FIN | FRA | GBR | GRC | IRL | ITA | LUX | NLD | PRT | SWE | EU |
|--|---------------------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|-----------|
| Tyre inflation | SF ₆ | 0.01 | 0.01 | 0.10 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.12 |
| Sound insulated windows | SF ₆ | 0.03 | 0.02 | 0.65 | 0.02 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.78 |
| Sport shoes | SF ₆ PFCs HFCs | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Cover gas in Mg die casting | SF ₆ | 0.00 | 0.00 | 0.79 | 0.00 | 0.07 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.12 | 0.00 | 0.00 | 0.00 | 0.00 | 1.09 |
| Self chilling beverage containers | HFCs | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| One component foams | HFC-134a HFC-152a | 0.00 | 0.02 | 1.74 | 0.01 | 0.04 | 0.01 | 0.10 | 0.10 | 0.01 | 0.01 | 0.08 | 0.00 | 0.03 | 0.01 | 0.02 | 2.18 |
| Novelty Aerosols | HFC-134a HFC-152a | 0.04 | 0.05 | 0.40 | 0.03 | 0.10 | 0.02 | 0.27 | 0.25 | 0.02 | 0.02 | 0.22 | 0.00 | 0.07 | 0.02 | 0.04 | 1.56 |
| Surface cleaning | HFCs | 0.00 | 0.00 | 0.01 | 0.00 | 0.02 | 0.00 | 0.08 | 0.08 | 0.00 | 0.00 | 0.09 | 0.00 | 0.01 | 0.00 | 0.00 | 0.30 |
| Fire-fighting | PFCs | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.002 | 0.000 | 0.000 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.007 |
| TOTAL | | 0.08 | 0.09 | 3.69 | 0.07 | 0.24 | 0.03 | 0.59 | 0.43 | 0.03 | 0.02 | 0.51 | 0.00 | 0.14 | 0.03 | 0.06 | 6.03 |

6 References

ADL; Global comparative Analysis of HFC and Alternative Technologies for Refrigeration, Air Conditioning Foam, Solvent, Aerosol Propellant and Fire Protection Applications; by J. Dieckmann and H. Magid, A.D. Little, Cambridge, reference number 49468, United Kingdom, 1999.

EC, Third Communication from the European Community under the UN Framework Convention on Climate Change; Brussels, 2001.

European Commission DG XVII: "Major energy savings, environmental and employment benefits by double-glazing and advanced double-glazing technology"; CPIV/FIZ Karlsruhe, 1995.

ECCP, Final Report on the European Climate Change Programme (long report), European Commission, Brussels, 2001a.

http://europa.eu.int/comm/environment/climat/eccp_longreport_0106.pdf

ECCP; Final Report on the European Climate Change Programme - Working Group Industry - Work Item Fluorinated Gases; Prepared by J. Harnisch and R. Gluckman on behalf of the European Commission, Brussels, 2001b.

<http://europa.eu.int/comm/enterprise/chemicals/sustdev/fluorgases/gas1.pdf>

Ecofys, Reduction of the emissions of HFC's, PFC's and SF₆ in the European Union; Commissioned by DG XI of the European Commission, H. Heijnes, M. van Brummelen, K. Blok; Utrecht, April 1999.

http://europa.eu.int/comm/environment/enveco/climate_change/9800043.pdf

Ecofys; Economic Evaluation of Emission Reductions of HFCs, PFCs and SF₆ in Europe; Special Report - Contribution to the study "Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change" on behalf of the Directorate General Environment of the Commission of the European Union, Harnisch, J. and C.A. Hendriks; Cologne, April 2000.

http://europa.eu.int/comm/environment/enveco/climate_change/emission_reductions.pdf

Hayman, G.D., R.G. Derwent; Atmospheric chemical reactivity and ozone-forming potentials of potential CFC replacements; *Environ Sci Technol*, Vol **31**, pp 327-336, 1997.

IPCC, Climate Change 1995 - The second IPCC Scientific Assessment; Intergovernmental Panel on Climate Change, World Meteorological Organization & United Nations Environmental Programme, Cambridge University Press, Cambridge.

IPCC, Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, accepted by the IPCC Plenary at its 16th session held in Montreal, 1-8 May, 2000.

March; Opportunities to Minimise Emissions of HFCs from the European Union; Commissioned by Directorate General Enterprise of the European Commission; United Kingdom, September 1998.

March; UK Emissions of HFCs, PFCs, and SF₆ and Potential Emission Reduction Options; Commissioned by the Department of the Environment, Transport and the Regions, United Kingdom, January 1999.

Öko-Recherche; Aktuelle und künftige Emissionen treibhauswirksamer fluoriierter Verbindungen in Deutschland; W. Schwarz and A. Leisewitz, A study for the German Umweltbundesamt, in German, Frankfurt, 1996.

<http://www.oekorecherche.de/deutsch/download/FKW96.pdf>

Öko-Recherche: 'Emissions and Reduction Potentials of Hydrofluorocarbons, Perfluorocarbons and Sulphur Hexafluoride in Germany'; A study commissioned by the German Environmental Protection Agency, W. Schwarz and A. Leisewitz, Germany, October 1999. <http://www.oekorecherche.de/english/download/f-gases.pdf>

Peutz Adviesbureau, Reduction of Additional (Non-CO₂) Greenhouse Gases; Consequences of using SF₆-free sound-proofing glass, report on behalf of Novem, Utrecht, 2002.

VROM; Member state policies on mitigating emissions of HFC, PFC and SF₆ in the European Union; Background document for the Workshop "Joining European efforts to limit emissions of HFCs, PFCs and SF₆ (Luxembourg - February 1&2, 2000) prepared by D. Yellen and J. Harnisch on behalf of the Dutch Ministry of Spatial Planning, Housing and the Environment (VROM), Utrecht, February 2000a.

VROM; HFCs, PFCs and SF₆: sources of emissions in Europe and reduction options; Background document for the Workshop "Joining European efforts to limit emissions of HFCs, PFCs and SF₆" (Luxembourg - February 1&2, 2000) prepared by Harnisch, J., K. Blok, R. Gluckman, D. Yellen on behalf of the the Dutch Ministry of Spatial Planning, Housing and the Environment (VROM), Utrecht, February 2000b.

VROM; Criteria for the design of policy instruments to limit emissions of HFCs, PFCs and SF₆; Background document for the Workshop "Joining European efforts to limit emissions of HFCs, PFCs and SF₆" (Luxembourg - February 1&2, 2000) prepared by R. Gluckman on behalf of the the Dutch Ministry of Spatial Planning, Housing and the Environment (VROM), Utrecht, January 2000c.

7 Glossary

| | |
|-------|--|
| AFEAS | Alternative Fluorocarbon Environmental Acceptability Study |
| AKPU | Arbeitskreis Polyurethanschaum |
| CFC | Chlorofluorocarbon |
| EFCTC | European Fluorocarbon Technical Committee |
| FEA | European Aerosol Federation |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gases |
| GWP | Global Warming Potential |
| HFC | Hydrofluorocarbon |
| HFE | Hydrofluroether |
| OCF | One Component Foams |
| MT | Million Tons |
| NIK | Not-in-kind |
| PFC | Perfluorocarbon |
| VOC | Volatile Organic Compounds |