Preparatory study for a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases

Annexes

to the Final Report

Prepared for the European Commission in the context of Service Contract No 070307/2009/548866/SER/C4

Authors:

Dr. Winfried Schwarz, Dr. André Leisewitz, Barbara Gschrey (Öko-Recherche)

Anke Herold, Sabine Gores (Öko-Institut)

Irene Papst, Jürgen Usinger (HEAT International GmbH)

Dr. Daniel Colbourne, Prof. Dr. Michael Kauffeld, Per Henrik Pedersen, Igor Croiset

September 2011

Content

Annex I: Questionnaires to Member States authorities and industry

I.1 Questionnaire to the competent authorities of the Member States

Review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases

Questionnaire
to the Competent Authorities of the Member States

Öko-Recherche GmbH
D-60329 Frankfurt/Main, Germany, Münchener Str. 23
Phone +49 69 252305; Fax + 49 69 252306
E-mail: a.leisewitz@oekorecherche.de; barbara.gschrey@oekorecherche.de

This questionnaire was developed by Öko-Recherche GmbH
within the contract to provide technical support to the
European Commission – DG Climate Action, Unit C2 Transport & Ozone

March 2010

Dear Madam or Sir,

In December 2009, the European Commission launched a project to support the **review of Regulation (EC) No 842/2006** on certain fluorinated greenhouse gases. This project is undertaken by Öko-Recherche GmbH (Frankfurt/Main, Germany) in association with several other companies and institutes.

This **questionnaire** to officials of the Competent Authorities of Member States will be a key component of the information gathering. Thus, your responses will be an important element of the study and will contribute to the broader review of Regulation (EC) No 842/2006.

Overall, the **main objectives** of this questionnaire are to:

- Assess the implementation, effectiveness and efficiency of the provisions of the Regulation;
- Evaluate interactions between the existing EU policy framework on fluorinated greenhouse gases and other EC and national legislation (including in particular national provisions stricter than those laid down in the Regulation, legislation on waste etc.);
- Assess and evaluate in particular the scope for clarification and simplification of the Regulation and possible options for strengthening the existing policy framework on fluorinated greenhouse gases.

In addition to this questionnaire to Competent Authorities, we will also contact industry and other stakeholders including NGOs and carry out a review of relevant reports and literature. Thus, we also ask you to kindly provide contacts of relevant experts and studies undertaken in your Member State.

When completing this questionnaire, it might be useful in some cases to coordinate with other officials working on e.g. waste and legal issues and with other experts from your Member State.

After receiving the written responses to this questionnaire, we might eventually contact you in order to carry out targeted telephone interviews on specific points that have been raised.

Your responses to this questionnaire will be treated **confidentially**. Individual responses will not be identified as such in any reports. Furthermore, the information gathered will be used exclusively in the framework of this study and not for any other purposes.

In case of **questions, comments or difficulties** regarding this questionnaire, please don't hesitate to contact us via email or telephone. If you are interested in further information on the role of this study and other work for the review of Regulation (EC) No 842/2006, please contact Mr. Marios Avraamides of the European Commission (DG Climate Action): marios.avraamides@ec.europa.eu.

Thank you,

Öko-Recherche GmbH
André Leisewitz / Barbara Gschrey

Review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases

Questionnaire
to the Competent Authorities of the Member States

Instructions

Completing the questionnaire

This questionnaire can be completed electronically in MS Word by filling in the response boxes. You can also print it out and complete it by hand.

Please answer the questionnaire as comprehensively as possible. Please use the possibility to comment and feel free to indicate issues that will require further discussion in follow-up interviews by email or telephone. If you have any difficulties in completing the questionnaire, please contact Öko-Recherche GmbH (see details below).

Coordination

Coordination with officials in other sectors or experts from your Member State might be useful with regard to some sections of the questionnaire.

Further information

Please send any reports and other information that you consider valuable for the review of Regulation (EC) No 842/2006 along with your response to this questionnaire.

Responses

Please return the completed questionnaire and any related materials

by 31 March 2010

by email to a.leisewitz@oekorecherche.de and barbara.gschrey@oekorecherche.de.

Our contact details
Öko-Recherche GmbH
Dr. André Leisewitz / Barbara Gschrey
D-60329 Frankfurt/Main, Germany, Münchener Str. 23
Phone +49 69 252305; Fax + 49 69 252306
E-mail: a.leisewitz@oekorecherche.de; barbara.gschrey@oekorecherche.de

Review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases

Questionnaire
to the Competent Authorities of the Member States

Your contact details:

Member State	
Contact person	
Institution	
Address	
Telephone	
Fax	
E-mail	

Content

1. F-Gas Regulation and national legislation

Background: The F-Gas Regulation is directly applicable in the Member States but some particular elements needed to be implemented at national level. Furthermore stricter measures compared to particular provisions in the Regulation may apply in some Member States.

1.1 Please indicate the current status of implementation of Article 5(2) on the establishment or adaptation of training and certification requirements on the basis of the minimum requirements for each sector concerned (including interim certification where relevant):

Sector	Comment
Stationary refrigeration, air conditioning and heat pumps	
Stationary fire protection systems and fire extinguishers	
High-voltage switchgear	
Equipment containing fluorinated greenhouse gas-based solvents	
Air conditioning systems in motor vehicles	

1.2 Please indicate the current status of implementation of Article 13 on penalties.

1.3 Has your Member State established or is in the process of establishing requirements which are stricter than those laid down in the Articles 3, 4, 5 and 6 of the F-Gas Regulation and its implementing acts?

Yes	
No	

1.4 If yes: Please indicate the respective national measure(s), the related provisions of the F-Gas Regulation and explain in which regard the national regulation is stricter[1].

[1] Please differentiate between the adoption of national measures that are stricter than the EU harmonised measures and the extension of the EU harmonised measures to non covered fields e.g. a requirement to check for leakage applications within the scope of Art 3(2) in a more frequent manner vs a requirement to check for leakage applications outside the scope of Art 3(2).

1.5 Provisions of the F-Gas Regulation might interact, complement and overlap with other pieces of EU and national legislation. Have you identified any synergies, complementarities and/ or overlaps of provisions in the F-Gas Regulation with other national measures in your Member State or other EU legislation? (Examples: Waste regulations, regulations on protection of the ozone layer etc.)

Yes	
No	

1.6 If yes: Please indicate the respective EU/national legislation, the Article(s) of the F-Gas Regulation relating to them and explain such complementarities and/or synergies and/or overlaps.

1.7 Any problems to be addressed or other comments?

2. Containment provisions (Art 3)

2.1 Regular leakage checks acc. Art 3(2) were compulsory as of July 2007. What is according to your experience the real practice? Has there been any delay? To which degree/extent regular leakage checks are undertaken to day?

If possible, please provide a quantified best estimate e.g. expressed as percentage of installations (reference date: 1.1.2010).

Please distinguish between the different sectors or subsectors affected:

Sector	Comment
Refrigeration equipment	
Air conditioning equipment	
Heat pumps	
Fire protection systems	

2.2 Leakage detection systems acc. to Art 3(3) were compulsory as of July 2007 (In case of fire protection systems installed before 4 July 2007 they shall be fitted by 4 July 2010). What is the real practice according to your experience? Has there been any delay? To which degree/extent leakage detection systems are installed today?

If possible, please provide a quantified best estimate e.g. expressed as percentage of installations (reference date: 1.1.2010).

Please distinguish between the different sectors or subsectors affected:

Sector	Comment
Refrigeration equipment	
Air conditioning equipment	
Heat pumps	
Fire protection systems	

2.3 Do you have specific requirements in relation to Art 3(3) (e.g. technical aspects, metering precision) in your Member State?

Yes	
No	

If yes: Please explain.

2.4 In which form are the records according to Art 3(6) kept (e.g. paper, electronically)?
If different forms of record-keeping are common, please describe to what extent each form is used.

2.5 Do the authorities in your Member State request representative samples of records maintained by the operators in order to review them?

Yes	
No	

If yes: Please explain.

2.6 Have records been reviewed and analysed? If yes: What does this analysis indicate (e.g. with regard to improvement of tightness of the equipment)?

Please distinguish between the different sectors or subsectors affected:

Sector	Comment
Refrigeration equipment	
Air conditioning equipment	
Heat pumps	
Fire protection systems	

2.7 Do national assessments/report or other studies/investigations about the impacts of the measures of Art 3 exist in your Member State?

Yes	
No	

If yes: Please indicate these studies and their main results.

2.8 Do you have any other information on <u>the effects</u> of

- regular leakage checks acc. Art 3(2),
- the installation of leakage detection systems acc Art 3(3) and
- the maintenance of records by the operators acc Art 3(6)?

Yes	
No	

If yes: Please describe.

2.9 Please name experts of your Member State who could provide information on the effectiveness of the containment provisions of Art 3.

2.10 Any other comments?

3. Recovery provisions (Art 4)

3.1 Please describe the practical arrangements in place in your Member State for proper recovery of F-gases according to Art 4(1) and 4(3).

If possible, please distinguish between the different sectors or subsectors affected:

Sector	Comment
Stationary refrigeration equipment	
Stationary air conditioning equipment	
Heat pumps	
Fire protection systems and fire extinguishers	
High voltage switchgear	
Equipment containing F-gas-based solvents	
Air conditioning in motor vehicles	
Other (please specify):	

3.2 Does a database or an assessment of recovered F-gases for the purpose of recycling, reclamation or destruction exist in your Member State?

Yes	
No	

3.3 If yes: How have the quantities of recovered F-gases evolved since the application of the F-Gas Regulation?

3.4 If no: Is it planned to set up a database or to conduct an assessment? If yes: When?

3.5 Has your Member State implemented control mechanisms in order to monitor compliance with the provisions acc Art 4?

Yes	
No	

If yes: Please describe the measures taken and the results of these efforts.

3.6 Is the personnel undertaking recovery of F-gases from other products and equipment acc Art 4(3) appropriately qualified?

Yes	
No	

3.7 How does your Member State ensure that F-gases contained in products and equipment is recovered before the final disposal of that equipment? Please describe.

3.8 Are there any difficulties which complicate proper recovery in your Member State?

3.9 Do other studies/ investigations about the impacts of the measures of Art 4 exist in your Member State?

Yes	
No	

If yes: Please indicate these studies and their main results.

3.10 Please name experts of your Member State who could provide information on the effectiveness of the recovery provisions of Art 4.

3.11 Any other comments?

4. Training and Certification requirements (Art 5(2) and implementing Regulations)

4.1 Please comment on problems encountered in your Member State during the establishment of training/certification programmes for each sector.

Sector	Comment
Stationary refrigeration, air conditioning and heat pumps	
Stationary fire protection systems and fire extinguishers	
High-voltage switchgear	
Equipment containing fluorinated greenhouse gas-based solvents	
Air conditioning in motor vehicles	

4.2 Please list the main training centres in your Member State for each sector with programmes covering the requirements of Art 5(2) (names, addresses of these training centres, if possible).

Sector	Comment
Stationary refrigeration, air conditioning and heat pumps	
Stationary fire protection systems and fire extinguishers	
High-voltage switchgear	
Equipment containing fluorinated greenhouse gas-based solvents	
Air conditioning in motor vehicles	

4.3 Please provide a quantified best estimate of the percentage of a) personnel and b) companies already certified (including holders of interim certificates where relevant) compared to persons/ companies which have to be certified in the respective sectors (reference date: 1.1.2010)?

Sector	Percentage certified (%)		Comment
	persons	companies	
Stationary refrigeration, air conditioning and heat pumps			
Stationary fire protection systems and fire extinguishers			
High-voltage switchgear		N/A	
Equipment containing fluorinated greenhouse gas-based solvents		N/A	
Air conditioning in motor vehicles (% persons attested)		N/A	

4.4 Please estimate the share of interim certification holders among certified personnel and companies (reference date: 1.1.2010).

Sector	Share of interim certification holders (%)
Stationary refrigeration, air conditioning and heat pumps	
Stationary fire protection systems and fire extinguishers	

4.5 To which extent do personnel and companies operating in your Member State use training centres and/or certification/attestation bodies abroad and in which Member States? Please comment per sector.

Sector	Comment
Stationary refrigeration, air conditioning and heat pumps	
Stationary fire protection systems and fire extinguishers	
High-voltage switchgear	
Equipment containing fluorinated greenhouse gas-based solvents	
Air conditioning in motor vehicles	

4.6 Are you aware of any problems in your Member State concerning the recognition of certificates or training attestations (air conditioning in motor vehicles) issued in other Member States and/or vice versa?

Yes	
No	

If yes: Please clarify per sector.

Sector	Comment
Stationary refrigeration, air conditioning and heat pumps	
Stationary fire protection systems and fire extinguishers	
High-voltage switchgear	
Equipment containing fluorinated greenhouse gas-based solvents	
Air conditioning in motor vehicles	

4.7 Has your Member State implemented control mechanisms in order to monitor compliance with the provisions acc Art 5(3) and 5(4)?

Yes	
No	

If yes: Please describe these control measures.

4.8 Has your Member State imposed penalties, acc. Art 13, to infringements of the provisions of the F-Gas Regulation related to training and/or certification/attestation?

Yes	
No	

If yes: Please indicate the types of infringement, the corresponding number of such occurrences and indicate the penalties imposed.

4.9 What are the main problems, encountered during the operation of the training and certification/attestation programmes in your Member State? Please comment per sector.

Sector	Comment
Stationary refrigeration, air conditioning and heat pumps	
Stationary fire protection systems and fire extinguishers	
High-voltage switchgear	
Equipment containing fluorinated greenhouse gas-based solvents	
Air conditioning in motor vehicles	

4.10 Please compare the current situation in your Member State to the situation prior to the F-Gas Regulation. In your view, to what extent have the training and certification programmes established under Article 5(2) improved or will improve the level of qualification of affected personnel and companies? Please explain per sector.

Sector	Comment
Stationary refrigeration, air conditioning and heat pumps	
Stationary fire protection systems	

and fire extinguishers	
High-voltage switchgear	
Equipment containing fluorinated greenhouse gas-based solvents	
Air conditioning in motor vehicles	

4.11 To what extent, in your view, do the training and certification programmes established under Article 5(2) have an impact or will have an impact on the leakage rates of affected equipment? Please explain per sector.

Sector	Comment
Stationary refrigeration, air conditioning and heat pumps	
Stationary fire protection systems and fire extinguishers	
High-voltage switchgear	
Equipment containing fluorinated greenhouse gas-based solvents	
Air conditioning in motor vehicles	

4.12 Any other comments?

5. Reporting provisions (Art 6)

5.1 Please estimate the share of companies reporting (%) compared to the number of companies which should report (companies above the 1 tonne threshold).
(reference : Reports in 2009 for calendar year 2008)

	producer	importer	exporter
%			
%			
%			

5.2 Has your Member State implemented control mechanisms in order to monitor compliance with the reporting obligations acc Art 6(1)?

Yes	
No	

If yes: Please describe these measures and their results.

5.3 Please consider your own experience on reporting. Are the producers and importers of F-gases able to relate the F-gas quantities reported to the main categories of use as required?

Yes	
No	

If no: What could be done to improve this situation?

5.4 Please make a best estimate of the quantities of F-gases produced, imported or exported by entities in your Member State in quantities below the minimum reporting threshold of 1 tonne (i.e. not covered by the reports) as a percentage (%) of the total quantities of F-gases produced, imported or exported in your Member State .

	produced	imported	exported
%			

5.5 Which other problems have you identified concerning the reporting requirements of Art 6(1)?

5.6 Has your Member State undertaken an analysis of the reports from producers, importers and exporters?

Yes	
No	

If yes: Please refer us to the analysis report or indicate the main results.

5.7 Has your Member State established reporting systems acc Art 6(4) for the relevant sectors referred to in (EC) No 842/2006 in order to acquire emission data to the extent possible?

Yes	
No	

If yes: Please describe these reporting systems, their connection to records maintained by operators under Article 3(6) if any, and their relation to the F-Gas emission inventories reported under Decision No 280/2004/EC concerning a mechanism for monitoring Community greenhouse gas emissions and for implementing the Kyoto Protocol (Monitoring Mechanism - UNFCCC inventories).

5.8 In your view, could these reporting systems be used to report estimates of emissions periodically to the Commission based on representative samples (acc Art 10(2f))? Please comment.

5.9 In your view, how can the reporting requirements under the F-Gas Regulation and the requirements under the Monitoring Mechanism be streamlined?

5.10 Any other comments?

6. Costs of Regulation (EC) No 842/2006 in the Member States

6.1 Do estimates of <u>additional public administrative costs</u> exist in your Member State for e.g.

- establishment and operation of training or certification programmes for personnel and companies (Art. 5),
- handling the reports (Art. 6),
- monitoring and enforcement of the provisions of the Regulation and sanctioning of their infringements (Art. 13)?

Yes	
No	

6.2 If yes: Please provide such estimates.

6.3 If yes: Please explain the underlying methodology of these calculations and the aspects covered.

6.4 Do estimates exist on <u>additional costs for economic actors</u> resulting from e.g.

- leakage control and documentation (Art. 3),
- arrangements for recovery (Art. 4),
- personnel training and certification (Art. 5),
- reporting (Art. 6) and
- labelling (Art. 7)?

Yes	
No	

6.5 If yes: Please provide such estimates.

6.6 If yes: Please explain the underlying methodology of these calculations and the aspects covered.

6.7 Do other additional costs related to (EC) No 842/2006 occur in your Member State? Please explain.

6.8 Any other comments?

7. Potential needs for clarification (definitions, procedures) and simplification of Regulation (EC) No 842/2006

7.1 Please indicate inconsistencies and the need for simplification and clarification of terminology, definitions, procedures etc of Regulation (EC) No 842/2006 and briefly describe the problem.

Article	Comment
Art 1: Scope	
Art 2: Definitions	
Art 3: Containment	
Art 4: Recovery	
Art 5: Training and certification	
Art 6: Reporting	
Art 7: Labelling	
Art 8. Control of use	
Art 9: Placing on the market	
Other Articles	

8. Possible options for reviewing of Regulation (EC) No 842/2006 and other options

8.1 In your opinion, would any of the following options to strengthen the F-Gas Regulation be useful? Why? Have you undertaken any analysis on this issue in your Member State which could be used in the review of the F-Gas regulation? If so, please provide a reference or a contact.

a) Controls on the production and/or consumption (placing on the market) of HFCs and/or other F-gases in the EU.

Yes	
No	

Why? - Please indicate available sources of information/data on this issue in your Member State.

b) Prohibition of use of SF_6 in magnesium die casting <850 kg/a (Art 8).

Yes	
No	

Why? - Please indicate available sources of information/data on this issue in your Member State.

c) Prohibition of other F-gas uses or prohibition of the placing on the market of further products or equipment containing or relying on F-Gases.

Yes	
No	

Which products or equipment? Why? - Please indicate available sources of information/data on this issue in your Member State.

d) Application of Art 3 and/or 4(1) to refrigeration and air conditioning systems in modes of transport (e.g. refrigerated road vehicles and to RAC in ships and rail vehicles).

Yes	
No	

Why? - Please indicate available sources of information/data on this issue in your Member State.

e) Establishment of maximum leakage rates for certain installations e.g. refrigeration and stationary air conditioning equipment.

Yes	
No	

Which installations? Why? – Please indicate available sources of information/data on this issue in your Member State.

f) Additional measures to strengthen recovery for recycling, reclamation or destruction.

Yes	
No	

Why? What types of measures? – Please indicate available sources of information/data on this issue in your Member State.

g) Best Available Technique Reference (BREF) documents instead of regulative measures in selected applications.

Yes	
No	

Why? - Please indicate available sources of information/data on this issue in your Member State.

h) Inclusion of additional F-gases in the Regulation ($C_{10}F_{18}$, NF_3, etc.).

Yes	
No	

Which gases? Why? - Please indicate available sources of information/data on this issue in your Member State.

8.2 Which other options to review Regulation (EC) No 842/2006 should be considered? Why?

8.3 In your view, what are the future challenges related to F-gases, and how should they be addressed?

8.4 How would you see a potential future agreement on F-gases, for example under the Montreal Protocol, implemented through Regulation (EC) No 842/2006?

8.5 Are there any issues related to F-gases that should be addressed outside Regulation (EC) No 842/2006? Please give examples, including non-regulatory options.

9. Your overall assessment of Regulation (EC) No 842/2006

9.1 Please give your opinion on effectiveness (i.e. the extent to which objectives set are achieved) and efficiency (i.e. the extent to which the desired effects are achieved at a reasonable cost) of Regulation (EC) No 842/2006 in your Member State. On a scale of 1 to 4, how effective/ efficient was the regulation in reducing F-gas emissions from each sector/ product group affected?

1: not effective/ efficient at all ... 4: very effective/ efficient

Sector/ product group		Scale 1 - 4		Comments
		Effective	Efficient	
9.1.1	Refrigeration, air conditioning and heat pumps			
9.1.2	Fire protection and fire extinguishers			
9.1.3	High voltage switchgear			
9.1.4	Equipment containing F-gas based solvents			
9.1.5	Mobile air conditioning			
9.1.6	Magnesium die casting			
9.1.7	SF6 containing tyres			
9.1.8	Non-refillable containers			
9.1.10	Self-chilling cans			
9.1.11	Other			

9.2 How effective has Regulation (EC) No 842/2006 been in your Member State in terms of the following criteria:

1: not effective/ efficient at all ... 4: very effective/ efficient

Criteria		Please tick for each category			
		1	2	3	4
9.2.1	Improving the technical competence of professionals handling F-gases in the most relevant sectors				
9.2.2	Improving the containment of F-gases during the lifetime of applications				
9.2.3	Promoting the recovery of F-gases from products/ equipment for recycling, reclamation, destruction of F-gases when needed during the lifetime of the applications and at the end of their life				
9.2.4	Monitoring the use of F-gases in the EU				
9.2.5	Monitoring emissions of F-gases in the EU				
9.2.6	Preventing the use of F-gases in applications where viable alternatives are available and/or improvement of containment/recovery is not feasible				
9.2.7	Harmonising requirements on the use of F-gases and the marketing and labelling of products and equipment containing F-gases across the EU in order to facilitate				

	the functioning of the internal market				
9.2.8	Promoting technological innovation towards technologies which are more environmentally friendly				
9.2.9	Reducing overall emissions of F-gases in the EU (overall effectiveness)				
9.2.10	Reducing overall emissions of F-gases in the EU at a reasonable cost (overall efficiency)				
9.2.11	Clarity and comprehensibility				
9.2.12	Completeness				

I.2 Questionnaire to Refrigeration and Air Conditioning Industry

Questionnaire Öko-Recherche GmbH – F Gas Review

<u>Preface</u>

In December 2009, the European Commission launched a project to support the review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases. This project is undertaken by Öko-Recherche GmbH (Frankfurt/Main, Germany) in association with several other companies and institutes (cf. Authorisation Letter Attached).

This questionnaire to companies of the RAC sector will be a key component of the information gathering. Thus, your responses will be an important element of the study and will contribute to the broader review of Regulation (EC) No 842/2006.

Overall, the main objectives of this questionnaire are to:

- Assess the implementation, effectiveness and efficiency of the provisions of the Regulation;
- Evaluate interactions between the existing EU policy framework on fluorinated greenhouse gases and other EC and national legislation (including in particular national legislation stricter than those laid down in the Regulation, legislation on waste etc.);
- Assess and evaluate the scope for clarification and simplification of the Regulation and possible options for modification of the existing policy framework on fluorinated greenhouse gases.

Öko-Recherche GmbH and EPEE agreed that this questionnaire is sent out to the EPEE Members and collected by the EPEE secretariat.

Responses: Please return the completed questionnaire and any related materials by <u>14 April 2010</u>

To: EPEE Secretariat
14A Rue du Luxembourg
1000 Bruxelles
Email: TBC

Contact details Öko-Recherche:

Öko-Recherche GmbH
Dr. André Leisewitz / Barbara Gschrey
D-60329 Frankfurt/Main, Germany, Münchener Str. 23
Phone +49 69 252305; Fax + 49 69 252306
E-mail: a.leisewitz@oekorecherche.de; barbara.gschrey@oekorecherche.de

Questionnaire Öko-Recherche – F Gas Review – to EPEE Members

Please fill in your company details:

Name of company ....

Address ....

Name of contact person ....

Contact details (tel/email) ....
....
....

Company field of activity:
Air-Conditioning.. ☐
Heat Pumps .... ☐
Domestic Refrigeration.. ☐
Commercial Refrigeration.. ☐
Industrial Refrigeration .... ☐

Company type:
Installer company .... ☐
Service company.. ☐
Operator.. ☐
Equipment manufacturer .... ☐
Refrigerant producer .... ☐
Training/Education center
Evaluation body
Certification body... ☐
Waste treatment of products containing refrigerant .... ☐
Reclaim facility of refrigerants.. ☐
Destruction facility of refrigerants .... ☐
Others (please specify).. ☐

Countries to which questionnaire replies apply ....
....
....

1. Questions relating to Article 3 of the F-Gas Regulation: Containment

1.1 Leak checks:

1.1.1 Do you carry out regular leak checks?......................☐ yes...............☐ no
Since when?...
How often?...
If not, why not?...

1.1.2 In which application segments?...
Supermarkets...☐
Light commercial applications..☐
Large commercial applications ....☐
Industrial applications..☐

1.1.3 In what type of equipment - Sector?
Air conditioning equipment ....☐
Refrigeration equipment ....☐
Heat pump equipment ....☐

1.1.4 In what type of equipment – Charge size?
Refrigerant charge $\geq$ 3kg ....☐
Refrigerant charge $\geq$ 30kg ....☐
Refrigerant charge $\geq$ 300kg ....☐

1.1.5 Please indicate the evolution of the number of leak checks over the past ten years due to different pieces of legislation (Regulation on Ozone Depleting Substances, F-Gas Regulation, Energy performance of buildings directive (and related standard EN 15240) about inspection of air conditioners, etc.). Please specify how you justify your statements.
Number of leak check remained stable..............................☐
Number of leak checks increased ....☐ slightly
....☐ Substantially
Please quantify (percentage, or any other indicator)..........☐ %

1.1.6 Are there any tangible results of the leak checks? Please specify how you justify your statements. ....☐ yes...............☐ no
Less refrigerant quantities required to top up equipment ...☐ yes...............☐ no
Less machine failures / technical problems ....☐ yes...............☐ no
Less power consumption...☐ yes...............☐ no
Less service interventions ....☐ yes...............☐ no
Any other, please specify ....☐ yes...............☐ no

1.1.7 Any other comments?
....
....

1.2 Awareness at operator level:

1.2.1 Are the operators aware of their obligations?
Please rate (1 = LOW awareness, 5 = HIGH awareness)....... ☐

1.2.2 Are operators aware that they have to keep a logbook for installations with a refrigerant circuit charge ≥ 3kg? .... ☐ yes ....☐ no

1.2.3 Are operators aware that their installations ≥ 3 kg have to be regularly checked for leakage?... ☐ yes ....☐ no

1.2.4 If so, do they know the control frequency....................... ☐ yes ....☐ no

1.2.5 Are operators of systems containing > 300kg refrigerant per circuit aware that leakage detection systems are mandatory.. ☐ yes ....☐ no

1.2.6 If so, do they know that such systems have to be checked at least once every 12 months on their proper functioning? .... ☐ yes ....☐ no

1.2.7 Are there differences between segments/applications? . ☐ yes ....☐ no
If so, please rate the following applications
(1= LOW awareness, 5 = HIGH awareness)

Supermarkets:
Large retailers (chains)...☐
Small retailers (franchised stores) ....☐
Groceries, convenience stores (pls specify) ....☐

Light commercial applications
Bakeries, butchers, etc..☐
Restaurants, snacks, catering ....☐
Flower shops, others (pls specify) ....☐

Large commercial applications
Canteens, etc. ....☐
Hospitals ....☐
Banks, insurances, hotels, office buildings ....☐
Shopping malls..☐
Leisure (sports, cinema…) ....☐
Others (pls specify) ....☐

Industrial applications
Food processing..☐
Chemical and pharmaceutical industry ....☐
Cold stores and logistics..☐
Others (pls specify) ....☐

1.2.8 Any other comments?
....
....

1.3 Awareness of personnel carrying out activities related to a refrigerant circuit :

Before answering this section, please specify your certification category first (I, II, III or IV):
....☐

1.3.1 Is the personnel aware of their obligations?
Please rate (1 = LOW awareness, 5 = HIGH awareness)..☐

1.3.2 Is the personnel aware that the operator has the obligation of Logbook keeping for installations with a refrigerant circuit charge ≥ 3kg?
....☐ yes..............☐ no

1.3.3 Is the personnel aware that installations ≥ 3 kg have to be regularly checked for leakage?...☐ yes..............☐ no

1.3.4 Is the personnel aware that for systems containing > 300kg refrigerant per circuit leakage detection systems are mandatory.........................☐ yes..............☐ no

1.3.5 If so, do they know that such systems have to be checked at least once every 12 months on their proper functioning? ....☐ yes..............☐ no

1.3.6 Are there differences between company types? ....☐ yes..............☐ no
If so, please rate the following types
(1= LOW awareness, 5 = HIGH awareness)
Companies with up to 5 employees:..................................☐
Companies with up to 50 employees:................................☐
Companies with up to 100 employees:..............................☐
Companies with more than 100 employees:......................☐

1.3.7 Any other comments?
....
....

1.4 Leakage detection systems:

Definition: "leakage detection system" means a calibrated mechanical, electrical or electronic device for detecting leakage of fluorinated greenhouse gases which, on detection, alerts the operator”

1.4.1 Have you already installed leak detection systems? .☐ yes..............☐ no

1.4.2 How often? ....

1.4.3 Have you ever installed leak detection systems before the F-Gas Regulation has come into force? ....☐ yes..............☐ no

1.4.4 Do you install more often leak detection systems since the F-Gas Regulation has come into force? ....☐ yes..............☐ no

1.4.5 What type of systems has been installed? Pls specify ....
....

1.4.6 Do you have any technical specifications which you can provide to Öko-Recherche?
....☐ yes..............☐ no

1.4.7 How exact are the leak detection systems that you are using/installing? Pls specify:
....

1.4.8 Are there any standards that apply regarding the leakage detection systems
....
....

1.4.9 Are leakage detection systems already widespread in the sector?
Please rate 1=not at all, 5=very widespread......................☐

1.4.10 Any other comments?
....
....

1.5 <u>Recording by the operators:</u>

1.5.1 Do the operators who are customers of your company and who own systems above 3 kg charge have logbooks for their installations? Please indicate percentage (all=100% etc.)
....

1.5.2 Are there differences between segments/applications? ..... ☐ yes .....☐ no
If so, please rate the following applications
(1= FEW operators have logbooks, 5 = ALL operators have logbooks)

Supermarkets:
Large retailers (chains)..☐
Small retailers (franchised stores) ....☐
Groceries, convenience stores (pls specify) ....☐

Light commercial applications
Bakeries, butchers, etc. ....☐
Restaurants, snacks, catering ....☐
Flower shops, others (pls specify) ....☐

Large commercial applications
Canteens, etc. ....☐
Hospitals ....☐
Banks, insurances, hotels, office buildings ....☐
Shopping malls..☐
Leisure (sports, cinema…) ....☐
Others (pls specify) ....☐

Industrial applications
Food processing...☐
Chemical and pharmaceutical industry ....☐
Cold stores and logistics...☐
Others (pls specify) ....☐

1.5.3 How precisely are the logbooks filled in (according to article 3.6 of the F-Gas Regulation) ? Please rate: 1 = Not precise (< 20%), 5 = Very precise (80-100%)

Dates and results of leakage inspections and servicing.....☐
Refrigerant type and quantity by refrigerant circuit.............☐
Quantities recovered/added during service, repair, disposal☐
Identification of company, technician, certifications ....☐

1.5.4 Is there a difference in recording before and after the entry into force of the F-Gas Regulation?..☐ yes..............☐ no

1.5.5 If so, what difference?
Before, no logbooks existed ....☐
Before, logbooks existed but were not filled in accurately..☐
Before, logbooks existed but were not filled in regularly ....☐

1.5.6 Any other comments?
....
....

1.6 <u>Quantitative data on the results of the implementation of the F-Gas Regulation</u>

1.6.1 Please provide Öko-Recherche with quantitative data indicating the evolution of leakage rates due to the entry into force of the F-Gas Regulation. (For example: summary of logbook data, quantities of refrigerants filled in, number of service interventions, etc.)

In case you cannot reply now, by when and under which conditions can you supply such data? Please specify (date, confidentiality agreement…)
....

1.6.2 Are you aware of any countries in the EU having established centralized databases or having access to any other official data relating to containment? Please specify (country and database/report, etc.)

.... ☐ yes .... ☐ no

1.6.3 Any other comments?

....

....

1.7 <u>Qualitative feedback on the implementation of the F-Gas Regulation</u>

1.7.1 Please provide Öko-Recherche with qualitative feedback indicating the evolution of leakage rates since the entry into force of the F-Gas Regulation.

In case you cannot reply now, by when and under which conditions can you supply such data? Please specify (date, confidentiality agreement…)

....

1.7.2 Any other comments?

....

....

1.8 <u>Technological assessment of the sector</u>

1.8.1 Have companies reacted to the increased requirements in terms of containment/emission reduction by adapting their technology / installing practices accordingly (e.g. smaller refrigerant charges, , tighter equipment)?

....☐ yes..............☐ no

1.8.2 If so, please indicate such changes, specifying the focus (e.g.: micro channel technology for smaller refrigerant charges, etc.)

....

....

1.8.3 Do EN standards to improve tightness such as EN378 for systems and prEN 16084 ("prEN 15834) for components and joints impact your technical developments? Please specify:..

....

1.8.4 Any other comments?

....

....

1.9 <u>Is this article of the F-Gas Regulation clear or does it need to be improved? If so, what needs to be improved and how?</u>

....

....

2. Questions relating to Article 4 of the F-Gas Regulation: Recovery, reclaim, recycling, destruction

2.1 General

2.1.1 Please indicate all companies in the EU (that you are aware of) reclaiming, recycling, destroying f-gases used in your industry sector.
Reclaiming F-gases..
Recycling F-gases...
Destroying F-gases ....

2.1.2 Do you know about any official, centralized (regional, national…) databases for quantities of recovered/reclaimed/recycled/destroyed f-gases? Please specify indicating contact details and country.
....☐ yes...............☐ no
....

2.1.3 Do you know of any other databases (e.g. national distributors, associations, service companies, etc.) or public reports or any other sources to find out quantities of recovered/reclaimed/recycled/destroyed f-gases? Please specify indicating contact details and country.
....☐ yes...............☐ no
....

2.1.4 If your answer to the previous question was yes, since when these databases have been put into place? Please specify
....

2.1.5 Who is entitled to recover/reclaim/recycle f-gases in your industry? Please specify the country for each reply if necessary.
Refrigerant Distributors............................... Recovery ☐..... Reclaim ☐......Recycling ☐
Wholesalers (components and refrigerants) Recovery ☐..... Reclaim ☐......Recycling ☐
Service companies .... Recovery ☐..... Reclaim ☐......Recycling ☐
Specialized companies................................ Recovery ☐..... Reclaim ☐......Recycling ☐
Others, please specify .... Recovery ☐..... Reclaim ☐......Recycling ☐

2.1.6 Do these companies have to fulfill any specific obligations (e.g. certified)? Which?.
Recovery: ....
Reclaim: ....
Recycling:...

2.1.7 How is the recovery/reclaim/recycling organized (certified companies, labeled refrigerant cylinders, analysis/control of recycled/reclaimed/recovered quantities). Please describe briefly, indicating the country/ies to which you refer:
Recovery ....
Reclaim ....
Recycling..

2.1.8 Any other comments?
....
....

2.2 Quantitative and qualitative indicators for the extent of the recovery and the percentage recycled, reclaimed, destroyed

2.2.1 Please provide Öko-Recherche with any quantitative feedback (for example summarized logbook data) indicating the evolution of quantities of recycled/reclaimed/recovered/destroyed f-gases since the entry into force of the F-Gas Regulation.

In case you cannot reply now, by when and under which conditions can you supply such data? Please specify (date, confidentiality agreement…)
....

2.2.2 Any other comments?
....
....

2.2.3 Please provide Öko-Recherche with any qualitative feedback (e.g. individual experiences with end-users) indicating the evolution of quantities of recycled/reclaimed/recovered/destroyed f-gases due to the entry into force of the F-Gas Regulation.

In case you cannot reply now, by when and under which conditions can you supply such data? Please specify (date, confidentiality agreement…)
....

2.2.4 Any other comments?
....
....

2.3 Is this article of the F-Gas Regulation clear or does it need to be improved? If so, what needs to be improved and how?

....
....

3. Questions relating to article 5 of the F-Gas Regulation: training and certification

3.1 Certified companies / personnel: quantitative information

3.1.1 If possible, please give a rough estimation of the number of RAC contractors (specialized companies carrying out activities related to a refrigerant circuit). Please clarify if this is the estimated number within a country or within a sector or within the customer database of the company answering this questionnaire, etc.

....

....

3.1.2 If possible, please indicate the number of certified RAC contractors (specialized companies carrying out activities related to a refrigerant circuit). Please clarify if this is the estimated number within a country or within a sector or within the customer database of the company answering this questionnaire, etc.

....

....

3.1.3 Is there any centralized directory/database indicating certified companies according to the F-Gas Regulation? Please indicate the countries you are referring to:

....☐ yes..............☐ no

....☐ yes..............☐ no

3.1.4 If so, please specify: who is updating it (e.g. association), where/how can it be accessed (e.g. Internet), since when does it exist:

....

....

3.1.5 What are the criteria (e.g. theoretical/practical exams, field experience, etc.) to obtain the certification (contracting companies and qualified personnel). Please indicate the sources where this information is readily available (e.g. association, school, etc.):

....

....

3.1.6 Are you aware of any problems regarding certification and training programs? If so, please specify:

....

3.1.7 Has the number of training centres increased since the F-Gas Regulation? Please specify (numbers before and after, names) if possible

....☐ yes..............☐ no

3.1.8 Has the number of training courses / diploma /certificates increased since the F-Gas Regulation? Please specify (numbers before and after, names) if possible

....☐ yes..............☐ no

3.1.9 Are there training centres in each member state? Please specify, if not
.... ☐ yes .... ☐ no
....

3.1.10 What happens if a member state has no training facility? (e.g. send people to another member state, will diploma be recognized, etc.). Please explain, if possible

....
....

3.1.11 Are there any standards that apply regarding the certification of companies and/or personnel? If so, which? (EN, national, prEN …)

....
....

3.1.12 Please provide Öko-Recherche with information about the evolution related to certified personnel within your company since the F-Gas Regulation has come into force

In case you cannot reply now, by when and under which conditions can you supply such data? Please specify (date, confidentiality agreement…)

....

3.1.13 Questions relating to company specific information:

Has the number of certified personnel increased? .... ☐ yes .... ☐ no
Please specify (absolute number, percentage) ....

Have you changed your company policy regarding certifications? Please specify
.... ☐ yes .... ☐ no

Are you taking any specific measures to further educate your personnel? Please specify
.... ☐ yes .... ☐ no

Are you taking any actions to make the operators aware of the need of certification/? Please specify .... ☐ yes .... ☐ no
....

Are you using certification / personnel as competitive edge vs your competitors?
.... ☐ yes .... ☐ no

Any other comments?
....

3.2 <u>Awareness at operator level</u>

3.2.1 Are the operators aware of the obligation that leak checking has to be done by a certified person ?... ☐ yes .....☐ no

3.2.2 Are there differences between segments/applications? ..... ☐ yes .....☐ no
If so, please rate the following applications
(1= LOW awareness, 5 = HIGH awareness)

Supermarkets:
Large retailers (chains)...☐
Small retailers (franchised stores) ....☐
Groceries, convenience stores (pls specify) ....☐

Light commercial applications
Bakeries, butchers, etc. ....☐
Restaurants, snacks, catering ....☐
Flower shops, others (pls specify) ....☐

Large commercial applications
Canteens, etc. ....☐
Hospitals ....☐
Banks, insurances, hotels, office buildings ....☐
Shopping malls..☐
Leisure (sports, cinema…) ....☐
Others (pls specify) ....☐

Industrial applications
Food processing...☐
Chemical and pharmaceutical industry ....☐
Cold stores and logistics..☐
Others (pls specify) ....☐

3.2.3 Any other comments?
....
....

3.3 <u>Awareness of personnel and companies carrying out activities related to a refrigerant circuit:</u>

3.3.1 Is the personnel aware of their obligation to be certified according to Regulation 303/2008? ....☐ yes ....☐ no

3.3.2 Are the companies aware of their obligation to be certified according to Regulation 303/2008? ....☐ yes ....☐ no

3.3.3 Are there differences between company types? ....☐ yes..............☐ no

3.3.4 If so, please rate the following types
(1= LOW awareness, 5 = HIGH awareness)
Companies with up to 5 employees:.................................☐
Companies with up to 50 employees:...............................☐
Companies with up to 100 employees:.............................☐
Companies with more than 100 employees:......................☐

3.3.5 Any other comments?
....
....

3.4 <u>Harmonization – Member States- Qualitative information</u>

3.4.1 Are you aware of any countries having problems with the certification? If so, please specify...☐ yes..............☐ no
....

3.4.2 What are these problems and what are the reasons for these problems. Please explain.
....
....

3.4.3 Please provide Öko-Recherche with information about experiences of your company as to recognition of certifications in different MS?

In case you cannot reply now, by when and under which conditions can you supply such data? Please specify (date, confidentiality agreement…)
....

3.4.5 Questions relating to company specific information:

How do you train your personnel?
In each MS...☐
Centralized...☐
If so, are certifications recognized in each MS?................☐ yes..............☐ no

When you employ new workers, do you recognize certification from each MS in the same way or do you make differences and if so, which? Why? Please specify
....

Have you ever come across any problems of cross border recognition of certification with your company? Please specify
....

From your experience, are all certifications in MS obtained according to F-Gas Regulation equivalent? Please specify (e.g. knowledge of the workers, requirements to obtain diploma and practical knowledge, etc.)

....

Do you perceive the certification requirements as barrier or as opportunity for the development of your companies' business? Why?.

....

3.4.6 Any other comments?

....
....

3.5 Is this article of the F-Gas Regulation clear or does it need to be improved? If so, what needs to be improved and how?

....
....
....

4. Questions relating to article 6 of the F-Gas Regulation: reporting

4.1 Reporting systems / databases

4.1.1 Are you aware of EU MS that do not yet have a reporting system in place according to article 6(4) of the F-Gas Regulation?" Please specify

....☐ yes..............☐ no

....

4.1.2 Do all companies report and, if not, what is the share (% or number) of companies who are not reporting (please indicate the country you are referring to)

....☐ yes..............☐ no

....

4.1.3 Are the importers able to relate the f-gas quantities to the main categories of use? Please specify (if not, why)

....☐ yes..............☐ no

....

4.1.4 Is the one ton limit reasonable? Please specify (if not, why)

....☐ yes..............☐ no

....

4.1.5 Are all importers / traders / producers aware of their obligations

....☐ yes..............☐ no

4.1.6 Embedded quantities in newly installed installations: What is the estimated share of theses quantities imported into / exported from the EU per year (%, absolute values, any other indicator). Please specify the type of equipment

....

4.1.7 Are the reported data reliable? Please specify (if not, why: not all companies reporting, lack of awareness, lack of resources, etc.)

....☐ yes..............☐ no

4.1.8 Are reported data assessed according to their reliability? If so, who does so, how often? Please indicate the source (report, etc.)

....☐ yes..............☐ no

....

4.1.9 If yes, what is the result of this assessment? Please specify

....

4.1.10 Are reported data compared to existing reports, studies, other data? If there are discrepancies, how are they handled?

....☐ yes..............☐ no

....

4.1.11 Any other comments?
....
....

4.2 Qualitative information

4.2.1 Please provide Öko-Recherche with information about how reporting requirements are fulfilled

In case you cannot reply now, by when and under which conditions can you supply such data? Please specify (date, confidentiality agreement…)
....

4.2.2 Questions relating to company specific information:

How often are you reporting? ....
To whom are you reporting?..
Are your data assessed according to their quality?..
If so, by whom? ....

4.2.3 Any other comments?
....
....

4.3 Is this article of the F-Gas Regulation clear or does it need to be improved? If so, what needs to be improved and how?

....
....
....

5. Article 3 to 7 of the F-Gas Regulation. Cost of implementation

5.1 Are you aware of any national investigation schemes about the cost of implementation of the F-Gas Regulation in the RAC industry? If so, please specify ....☐ yes☐ no

....

5.2 Can you provide Öko-Recherche with information about the cost of implementation of the F-Gas Regulation? ....☐ yes..............☐ no

By when and under which conditions? Please specify (date, confidentiality agreement…)

....

....

5.3 Questions relating to company specific information:

5.3.1 Leakage control

What is the cost of leakage control activities for your company?

Please indicate how you calculate the costs and how you weigh them (absolute values, percentages vs. your turnover by customer, manpower required, etc.)

....

....

Can you pass this cost on to your customers? Who carries the cost?

....

Does additional service / leakage control requirements represent a business opportunity for you or a barrier? Please specify

....

Did you have to invest in additional leak detection equipment?

....☐ yes..............☐ no

What is the profitability of such equipment?

High...☐

Medium ....☐

Low ....☐

5.3.2 Documentation

What is the cost of documentation activities (logbooks, etc.) for your company?

Please indicate how you calculate the costs and how you weigh them (absolute values, percentages vs. your turnover by customer, manpower required, etc.)

....

....

Can you pass this cost on to your customers? Who carries the cost?

....

Do documentation requirements represent a business opportunity for you or a barrier? Please specify

....

5.3.3 Certification

What is the cost of certification for your company?

Please indicate how you calculate the costs and how you weigh them (absolute values, percentages vs. your turnover by customer, manpower required, etc.)

....

....

Can you pass this cost on to your customers? Who carries the cost?

....

Is there a difference between company types? Pls specify ☐ yes .... ☐ no

Companies with up to 5 employees: ....

Companies with up to 50 employees: ....

Companies with up to 100 employees: ....

Companies with more than 100 employees: ....

What is the cost of certification for the installers in your company?

Please indicate how you calculate the costs and how you weigh them (absolute values, percentages vs. your turnover by customer, manpower required, etc.)

....

....

Can you pass this cost on to your customers? Who carries the cost?

....

Do certification requirements represent a business opportunity for you or a barrier? Please specify: ....

5.3.4 Recovery

What is the cost of recovery activities for your company?

Please indicate how you calculate the costs and how you weigh them (absolute values, percentages vs. your turnover by customer, manpower required, etc.)

....

....

Can you pass this cost on to your customers? Who carries the cost?

....

Did you have to invest in additional recovery equipment?

.... ☐ yes .... ☐ no

5.3.5 Reporting

What is the cost of reporting requirements for your company?

Please indicate how you calculate the costs and how you weigh them (absolute values, percentages vs. your turnover by customer, manpower required, etc.)

....

....

Can you pass this cost on to your customers? Who carries the cost?

....

5.3.6 Labelling

What is the cost of labeling activities for your company?

Please indicate how you calculate the costs and how you weigh them (absolute values, percentages vs. your turnover by customer, manpower required, etc.)

....
....

Can you pass this cost on to your customers? Who carries the cost?

....

5.4 Any other comments?

....
....

5.5 Is this article of the F-Gas Regulation clear or does it need to be improved? If so, what needs to be improved and how?

....
....

6. Control

6.1 Are you aware of any national/regional control mechanisms in place to verify:
(Please always specify the country)

If containment requirements are fulfilled, e.g. inspection of logbooks, leakage rates, leak detection equipment, etc. ....☐ yes ... ☐ no ....
If there are control mechanisms for recovery obligations? ...☐ yes ... ☐ no ....
If qualification / certification requirements are respected? ..☐ yes ... ☐ no ....
If reporting requirements are respected? ....☐ yes ... ☐ no ....

6.2 If so, please specify, indicating the country for each reply:

Name of control body ....
Number of control bodies ....
Type of control...
Number of controls ....
Announced/unannounced...
Application segments (please specify, e.g. supermarkets, bakeries, etc.)...........
....

6.3 Penalties? ....

6.4Any other comments?
....
....

7. Improvements

The overall goal of the Regulation is to improve the tightness of equipment and to reduce F-gas emissions. Keeping this target in mind, can you please give your view on:

7.1 What is your overall assessment of the F-Gas Regulation in terms of:
Tightness of installations ....
Emissions and emission factors ....
Qualified personnel ....
Certified companies..
Recovery of f-gases ....
Monitoring the use of f-gases ....
Monitoring emissions of f-gases ....
Promoting alternatives to f-gases ....
Harmonising requirements on the use of f-gases across the EU ....
....

7.2 Are there any inconsistencies in the Regulation? Please specify
....
....

7.3 Is there a need for clarification of definitions, procedures, etc. (esp. art. 4 to 6)?
....
....

7.4 Is there a need/possibility for simplification_of procedures (to ensure a smoother implementation for private stakeholders) (especially Art 4 to 6)?
....
....

7.5 Is there a need for guidance/promotion of best practices to improve uniformity in implementation and interpretation of the Regulation?
....
....

7.6 Is there any other need for modification of the Regulation?
....
....

I.3 Questionnaire to Fire Protection Industry

Review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases

Questionnaire
To the European Industry of Fire Protection Systems

Öko-Recherche GmbH
D-60329 Frankfurt/Main, Germany, Münchener Str. 23
Phone +49 69 252305; Fax + 49 69 252306
E-Mail: a.leisewitz@oekorecherche.de; barbara.gschrey@oekorecherche.de

March 2010

Preface

In December 2009, the European Commission launched a project to support the review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases. This project is undertaken by Öko-Recherche GmbH (Frankfurt/Main, Germany) in association with several other companies and institutes (cf. Authorisation Letter Attached).

This questionnaire to associations of companies and companies installing/using/servicing Fire Protection Systems and Fire Extinguishers will be a key component of the information gathering. Thus, your responses will be an important element of the study and will contribute to the broader review of Regulation (EC) No 842/2006.

Overall, the main objectives of this questionnaire are to:

- Assess the implementation, effectiveness and efficiency of the provisions of the Regulation;
- Evaluate interactions between the existing EU policy framework on fluorinated greenhouse gases and other EC and national legislation (including in particular national legislation stricter than those laid down in the Regulation, legislation on waste etc.);
- Assess and evaluate the scope for clarification and simplification of the Regulation and possible options for modification of the existing policy framework on fluorinated greenhouse gases.

Questions on status and results of the implementation of (EC) No 842/2006 regarding Fire Protection Systems and Fire Extinguishers have also been sent to the competent authorities of the EU-27 Member States within the context of a broader questionnaire.

This questionnaire is addressed to he European Fire Protection industry and we kindly ask you to contribute your knowledge on the practical implementation and realisation of the F-Gas Regulation.

Responses:
Please return the completed questionnaire and any related materials by

10 May 2010

to Öko-Recherche GmbH.

Contact details Öko-Recherche:
Öko-Recherche GmbH
Dr. André Leisewitz / Barbara Gschrey
D-60329 Frankfurt/Main, Germany, Münchener Str. 23
Phone +49 69 252305; Fax + 49 69 252306
E-mail: a.leisewitz@oekorecherche.de; barbara.gschrey@oekorecherche.de

Your contact details:

Member State	
Institution	
Contact person	
Address	
Telephone	
Fax	
E-mail	

1. Questions on Voluntary Agreements and National Legislation regarding F-gases in Fire Protection Systems and Fire Extinguishers

1.1 Are there any voluntary agreements existing on F-gases for Fire Protection Systems and Fire Extinguishers in EC Member States (EU 27)?

Please indicate by Member State and explain with regard to objectives and results.

Member state/ country	
Title of the voluntary agreement	
a) National	
b) English Translation	
Voluntary agreement existing since	
Internet link / or published where	
Scope of the voluntary agreement	
Participants	
Main content and objectives	
List of achievements	
Additional information	
Attachments	

1.2 Is there any national legislation on F-gases for Fire Protection Systems and Fire Extinguishers in EC Member States (EU 27) which is stricter than (EC) No 842/2006?

Yes	
No	

If yes, please indicate the respective national legislation, the related provisions of the F-Gas Regulation and explain in which regard the national regulation is stricter.

Member State	
Title of the national legislation	
a) National	
b) English Translation	
Into force since	
Internet link / or published where	
Main content and objectives compared to the F-Gas Regulation	
Additional information	
Attachments	

2. Questions on Containment provisions according to (EC) No 842/2006, Art. 3

Questions to EUROFEU and related associations in Member States

2.1 To which degree/extent regular leakage checks of the F-gas containing fire protection systems according to the provisions of (EC) 842/2006, Art. 3, are undertaken today in your Member State?

Please provide a quantified best estimate by Member State e.g. expressed as percentage of installations (reference Date 1.1.2010) and comment.

Member State		Percentage of systems with regular leakage checks [%]			Comment
		Systems ≥ 3 kg	Systems ≥ 30 kg	Systems ≥ 300 kg	
Austria	AT				
Belgium	BE				
Bulgaria	BG				
Cyprus	CY				
Czech Republic	CZ				
Denmark	DK				
Estonia	EE				
Finland	FI				
France	FR				
Germany	DE				
Greece	EL				
Hungary	HU				
Ireland	IE				
Italy	IT				
Latvia	LV				
Lithuania	LT				
Luxemburg	LU				
Malta	MT				
Netherlands	NL				
Poland	PL				
Portugal	PT				
Romania	RO				
Slovakia	SK				
Slovenia	SL				
Spain	ES				
Sweden	SE				
United Kingdom	UK				

2.2 To which degree/extent leakage detection systems according to Art 3(3) are installed today in your Member State?

Please provide a quantified best estimate by Member State e.g. expressed as percentage of installations (reference Date 1.1.2010) and comment

Member State		Percentage of systems with leakage detection systems [%]	Comment
Austria	AT		
Belgium	BE		
Bulgaria	BG		
Cyprus	CY		
Czech Republic	CZ		
Denmark	DK		
Estonia	EE		
Finland	FI		
France	FR		
Germany	DE		
Greece	EL		
Hungary	HU		
Ireland	IE		
Italy	IT		
Latvia	LV		
Lithuania	LT		
Luxemburg	LU		
Malta	MT		
Netherlands	NL		
Poland	PL		
Portugal	PT		
Romania	RO		
Slovakia	SK		
Slovenia	SL		
Spain	ES		
Sweden	SE		
United Kingdom	UK		

Questions to fire protection companies

Leakage checks according to the provisions of (EC) 842/2006, Art. 3:

2.3 Do you carry out regular leakage checks according to the provisions of (EC) 842/2006, Art. 3, at the fire protection systems installed/served by your company?

.... ☐ yes………………… ☐ no

Since when? ....
How often?..
If not, why not?...

2.4 In what type of equipment – Charge size?

charge ≥ 3kg ....………………………….... ☐
charge ≥ 30kg ....………………………… ☐
charge ≥ 300kg ....……………………….. ☐

2.5 Please indicate the evolution of the number of leak checks over the past six years (from 2004 onwards). Please specify how you justify your statements.

Number of leak check remained stable .... ☐
Number of leak checks increased .... ☐ slightly
.... ☐ substantially
Please quantify (percentage, or any other indicator) .... ☐ %

2.6 Are there any tangible results of the leak checks? Please specify how you justify your statements.

.... ☐ yes ..... ☐ no

Less F-gas quantities required to top up equipment........ ☐ yes ..... ☐ no
Less system failures / technical problems .... ☐ yes ..... ☐ no
Less service interventions.................................... .... ☐ yes ..... ☐ no
Any other, please specify .... ☐ yes ..... ☐ no

2.7 Any other comments?

Awareness at operator level

2.8 Are the operators (companies/institutions using fire protection systems) aware of their obligations?

Please rate (1 = LOW awareness, 5 = HIGH awareness) . ………….……..☐

2.9 Are operators aware that they have to keep a logbook for installations with a F-gas charge ≥ 3kg? ....☐ yes..............☐ no

2.10 Are operators aware that their installations ≥3 kg have to be regularly checked for leakage? ....☐ yes..............☐ no

2.11 If so, do they know the control frequencies? ....☐ yes..............☐ no

2.12 Are operators of systems containing ≥300 kg F-gas aware that leakage detection systems are mandatory?...☐ yes..............☐ no
(in case of fire protection systems ≥300 kg installed before 4 July 2007, leakage detection systems shall be fitted by 4 July 2010)

2.13 If so, do they know that such systems have to be checked at least once every 12 months on their proper functioning? ....☐ yes..............☐ no

2.14 Are the operators of fire protection systems where there is an existing inspection regime in place to meet ISO 14520b standard aware that these inspections may fulfil the obligations of (EC) No 842/2006 (Art. 3 (5))? ....☐ yes..............☐ no

2.15 Any other comments?

<u>Leakage detection systems according to (EC) No 842/2006, Art. 3(3)</u>

(in case of fire protection systems ≥300 kg installed before 4 July 2007, leakage detection systems shall be fitted by 4 July 2010)

2.16 Did you already install leakage detection systems? ☐ yes ☐ no

If yes:

- how often? ………………………………
- Already before the F-Gas regulation has come into force? ☐ yes ☐ no
- Do you install more often leak detection systems since the F-Gas Regulation has come into force? ☐ yes ☐ no

2.17 What type of systems has been installed? Please specify

Type	Description	Comment
Technical specification?		
How exact are the systems?		
Other information?		

2.18 Are there any standards that apply regarding leakage detection systems? If yes, please specify

2.19 Are leakage detection systems already widespread in the sector?

Please rate 1 = not at all, 5 = 100% ☐

2.20 Any other comments?

Recording by operators

2.21 Do the operators of systems ≥3 kg who are customers of your company maintain records according to (EC) 842/2006, Art. 3(6), e.g. logbooks for their installations?

If yes, please indicate as percentage (all = 100% etc.) ☐

2.22 Is there a difference in recording before and after the entry into force of the F-Gas regulation? ☐ yes ☐ no

If yes, what is the difference? Please comment

Quantitative data on the results of the implementation of the F-Gas Regulation

2.23 Can you provide us with quantitative data indicating the evolution of F-gas emissions from Fire Protection Systems before and after the entry into force of the F-Gas Regulation (e.g. 2004 ff)? ☐ yes ☐ no

If yes, please specify by Member State

Member State	Data (year,	comment

2.24 Are you aware of any EU-27 Member States having established centralised databases or assessments on F-gas emissions from Fire Protection Systems before and after the entry into force of the F-Gas Regulation?

If yes, please indicate by Member State and comment on details

Member State	Database, assessment	comment

3. Questions on recovery provisions according to (EC) No 842/2006, Art. 4

3.1 Please describe in general the practical arrangements in place for proper recovery of HFC from Fire Protection Systems and Fire Extinguishers according to Art.4(1) of (EC) 842/2006 within the EU-27. Please indicate whether there are significant differences between Member States (and which MS).

3.2 Please provide us with a list of companies in the EU-27 Member States taking back HFC (by type) from Fire Protection Systems and Fire Extinguishers for recycling, reclamation, destruction. Please mark in the columns what the companies are doing.

Member State/ Name and contact data of companies	Re-cycling	Recla-mation	De-struc-tion	Comment (e.g. company operating since …; range of HFC (by type) annually reclaimed/destructed etc.)

3.3 Please give any representative example of some companies servicing/operating Fire Protection Systems and Fire Extinguishers with regard to quantities of HFC (by type) recycled, reclaimed, destructed within one year 2008 or 2009 (please indicate the year).

Member State/ Name and contact - data of companies, utilities, associations, …	Quantity of recovered HFC in 2008 or 2009 [kg]	Quantity of recycled HFC in 2008 or 2009 [kg]	Quantity of reclaimed HFC in 2008 or 2009 [kg]	Quantity of destructed HFC in 2008 or 2009 [kg]

3.4 Has there been recovery, recycling, reclamation, destruction (RRRD) of HFC from Fire Protection Systems and Fire Extinguishers prior to the implementation of (EC) No 842/2006? Please indicate by Member State:

RRRD of HFC prior to the implementation of (EC) No 842/2006				
Member State				
	Recovery	Recycling	Reclamation	Destruction
yes				
no				
Member State				
yes				
no				

3.5 Does a database or an assessment of recovered HFC (by type) from Fire Protection Systems and Fire Extinguishers for the purpose of recycling, reclamation or destruction exist? Please indicate by Member State:

Database/assessment on RRRD of HFC (EC) No 842/2006				
Member State				
	Recovery	Recycling	Reclamation	Destruction
yes				
no				
Member State				
yes				
no				

3.6 If the answer to question 3.5 was yes in all or some aspects, please provide information on the RRRD quantities before and after the implementation of the F-Gas Regulation. Please indicate by Member States and the respective years.

Information should cover the entire installed Fire Protection Systems and Fire Extinguishers with HFC in the Member State. If this is not possible, then please provide details of some major companies carrying out these activities, for example, reclamation and / or destruction.

RRRD of HFC (by type) before and after the implementation of (EC) No 842/2006								
Member State/ all or major companies (please indicate, with name and contact data)	Recovery		Recycling		Reclamation		Destruction	
	before [year/ to]	after [year/ to]	before [year/ to]	after [year/ to]	before [year/ to]	after [year/ to]	before [year/ to]	after [year/ to]

3.7 Please comment on the possible reasons for the trend indicated under question 3.6 with regard to RRRD and the relevance of the F-Gas Regulation.

(Reasons: Please consider also factors as age structure of the equipment etc.)

RRRD-sector	Reasons for the trend	Relevance of F-Gas Regulation
recovery		
recycling		
reclamation		
destruction		

3.8 If the answer on question 3.5 was no: Is it planned to set up a database or an assessment for controlling improvements of HFC recovery, recycling, reclaiming and / or destruction from Fire Protection Systems and Fire Extinguishers? Please specify by Member State in detail what is planned and when?

3.9 Are there any problems or barriers for RRRD of HFC from Fire Protection Systems and Fire Extinguishers resulting from national/international legal provisions with regard to cross-border transport, waste etc?

Yes	
No	

If yes, please describe, if necessary by Member State, and indicate the problems

Problems and barriers for RRRD of HFC from Fire Protection Systems and Fire Extinguishers		
Member State	description	comment
National barriers		
Cross border transport inside EU-27		
Import/export in/from EU-27		
other		
Member State		
National barriers		
Cross border transport inside EU-27		
Import/export in/from EU-27		
other		

3.10 Any other information and comments?

4. Questions on tightness of Fire Protection Systems and Fire Extinguishers

4.1 Can you provide us with any indicators on the tightness of Fire Protection Systems and Fire Extinguishers containing HFC (by type) in the EU-27 Member States during the past 5 years?

Indicators could be e.g. leakage rates. Please indicate by type of HFC and explain the relevance of the indicator.

Indicators on the tightness of Fire Protection Systems 2005-2009					
Year	2005	2006	2007	2008	2009
Type of HFC:					
Indicator (please specify)					
Type of HFC:					
Indicator (please specify)					
Comment on the relevance of indicators:					

4.2 Any additional information and comments?

5. Questions with regard to (EC) No 842/2006, Art. 4(1) [recovery by certified personnel] and 5 [training and certification] plus (EC) No 304/2008

5.1 Please indicate the current status of implementation of (EC) 842/2006 Art 5(2) on the establishment or adaptation of training and certification requirements in EU-27 based on the minimum requirements for the sector of Fire Protection Systems and Fire Extinguishers according to (EC) No 304/2008.

Member State		Art. 5(2) legally implemented (as of 30.3.2010)		If no: implementation expected up to? (mmyyyy)	Comment
		yes	no		
Austria	AT				
Belgium	BE				
Bulgaria	BG				
Cyprus	CY				
Czech Republic	CZ				
Denmark	DK				
Estonia	EE				
Finland	FI				
France	FR				
Germany	DE				
Greece	EL				
Hungary	HU				
Ireland	IE				
Italy	IT				
Latvia	LV				
Lithuania	LT				
Luxemburg	LU				
Malta	MT				
Netherlands	NL				
Poland	PL				
Portugal	PT				
Romania	RO				
Slovakia	SK				
Slovenia	SL				
Spain	ES				
Sweden	SE				
United Kingdom	UK				
Remarks:					

5.2 Please list the authorized <u>centres/bodies of examination and certification</u> of personnel involved in RRRD of HFC from Fire Protection Systems and Fire Extinguishers by Member State.

Please indicate if possible names and addresses of the centres/bodies.

Member State		Centre/body for		Name & address	Comment
		Exami-nation	Certifi-cation		
Austria	AT				
Belgium	BE				
Bulgaria	BG				
Cyprus	CY				
Czech Republic	CZ				
Denmark	DK				
Estonia	EE				
Finland	FI				
France	FR				
Germany	DE				
Greece	EL				
Hungary	HU				
Ireland	IE				
Italy	IT				
Latvia	LV				
Lithuania	LT				
Luxemburg	LU				
Malta	MT				
Netherlands	NL				
Poland	PL				
Portugal	PT				
Romania	RO				
Slovakia	SK				
Slovenia	SL				
Spain	ES				
Sweden	SE				
United Kingdom	UK				

Remarks:

5.3 Please provide information or best estimate about the <u>number of personnel certificates issued</u> according to (EC) 842/2006, Art. 5(2) for recovery of F-gases from Fire Protection Systems and Fire Extinguishers (as of 31. 03. 2010)

Please enter the data in the attached excel-file.

D:\Data\Certificates in EU-27_high voltag

5.4 Please provide a quantified best estimate of the percentage of involved personnel already certified for recovery, recycling, reclaiming and / or destruction of F-gases from Fire Protection Systems and Fire Extinguishers (as of 31. 03. 2010)

(Personnel already certified in % of personnel which has to be certified)

Member State		Percentage certified as of 31.03.2010 [%]	Comment
Austria	AT		
Belgium	BE		
Bulgaria	BG		
Cyprus	CY		
Czech Republic	CZ		
Denmark	DK		
Estonia	EE		
Finland	FI		
France	FR		
Germany	DE		
Greece	EL		
Hungary	HU		
Ireland	IE		
Italy	IT		
Latvia	LV		
Lithuania	LT		
Luxemburg	LU		
Malta	MT		
Netherlands	NL		
Poland	PL		
Portugal	PT		
Romania	RO		
Slovakia	SK		
Slovenia	SL		
Spain	ES		
Sweden	SE		
United Kingdom	UK		

5.5 What happens in Member States without implementation of (EC) 842/2006 Art 5(2) on the basis of the minimum requirements for the sector of Fire Protection Systems and Fire Extinguishers according to (EC) No 304/2008 with regard to training and certification (e.g. no activity; training / certification abroad; etc.)?

Member State	Training	Certification

5.6 Is there a uniform implementation and practice of the F-Gas Regulation amongst EC Member States with regard to the provisions for the sector of Fire Protection Systems and Fire Extinguishers and where do you see problems?

If the answer is no, please describe the problems (e.g. regarding training and certification; time-offset of the national implementation of the F-Gas Regulation etc.)

5.7 Any other comments?

6. Questions with regard to (EC) No 842/2006, Art. 6 (reporting)

6.1 Is there any import/export of HFC in prefilled Fire Protection Systems and Fire Extinguishers in or from the European Community:

Yes	
No	

If yes: Please make a best estimate of the quantities of HFC (by type) imported or exported in prefilled Fire Protection Systems and Fire Extinguishers by entities in the Member States in/from the EC for the last 5 years.

Quantities of HFC (by type) imported or exported in prefilled Fire Protection Systems and Fire Extinguishers 2005-2009			
Year	Imported in the EC (t)	Exported from the EC (t)	Comment
2005			
2006			
2007			
2008			
2009			

6.2 Are there already established national reporting systems for the sector of Fire Protection Systems and Fire Extinguishers according to (EC) No 842/2006 Art 6(4)?

If yes, please describe by Member State and explain practical experiences and results

Member State	Title/characterisation of the reporting system; in force since	Description, practical experience, results, attachments

7. Costs of Regulation (EC) 842/2006 for the sector of Fire Protection Systems and Fire Extinguishers

7.1 Please provide a best estimate on additional non-current costs for the sector of Fire Protection Systems and Fire Extinguishers resulting from provisions of the F-Gas regulation for e.g. recovery (Art. 4), training and certification (Art. 5), reporting (Art. 6).

Please indicate by Member State and methodology

Assessment of non-current costs			
Member State	Estimate of non-current costs (€)	Methodology of calculation	Comment

7.2 Please provide a best estimate on additional annually current costs for the sector of Fire Protection Systems and Fire Extinguishers resulting from provisions of the F-Gas regulation for e.g. recovery (Art. 4), training and certification (Art. 5), reporting (Art. 6).

Please indicate by Member State and methodology

Assessment of annually current costs			
Member State	Estimate of annually current costs (€)	Methodology of calculation	Comment

7.3 How do you weigh these additional non-current and current costs (e.g. percentage of turn-over of your industry etc.)?

Please explain

8. Potential needs for clarification (definitions, procedures etc.) and simplification of Regulation (EC) No 842/2006

8.1 Please indicate inconsistencies and the need for simplification and clarification of terminology, definitions, procedures etc of Regulation (EC) No 842/2006 and briefly describe the problem.

Article	Comment
Art 4: Recovery	
Art 5: Training and certification	
Art 6: Reporting	
Other Articles	
Suggestions for improvement	

8.2 Any other suggestions and comments?

9. Your overall assessment of Regulation (EC) No 842/2006

9.1 Please give your <u>opinion on effectiveness</u> (i.e. the extent to which objectives set are achieved) <u>and efficiency</u> (i.e. the extent to which the desired effects are achieved at a reasonable cost) of Regulation (EC) No 842/2006 with regard to the sector of Fire Protection Systems and Fire Extinguishers if possible by Member States.

On a scale of 1 to 4, how effective/ efficient was the regulation in reducing HFC emissions from the sector of Fire Protection Systems and Fire Extinguishers?

1: not effective/ efficient at all ... 4: very effective/ efficient

Member State	Scale 1 - 4		Comments
	Effective	Efficient	

9.2 How effective has Regulation (EC) No 842/2006 been with regard to the sector of Fire Protection Systems and Fire Extinguishers in terms of the following criteria:

1: not effective/ efficient at all ... 4: very effective/ efficient

Criteria		Please tick for each category			
		1	2	3	4
9.2.1	Improving the technical competence of professionals handling HFC				
9.2.2	Improving the containment of HFC during the lifetime of applications				
9.2.3	Promoting the recovery of HFC from equipment for recycling, reclamation, destruction				
9.2.4	Monitoring the use of HFC in the EU				
9.2.5	Monitoring emissions of HFC from the sector of Fire Protection Systems and Fire Extinguishers in the EU				
9.2.6	Preventing the use of HFC in applications where viable alternatives are available				
9.2.7	Harmonising requirements on the use of HFC in the sector of Fire Protection Systems and Fire Extinguishers across the EU				
9.2.8	Promoting technological innovation towards technologies which are more environmentally friendly				
9.2.9	Reducing emissions of HFC in the EU (overall effectiveness)				
9.2.10	Reducing emissions of HFC in the EU at a reasonable cost (overall efficiency)				
9.2.11	Clarity and comprehensibility				
9.2.12	Completeness				

I.4 Questionnaire to high voltage switchgear industry

Review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases

Questionnaire
To the European Industry of High Voltage Switchgear

Öko-Recherche GmbH
D-60329 Frankfurt/Main, Germany, Münchener Str. 23
Phone +49 69 252305; Fax + 49 69 252306
E-Mail: a.leisewitz@oekorecherche.de; barbara.gschrey@oekorecherche.de

March 2010

Preface

In December 2009, the European Commission launched a project to support the review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases. This project is undertaken by Öko-Recherche GmbH (Frankfurt/Main, Germany) in association with several other companies and institutes (cf. Authorisation Letter Attached).

This questionnaire to associations/companies of the High Voltage Switchgear industry sector will be a key component of the information gathering. Thus, your responses will be an important element of the study and will contribute to the broader review of Regulation (EC) No 842/2006.

Overall, the main objectives of this questionnaire are to:

– Assess the implementation, effectiveness and efficiency of the provisions of the Regulation;
– Evaluate interactions between the existing EU policy framework on fluorinated greenhouse gases and other EC and national legislation (including in particular national legislation stricter than those laid down in the Regulation, legislation on waste etc.);
– Assess and evaluate the scope for clarification and simplification of the Regulation and possible options for modification of the existing policy framework on fluorinated greenhouse gases.

Questions on status and results of the implementation of (EC) No 842/2006 regarding the High Voltage Switchgear industry have also been sent to the competent authorities of the EU-27 Member States within the context of a broader questionnaire.

This questionnaire is addressed to he European High Voltage Switchgear industry (manufacturers, utilities, service companies) and we kindly ask you to contribute your knowledge on the practical implementation and realisation of the F-Gas Regulation.

Responses:
Please return the completed questionnaire and any related materials by
23 April 2010

to Öko-Recherche GmbH

Contact details:

Öko-Recherche GmbH
Dr. André Leisewitz / Barbara Gschrey
D-60329 Frankfurt/Main, Germany, Münchener Str. 23
Phone +49 69 252305; Fax + 49 69 252306
E-mail: a.leisewitz@oekorecherche.de; barbara.gschrey@oekorecherche.de

Your contact details:

Member State	
Institution	
Contact person	
Address	
Telephone	
Fax	
E-mail	

1. Questions on Voluntary Agreements and National Legislation regarding F-gases in High Voltage Switchgear Equipment

1.1 Are there any <u>voluntary agreements</u> existing on SF_6 for High Voltage Switchgear equipment in EC Member States (EU 27) and associated countries?

Please indicate by Member State and explain with regard to objectives and results.

Member State/ country	
Title of the voluntary agreement	
a) National	
b) English Translation	
Voluntary agreement existing since	
Internet link / or published where	
Scope of the voluntary agreement	
Participants	
Main content and objectives	
List of achievements	
Additional information	
Attachments	

1.2 Is there any <u>national legislation</u> on SF_6 for High Voltage Switchgear equipment in EC Member States (EU 27) and associated countries which is <u>stricter</u> than (EC) No 842/2006?

Yes	
No	

If yes, please indicate the respective national legislation, the related provisions of the F-Gas Regulation and explain in which regard the national regulation is stricter.

Member State	
Title of the national legislation	
a) National	
b) English Translation	
Date of entry into force	
Internet link / publication reference	
Main content and objectives compared to the F-Gas Regulation	
Additional information	
Attachments	

2. Questions on Recovery, Recycling, Reclamation, Destruction (RRRD) Provisions of (EC) 842/2006 (Art. 4)

2.1 Please describe in general the practical arrangements in place for proper recovery of SF_6 according to Art 4(1) of (EC) 842/2006 within the EU-27. Please indicate whether there are significant differences between Member States (and which MS).

2.2 Please provide us with a list of companies in the EU-27 Member States taking back SF_6 from High Voltage Switchgear equipment for recycling, reclamation, destruction. Please mark in the columns what the companies etc. are doing.
(If there is a problem with the column "recycling" – e.g. to many companies, definition for companies recycling not possible etc. – please take for this aspect the following question 2.3)

Member State/ Name and contact data of companies, utilities, associations, …	Re-cycling[1]	Recla-mation	Destruc-tion	Comment (e.g. company operating since …; range of SF_6 annually reclaimed/destructed etc.)

[1] If a definition of companies / utilities for recycling of SF_6 is not possible:
Please give the information within question 2.3 (indicate any representative examples of companies / utilities etc.).

2.3 Please give any <u>representative example</u> of some companies / utilities operating high voltage switchgear equipment with regard to quantities of SF_6 recycled, reclaimed, destructed within one year 2008 or 2009 (please indicate the year).

Member State/ Name and contact - data of companies, utilities, associations, …	Quantity of recovered SF_6 in 2008 or 2009 [kg]	Quantity of recycled SF_6 in 2008 or 2009 (quality acc. to IEC 60480) [kg]	Quantity of reclaimed SF_6 in 2008 or 2009 [kg]	Quantity of destructed SF_6 in 2008 or 2009 [kg]

2.4 Has there been recovery, recycling, reclamation, destruction (RRRD) of SF_6 from High Voltage Switchgear equipment <u>prior to the implementation of (EC) No 842/2006</u>? Please indicate by Member State:

RRRD of SF_6 prior to the implementation of (EC) No 842/2006				
Member State				
	Recovery	Recycling	Reclamation	Destruction
yes				
no				

2.5 Does a database or an assessment of recovered SF_6 from High Voltage Switchgear equipment for the purpose of recycling, reclamation or destruction exist? Please indicate by Member State:

Database/assessment on RRRD of SF_6 (EC) No 842/2006				
Member State				
	Recovery	Recycling	Reclamation	Destruction
yes				
no				

2.6 If the answer to question 2.5 was yes in all or some aspects, please provide information on the RRRD quantities before and after the implementation of the F-Gas Regulation. Please indicate by Member States and the respective years.

Information should cover the entire High Voltage Switchgear Industry (HVSI) in the Member State. If this is not possible, please provide details of the major companies carrying out these activities, for example, reclamation and / or destruction.

RRRD of SF6 before and after the implementation of No 842/2006								
Member State/ entire HVSI or major companies (please indicate name and contact data)	Recovery		Recycling		Reclamation		Destruction	
	before [year/ to]	after [year/ to]	before [year/ to]	after [year/ to]	before [year/ to]	after [year/ to]	before [year/ to]	after [year/ to]

2.7 Please comment on the possible reasons for the trend indicated under question 2.6 with regard to RRRD and the relevance of the F-Gas Regulation.

(Reasons: Please consider also other factors as age structure of the equipment etc.)

RRRD-sector	Reasons for the trend	Relevance of F-Gas Regulation
Recovery		
Recycling		
Reclamation		
Destruction		

2.8 If the answer to question 2.5 was no: Is it planned to set up a database or an assessment for controlling improvements of SF_6 recovery, recycling, reclaiming and / or destruction from High Voltage Switchgear equipment? Please specify by Member State in detail what is planned and when?

2.9 Can you provide us with information / a best estimation on the development of the stock of equipment for recovery & recycling of SF_6 from High Voltage Switchgear equipment within the EU-27 during the last 5 years?

If possible, indicate this by number of equipment and by level of provision of equipment (e.g. percentage).

Year	Number of equipment	Level of provision of equipment (%)	Comment (e.g. source, estimation etc.)
2005			
2006			
2007			
2008			
2009			

2.10 Are there any <u>problems or barriers</u> for RRRD of SF_6 from High Voltage Switchgear equipment resulting from national/international legal provisions <u>with regard to cross-border transport, waste etc</u>?

Yes	
No	

If yes, please describe the problems or barriers by Member State.

Problems and barriers for RRRD of SF_6 from High Voltage Switchgear industry		
	Description	Comment
Member State		
National barriers		
Cross border transport inside EU-27		
Import/export in/ from EU-27		
other		
Member State		
National barriers		
Cross border transport inside EU-27		
Import/export in/ from EU-27		
other		

2.11 Any other information and comments?

3. Questions on tightness and standards of High Voltage Switchgear equipment

3.1 Can you provide us with any indicators on the tightness of High Voltage Switchgear equipment containing SF_6 in the EU-27 Member States during the past 5 years?

Indicators could be e.g. leakage rates. Please indicate by type of equipment and explain the relevance of the indicator.

Indicators on the tightness of High Voltage Switchgear equipment 2005-2009					
Year	2005	2006	2007	2008	2009
Type of equipment:					
Indicator (please specify)					
Type of equipment:					
Indicator (please specify)					
Type of equipment:					
Indicator (please specify)					
Comment on the relevance of indicators:					

3.2 Please provide us with information on relevant European/ international standards for tightness of High Voltage Switchgear equipment containing SF_6 in the EU-27 Member States in general.

Relevant European or international standards for tightness of High Voltage Switchgear equipment containing SF_6	
Classification, no and title	
Date of entry into force	
Valid for which countries / regions in the world?	
Main content / summary regarding tightness of equipment	
Requirements for leakage rates and / or other measures to limit emissions of SF_6	
Attachments e.g. of the relevant standards	
Are there plans for other standards? If so, which ones?	
Is there any assessment of the real impact of these standards on the tightness of HVS equipment/SF_6 emissions in EU 27?	

If yes: please describe results and indicate the source	
Do the standards describe the current state of the art? If yes: please explain what is relevant for tightness	
Which reduction in % of SF_6 emissions from HVS equipment in the EU 27 is expected by those standards in the next 5 years?	
Additional advice and information?	

3.3 Is there any further information on relevant national standards/ guidelines/ recommendations for tightness of High Voltage Switchgear equipment containing SF_6 in the individual EU-27 Member States?

National standards/guidelines/recommendations of relevance for tightness of High Voltage Switchgear equipment containing SF_6	
Member State	
Classification, no and title	
Date of entry into force	
Main content / summary regarding tightness of equipment	
Attachments e.g. of the relevant standards etc.	
Are there plans for other standards? If so, which ones?	
Is there any assessment of the real impact of these standards/guidelines/ recommendations on the tightness of HVS equipment/SF_6 emissions? If yes: please describe results and indicate the source	
Do the documents describe the current state of the art? If yes: please explain what is relevant for tightness	
Which reduction in % of SF_6 emissions from HVS equipment is expected by those standards in the next 5 years?	
Additional advice and information?	

3.4 Please give information on improvements for "state of the art technology" realised in the past (last 10 years) and expected in the near future for High Voltage Switchgear equipment and SF_6 handling equipment (EU-27 in general).

Improvements for "state of the art technology" in the past (last 10 years) and the near future with respect to	
reduction of SF_6 leakage rates and SF_6 leaks	
reduction of SF_6 emissions during testing, production, erection on site, maintenance and repairs, end of life.	
reduction in specific volume of SF_6 with comparable data and functions	
methods and devices for checking tightness during routine tests, operation, after maintenance or repair	
estimated reduction of SF_6 emissions in % from high-voltage switchgear GIS >52kV in the EU 27 expected by these measures?	
Additional advice and information	

3.5 Any additional information and comments?

4. Questions with regard to (EC) No 842/2006, Art. 4(1) [recovery by certified personnel] and 5 [training and certification] plus (EC) No 305/2008

4.1 Please indicate the current status of implementation of (EC) 842/2006 Art 5(2) on the establishment or adaptation of training and certification requirements in EU-27 based on the minimum requirements for the High Voltage Switchgear industry according to (EC) No 305/2008.

Member State		Art. 5(2) legally implemented (as of 30.3.2010)		If no: implementation expected when? (mm/yyyy)	Comment
		yes	no		
Austria	AT				
Belgium	BE				
Bulgaria	BG				
Cyprus	CY				
Czech Republic	CZ				
Denmark	DK				
Estonia	EE				
Finland	FI				
France	FR				
Germany	DE				
Greece	EL				
Hungary	HU				
Ireland	IE				
Italy	IT				
Latvia	LV				
Lithuania	LT				
Luxemburg	LU				
Malta	MT				
Netherlands	NL				
Poland	PL				
Portugal	PT				
Romania	RO				
Slovakia	SK				
Slovenia	SL				
Spain	ES				
Sweden	SE				
United Kingdom	UK				
Remarks:					

4.2 Please list the authorized centres/ bodies of examination and certification of personnel involved in RRRD of SF_6 from High Voltage Switchgear equipment by Member State.

Please indicate if possible names and addresses of the centres/bodies.

Member State		Centre/ body for		Name & address	Comment
		Exami-nation	Certifi-cation		
Austria	AT				
Belgium	BE				
Bulgaria	BG				
Cyprus	CY				
Czech Republic	CZ				
Denmark	DK				
Estonia	EE				
Finland	FI				
France	FR				
Germany	DE				
Greece	EL				
Hungary	HU				
Ireland	IE				
Italy	IT				
Latvia	LV				
Lithuania	LT				
Luxemburg	LU				
Malta	MT				
Netherlands	NL				
Poland	PL				
Portugal	PT				
Romania	RO				
Slovakia	SK				
Slovenia	SL				
Spain	ES				
Sweden	SE				
United Kingdom	UK				
Remarks:					

4.3 Please provide information or best estimate about the <u>number of personnel certificates issued</u> according to (EC) 842/2006, Art 5(2) for recovery of F-gases from High Voltage Switchgear (as of 31.03.2010).
Please enter the data in the attached Excel-file.

4.4 Please provide a quantified best estimate of the <u>percentage of involved personnel already certified</u> for recovery, recycling, reclaiming and / or destruction of F-gases (High Voltage Switchgear equipment) (as of 31.03.2010).
(Personnel already certified in % of personnel which has to be certified)

Member State		Percentage certified as of 31.03.2010 [%]	Comment
Austria	AT		
Belgium	BE		
Bulgaria	BG		
Cyprus	CY		
Czech Republic	CZ		
Denmark	DK		
Estonia	EE		
Finland	FI		
France	FR		
Germany	DE		
Greece	EL		
Hungary	HU		
Ireland	IE		
Italy	IT		
Latvia	LV		
Lithuania	LT		
Luxemburg	LU		
Malta	MT		
Netherlands	NL		
Poland	PL		
Portugal	PT		
Romania	RO		
Slovakia	SK		
Slovenia	SL		
Spain	ES		
Sweden	SE		
United Kingdom	UK		

4.5 What happens in <u>Member States without implementation</u> of (EC) 842/2006 Art 5(2) based on the minimum requirements for the High Voltage Switchgear industry according to (EC) No 305/2008 with regard to training and certification (e.g. no activity; training / certification abroad; etc.)?

Member State	Training	Certification

4.6 Is there a uniform implementation and practice of the F-Gas Regulation amongst EC Member States with regard to the provisions for the High Voltage Switchgear industry and where do you see problems?

If no, please describe the problems (e.g. regarding training and certification; time-offset of the national implementation of the F-Gas Regulation etc.)

4.7 Are there any measures taken by the High Voltage Switchgear industry itself and / or by national authorities to ensure a uniform practice of the provisions of the F-Gas Regulation amongst the Member States (recommendations, guidelines, mutual assistance to implement practical arrangements in the individual Member States etc)?

If yes, please describe the measures, if necessary by Member States, and refer to publications, internet links etc.

4.8 Any other comments?

5. Questions with regard to (EC) No 842/2006, Art. 6 (reporting)

5.1 Import/export of SF_6 in prefilled High Voltage Switchgear equipment in or from the European Community:

a) Is the import/export covered by the provisions of Art 6?

Yes	
No	

b) Is this import/ export of SF_6 in prefilled High Voltage Switchgear equipment by entities in the Member States below the minimum reporting threshold of 1 tonne p.a. (i.e. not covered by the reports)?

Yes	
No	

c) Please make a best estimate of the quantities of SF_6 imported or exported in prefilled High Voltage Switchgear equipment by entities in the Member States in/ from the EC for the last 5 years.

Quantities of SF_6 imported or exported in prefilled High Voltage Switchgear equipment in 2005-2009			
Year	Imported in the EC (t)	Exported from the EC (t)	Comment
2005			
2006			
2007			
2008			
2009			

5.2 Are there already established national reporting systems for the High Voltage Switchgear industry according to (EC) No 842/2006 Art 6(4)?

If yes, please describe by Member State and explain practical experiences and results.

Member State	Title/characterisation of the reporting system; date of entry into force	Description, practical experience, results, attachments

6. Costs of Regulation (EC) 842/2006 for the High Voltage Switchgear industry

6.1 Please provide a best estimate on <u>additional non-current costs</u> for the High Voltage Switchgear industry resulting from provisions of the F-Gas regulation for e.g. recovery (Art. 4), training and certification (Art. 5), reporting (Art. 6).

Please indicate by Member State and methodology.

Assessment of non-current costs			
Member State	Estimate of non-current costs (€)	Methodology of calculation	Comment

6.2 Please provide a best estimate on <u>additional annually current costs</u> for the High Voltage Switchgear industry resulting from provisions of the F-Gas regulation for e.g. recovery (Art. 4), training and certification (Art. 5), reporting (Art. 6).

Please indicate by Member State and methodology.

Assessment of annually current costs			
Member State	Estimate of annual current costs (€)	Methodology of calculation	Comment

6.3 How do you weigh these additional non-current and current costs (e.g. as percentage of turn-over of your industry etc.)?

Please explain

7. Potential needs for clarification (definitions, procedures etc.) and simplification of Regulation (EC) No 842/2006

7.1 Please indicate inconsistencies and the need for simplification and clarification of terminology, definitions, procedures etc of Regulation (EC) No 842/2006 and briefly describe the problem.

Article	Comment
Art 4: Recovery	
Art 5: Training and certification	
Art 6: Reporting	
Other Articles	
Suggestions for improvement	

7.2 Any other suggestions and comments?

8. Your overall assessment of Regulation (EC) No 842/2006

8.1 Please give your opinion on

- effectiveness (i.e. the extent to which objectives set are achieved) and
- efficiency (i.e. the extent to which the desired effects are achieved at a reasonable cost)

of Regulation (EC) No 842/2006 with regard to the High Voltage Switchgear industry, if possible by Member States.

On a scale of 1 to 4, how effective/ efficient was the regulation in reducing SF_6 emissions from the High Voltage Switchgear industry?

1: not effective/ efficient at all ... 4: very effective/ efficient

Member State	Scale 1 - 4		Comments
	Effective	Efficient	

8.2 How effective has Regulation (EC) No 842/2006 been with regard to High Voltage Switchgear industry in terms of the following criteria:

1: not effective/ efficient at all ... 4: very effective/ efficient

Criteria		Please tick for each category			
		1	2	3	4
8.2.1	Improving the technical competence of professionals handling SF_6				
8.2.2	Improving the containment of SF_6 during the lifetime of applications				
8.2.3	Promoting the recovery of SF_6 from equipment for recycling, reclamation, destruction				
8.2.4	Monitoring the use of SF_6 in the EU				
8.2.5	Monitoring emissions of SF_6 from High Voltage Switchgear industry in the EU				
8.2.6	Preventing the use of SF_6 in applications where viable alternatives are available				
8.2.7	Harmonising requirements on the use of SF_6 in the High Voltage Switchgear industry across the EU				
8.2.8	Promoting technological innovation towards technologies which are more environmentally friendly				
8.2.9	Reducing emissions of SF_6 in the EU (overall effectiveness)				
8.2.10	Reducing emissions of SF_6 in the EU at a reasonable cost (overall efficiency)				
8.2.11	Clarity and comprehensibility				
8.2.12	Completeness				

Annex II: Cost data

II.1 Service costs acc to Art 3 and/or 4(1) by sectors

General rate per working hour € 50.

The numbers of the sectors refer to the numbers of the EU sector sheets (annex V).

	1	2	3	4	5	6	7	8	9	10	11	12
Sector	Leak checks prior to Regulation	One leak check /hours	frequ. /year	EF use	Repair /hours	Frequ./ year	Recording /hours	Life-time years	Reco-very /hours	Cost leak detect. system year	Cost Art 4 €/year	Cost Art3+4 €/year
1 Domestic refrigeration	0%			*0.003*			*0.33*	15	0.5		**0.10**	*67*
2 Commercial stand-alone	0%	*1*	*1*	*0.01*	*2*	*0.02*	0.33	10	0.5		**2.50**	*70*
3 Condensing units	20%	3	1	0.1	4	0.4	0.33	15	1			**160**
4 Centralized systems	50%	8	2	0.15	8	1.2	0.67	12	2	100		**602***
5 Industrial refr small	60%	8	2	0.1	8	0.8	0.67	30	3	700		**1,098**
6 Industrial ref large	70%	12	2	0.1	8	0.8	0.67	30	6	800		**1,243**
7 Refrigerated vans	0%	*1*	*1*	0.3	*2*	*0.6*	*0.33*	8	1		*6.25*	
8 Refrigerated trucks &trailers	50%	*2*	*1*	0.2	*4*	*0.8*	*0.33*	8	1			*113*
9 Fishing vessel ref	15%	*12*	*2*	*0.4*	*8*	*3.2*	*0.67*	30	10	700		*1,930*
10 Factory sealed AC	0%	*1*	*1*	*0.03*	*2*	*0.06*	*0.33*	10	0.5		**2.50**	*72*
11 Single split AC	0%	*2*	*1*	*0.05*	*4*	*0.2*	*0.33*	10	1		**5.00**	*132*
12 Multi split (VRF) AC	15%	3.5	1	0.08	4	0.32	0.33	10	1			**185**
13 Rooftop AC	10%	3	1	0.05	4	0.2	0.33	10	1			**167**
14 Chillers (displacement)	20%	2	2	0.04	4	0.16	0.67	12	1			**206**
15 Centrifugal Chillers	35%	4	2	0.04	6	0.24	0.67	25	1.5	500		**808**
16 Heat pumps	*0%*	*2*	*1*	*0.035*	*4*	*0.14*	*0.33*	15	1		**3.33**	*127*
17 Cargo ship MAC	*10%*	*5*	*2*	*0.4*	*8*	*3.2*	*0.67*	30	4			*650*
18 Passenger ship MAC	*20%*	*12*	*2*	*0.4*	*8*	*3.2*	*0.67*	30	8	700		*1,867*
19 Rail vehicle MAC	*75%*	*2*	*1*	*0.07*	*8*	*0.56*	*0.33*	25	1			*72*
20 + 21 Fire protection	75%	2	2	0.025	2	0.05	0.67	20	2			**91**
27 Electrical MV switchgear	0%							40	1.5		**1.88**	

* Centralised commercial systems: only 10% >300 kg, leak detection system required.

Explanation of the service cost table

Basis of calculation for the assessment is the cost of one working hour by certified personnel, which is assumed to amount on average to € 50 in Europe. It should be noted that € 50 or one hour working time (including travelling) is often the minimum price for one on-site visit of a certified person for leak check or end-of-life recovery, even if the actual work takes less time. This rule applies to all equipment > 3kg.

In the following, service cost for large industrial refrigeration equipment is used as example, with numbers given in brackets. The total annual cost of Art 3+4 for large industrial plants are calculated at €1,098 (12th column).

- The first column displays the the percentage of regular leak checks in a sector prior to the F-gas Regulation. The share is quantitatively considered in the following columns, reducing the annual working time for additional leak checks acc to Art 3. Large industrial refrigeration systems are assumend to have been checked regularly at 70% before the Regulation.
- The next two columns (2 and 3) indicate the time expenditure for one regular leak check, in hours (12), and the frequency per year (2 times), which depends on the charge size of the equipment. Large industrial systems show refrigerant charges of 4,000 kg on average.
- Columns 4-6 estimate the time for the quickest possible repair of a detected leakage. Column 5 indicates the time which is assumed for the repair of one leak (8 hours). The frequency of leak repairs per year (column 6) depends on the use-phase-emission factor EF (column 4). The higher the EF, the more frequent the leaks have to be repaired. An emission factor of 0.1 implies annual frequency for repairs of 0.1. The time for one repair is 8 hours (column 5); therefore the repair time per year is 0.8 hours (0.1 x 8). The emission factor which is used is that in the model AnaFgas.
- Column 7 shows the time estimated necessary for recording. The recording time for one regular check is assumed to range at 20 minutes (0.33 hours). It is 40 minutes for refrigeration plants because the leak checks must be carried out twice a year.
- The 8th and 9th columns estimate the time necessary for recovery of the F-gas at end of life. For industrial refrigeration equipment 6 hours are deemed necessary. In order to annualise this time expenditure, it is divided by the lifetime, which is 30 years for industrial refrigeration plants (column 8).
- The 10th column includes the annualised costs of a leak detection system which is mandatory for equipment containing charges of F-gases of >300 kg. The assumption for large industrial refrigeration is € 800 per year. The installation of a leak detection system is the reason why the leak check frequency (column 2) is not 4 but only 2 times/ year.

Columns 11 and 12 require further explanation.

In both column 11 and 12, the calculation of total annual service cost follows the general formula “annual hours for leak checks (col 1, 2, 3) + annual hours for quick repair of leaks (col 4, 5, 6) + annualised hours for recording (col 7) + annualised hours for end-of-life recovery (col 8, 9)” multiplied by “hourly rate of € 50”. In case of large systems > 300 kg, the annualised costs (no discounting) of the leak detection system must be added.

The total cost from Art 3 and 4 are € 1,243 for the operator of large refrigeration equipment.

Col 11 indicates annual cost for equipment < 3 kg from Art 4 only. In bold letters the sectors are listed that are already covered by the existing F-gas Regulation, in italics the cost for sectors are listed which could be possibly subject to an amended Regulation. As for Art 4, the only sector of concern is refrigerated vans (average charge size: 1.5 kg).

The cost for Domestic Refrigeration (€ 0.10) is calculated differently. As recovery at end-of-life is already subject to the WEEE Directive, additional cost arise only from the requirement that recovery must be carried out be certified personnel. The labour costs are therefore estimated € 5.00 higher per hour. Divided by 15 years lifetime, the additional annual cost is € 0.33. As there is 0.3 hours time assumed for end-of-life treatment, annualised additional cost from application of Art 4 is 0.33 x 0.3 = 0.10.

Column 12 shows the additional annualised cost for equipment from application of Art 3 and 4: in bold for stationary systems > 3 kg which are already covered by the existing Regulation, in italics for small-charged (< 3 kg) and mobile equipment (> 3kg) for which application of Art 3 and 4 is discussed as political options in chapter 8.

II.2 Costs of refrigerants, foam blowing agents, and fire extinguishing agents

Refrigeration/air conditioning	
HFC-134a €/kg	10
Unsaturated HFC-1234yf €/kg	60
Blend unsaturated HFCs/HFC €/kg	30
NH_3 €/kg	2
Propane (R-290) €/kg	5
Iso-butane (R-600a)	5
CO_2 €/kg	4
410A €/kg	15
404A €/kg	15
407C €/kg	15
R-32 €/kg	13

Foam blowing	
HFC-134a €/kg	5
HFC-152a €/kg	2
HFC-365mfc/227ea €/kg	5
HFC-245fa €/kg	5
Hydrocarbons/organic solvents €/kg	0.80
Unsaturated HFCs €/kg	12
HCFC-141b	1.50
HCFC-22	1.30
HCFC-142b	1.30

Fire protection	
HFC-227ea €/kg	12
HFC-23 €/kg	12
FK-5-1-12 €/kg	22

Aerosol	
Unsaturated HFCs €/kg	14.30*

* cost difference to HFC-134a

Electricity	
1 kWh (el) €	0.14
1 kWh (el) € (road vehicles)	0.20
1 kWh (el) € (ships)	0.07

Discount rate	
Discount rate %	4%

Annex III: Description of the model AnaFgas

III.1 Domestic Refrigeration

The calculation of emissions from household refrigerators and freezers is only to limited extent based on national common reporting format (CRF) tables and National Inventory Reports (NIR). This is primarily because data from most MS with own production are not plausible, exept for one MS. Several reports do not distinguish HC from HFC refrigerants so that the reported quantities in the banks of some MS are up to 50 times higher than they can be since the general replacement of HFCs/CFCs by R-600a by the European manufacturers. The general idea for emissions calculation is shown in following equations:

$$EM_{Manu,n} = Manu_{Cons,n} * EF_{Manu,n}$$
$$EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}$$
$$EM_{Disposal,n} = Disposal_n * EF_{Disposal,n}$$
$$Bank_n = Bank_{n-1} - EM_{Lifetime,n-1} + HFC\_in\_new\_units_n - Disposal_n$$
$$Disposal_n = HFC\_in\_new\_units_{n-Lifetime} * (1 - EF_{Lifetime})^{Lifetime}$$
$$HFC\_in\_new\_units_n = Bank_n - Bank_{n-1} + EM_{Lifetime,n-1}$$

$EF_{Manu,n}$	= Manufacturing emission factor in year n
$EF_{Lifetime,n}$	= Lifetime emission factor in year n
$EF_{Disposal,n}$	= Disposal emission factor in year n
$Bank_n$	= Sum of gases in appliances in year n

As initially stated, countries provide different information about domestic refrigeration with their CRF tables and NIRs. Information about quantities for manufacturing is not used for estimation of the banks also because export and import of filled appliances had to be taken into account. The bank cannot be calculated from annual HFC demand for first fill but must be estimated from the amount of HFCs in new units annually sold to the domestic market. HFC banks and their annual growth are reported directly in many cases. In view of the long lifetime (mostly 15 years are assumed), disposal of HFC-based appliances has not been reported so far before 2008. The quantity for disposal is identical to the difference in bank size between two subsequent years, 15 years earlier minus lifetime emissions because no refill is usual for domestic appliances.

Country-specific activity data

HFC quantity for manufacturing: For Denmark, Greece, Portugal, Slovenia and UK data until 2008 is available. They could be used to limited extent.

HFC in new units: Data for Austria, Estonia, France and Germany from CRF tables or NIR is available.

Bank: The following countries report data on the banks of HFC-134a for domestic refrigeration: Denmark, Greece, Hungary, Latvia, Poland, Portugal, Slovenia and Sweden. Data from two MS only are considered plausible.

WOM scenario

Projections are made by extrapolation of the HFC amount in new units, generally using last available activity data which are kept unchanged at that level until 2050. It is assumed for all MS with own production that after 2015 HFCs are no longer used for manufacturing. This assumption is in line with the phase-out schedule of Denmark.

New units sold to the EU market are assumed to be imported from outside the EU. Their – low – number in 2008 is kept constant until 2050

Emission parameters (WOM)

Lifetime of equipment: 15 years.
$EM_{Lifetime,n}$: For all MS the same default value 0.3% is used. Leakage rates are not considered to be country-specific but technology-specific.
It is not assumed that refrigerant loss through leakage in the use-phase is compensated by refill so that demand for HFCs is limited to first fill before 2015..
$EM_{Disposal,n}$: default 40%. Exemption is Sweden who report 5% in CRF.

WM scenario

Household refrigerators are already covered by the WEEE Directive which requires appropriate end-of-life treatment including recovery (collection schemes). The application of Art 4(1) of the F-gas Regulation requires that end-of-life recovery must be carried out by certified personnel. The additional reduction effect on disposal emissions is estimated at 10%, lowering the disposal emissions from 40 % to 30 %, from 2010 to 2015.

Use-phase emission factor is not changed.

The number of new units imported to the EU is the same as under the WOM scenario.

III.2 Industrial Refrigeration

For detailed modelling of the industrial refrigeration sector the information provided by CRF tables or NIRs is too general. Therefore, the model approach does not rely on national reporting even though it can draw upon information from selected NIRs in some cases.

The model uses a bottom-up approach originally developed by Denis Clodic et al. for France (INV01)[2]. All French CRF/NIR reporting on refrigeration sectors has been relying on this method from the beginning. The idea for the estimation of the refrigerant bank is, not to start from number of equipment and its average charges but from the cooling demand for the production of goods in a sector and the installed refrigeration capacity for that. From the estimated installed capacity (in kilowatt) the refrigerant bank can be derived, based on sector specific indices of charge (kg per kW), which are typical of identical sectors all over Europe. Such an approach is advisable because statistical data on refrigeration equipment is rare and hardly available for the 27 European countries. In contrast, statistical data on annual production of goods that require cooling are sufficiently available for individual countries.

Calculation is based on detailed knowledge about industrial refrigeration in France and Germany. The sector specific indices are all based on empirical key factors (ratios) gained in these two countries, in particular in France whose values are checked and, if necessary, modified by German findings.

About 75% of industrial refrigeration is required for food production, with the sector of basic chemicals constituting most of the demand for the remaining 25% refrigerants in other industrial sectors.

1. For each MS data on annual production of food and beverage products are collected for the 1995-2007 time, for the sectors listed below. As the quantities of products determine the size of banked refrigerants, projections on the future production are also made.

- Beer production. Several sources[3]. Constancy until 2050.
- Wine production. Source Eurostat, Constancy until 2050.
- Meat production. Source Statistics Division FAO 2009, Constancy until 2050.
- Dairy industry. Milk production; source Eurostat, Constancy until 2050.
- Milk farms: Milk production (see Dairy industry).
- Frozen food. Several sources[4]. From 2009 increase, in pace with GDP growth until 2030. Constancy 2031-2050.

---

[2] INV01 = L. Palandre, S. Barroult, D. Clodic, Inventaire et prévisions des fluides frigorigènes et de leurs émissions, selon les recommendations du GIEC, liées aux obligations du protocole de Kyoto. Année 2001, Rapport final, Mai 2003 – Anné 2001. document 2 « Methode d'inventaires – Outil de calcul et données de base pour la France.
The appropriate approach to industrial refrigeration was also discussed in a telephone conference with the Confederation of the Food and Drink Industries in the EU (ciaa), 2 June, 2010. Participants: Balázs Pályi (ciaa Manager Environmental Affairs), René van Gerwen (Unilever), Paul Homsy (Nestlé), Winfried Schwarz (Öko-Recherche), Barbara Gschrey (Öko-Recherche).

[3] Internet research, amongst others: The Contribution Made by Beer to the European Economy, a report commissioned by The Brewers of Europe and conducted by Ernst & Young, 2006 and 2009. http://www.brewersofeurope.org/docs/publications/Country%20chapters%20Economic%20impact%20of%20beer.pdf

- Fruit juice/sparkling water. Germany[5] is used as basic data: specific fruit juice consumption per capita has been applied to all countries, multiplied with population.
- Chocolate production. Absolute values for 1996[6]. Updated. Constancy until 2050.

Three more sectors with high cooling demand are included in the model calculation:

- Cold storage capacity. Real data available on the volume in public and retail-operated cold store houses for Belgium, France, Germany and Netherlands[7]. For other countries capacities are calculated with per capita values: 150 m^3 / 1000 inhabitants for EU-15 countries, 75 m^3 / 1000 inhabitants for EU-12 countries. With steady growth of total population cold storage capacities grow in the whole time period.
- Ice rinks. Number of ice rinks in EU-27[8]. Ongoing growth until 2015, then constant.
- Other Industry. 50% of non-food industrial refrigeration capacity installed in chemical industry. French refrigerant data in [INV 01], German refrigerant data in [DKV 02]. Capacities of individual MS estimated by reference to German figures, according to Eurostat number of persons employed in the sector of basic chemicals[9]. Installed capacities are considered to remain constant until 2050.

Refrigeration capacity of industrial chillers is not considered here though the capacities are high. The equipment is recorded under stationary air conditioning where no distinction is made between chillers for air conditioning and industrial processes.

Cooling demand for fruit and vegetables is not analysed separately to avoid double counting. The cooling demand is already included in the capacity for cold storage.

2. For each industrial refrigeration sector (above listed) the installed refrigeration capacity in kW per tonne annual product or (in case of cold storage) per cubic metre store volume is established. Capacities for ice rinks are established per unit, capacity of “other” industry (basic chemicals) is established as a whole. The data on specific refrigeration capacities had

---

[4] British Frozen Food Federation: Total frozen food markets, value & volume several years. Quick Frozen Foods International, several years, i. a. http://goliath.ecnext.com/coms2/browse_R_Q002. Deutsche Tiefkühlinstitut (DTI), several press releases.

[5] DKV Statusbericht Nr. 22, Energiebedarf für die technische Erzeugung von Kälte (energy demand for technial production of refrigeration), Stuttgart, June 2002 [DKV 02].

[6] Chocolate Production in Europe. Production 1996 in metric tonnes. http://www1.american.edu/ted/chocolat.htm. Further information from european cocoa association eca, Brussels, http://www.eurococoa.com .

[7] Data provided by ECSLA (European Cold Storage and Logistics Association), survey carried out for Öko-Recherche, communicated 10. June, 2010. Further sector experts consulted: Jan Peilnsteiner *VDKL* Verband Deutscher Kühlhäuser und Kühllogistikunternehmen e.V., Bonn, pers comm 29. June 2010.

[8] The International Ice Hockey Federation (IIHF) Survey of Players (2009). http://www.iihf.com/iihf-home/the-iihf/survey-of-players.html. Survey on ice rinks in Finland, see Emission abatement options and cost effects for fluorinated greenhouse gases. Emission projections for fluorinated greenhouse gases up to 2050, Finnish Environment Institute (SYKE), Tuuli Alaja, 7.12.2009, p. 47.50 (includes refrigeration data). Further information incl. refrigeration data: DKV Statusbericht Nr. 22, op. cit.; [INV 01] p. 39.

[9] Eurostat Statistics in focus, 58/2008, The Manufacture of Basic Chemicals. http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-SF-08-058/EN/KS-SF-08-058-EN.PDF.

to be determined empirically because there is no direct thermodynamic correlation between goods production (which is a dynamic value) and refrigeration capacity (a static value)[10] which defines the refrigerant quantity.

Clodic et al. presented in 2003 [INV 01] and 2010 [INV 07] a number of typical ratios for the cooling capacities in the food and beverage industry[11], expressed in kW/t or kW/m^3. Our model relies on these ratios, which have been checked and sometimes slightly modified for this study by evaluation of several cases of industrial refrigeration plants reported in German technical journals from 1997 to 2009, like Die Kälte und Klimatechnik or KI Kälte.Luft.Klimatechnik. The ratios used in the model are shown in table IND (specific installed refrigeration capacity).

3. Next step is the establishment of the installed refrigerant quantities per t annual product or m^3 store volume by means of another type of index, namely the ratio of refrigerant charge (kg) per installed refrigeration capacity (kW). The sector typical charge ratios (kg/kW) are likewise taken from Clodic et al. [INV 01], and have been modified (reduced) in some case based on own expertise[12] (See table IND, right column).

Table IND Sector assumptions for industrial refrigeration

Sector of Industrial refrigeration	Installed refrigeration capacity	Temperature ranges		Cooling types		Average charges
		positive	negative	direct	indirect	kg / kW
Food industry						
Beer production	0.045 kW / t	100%	0%	55%	45%	3.65
Wine production	0.0344 kW / t	100%	0%	0%	100%	2
Meat production	0.045 kW / t	70%	30%	92%	8%	5.612
Dairy industry	0.013 kW / t	80%	20%	20%	80%	2.88
Chocolate production	0.0095 kW / t	100%	0%	90%	10%	4.7
Frozen food	0.0525 kW / t	0%	100%	92%	8%	7,6
Fruit juice / Gaseous drinks	0.003 kW / t	100%	0%	100%	0%	5
Milk farms	0.0167 kW / t	100%	0%	90%	10%	1.5
Other Industry						
Cold storage	0.032 kW / m^3	30%	70%	75%	25%	6
Ice rinks	250 kW / unit	0%	100%	50%	50%	500
Other industry (50% chemical)	no specifc value	60%	40%	50%	50%	5

Refrigeration is performed in negative or positive temperature ranges, and either with direct or indirect evaporation. Refrigerant charges per kW in low cooling are higher than for normal/medium cooling, and higher for direct evaporation (one circuit) than for indirect cooling (two circuits). As a consequence, the sector specific refrigerant charges not only result from the charge ratio (kg/kW) but also from the temperature range and the relation between direct and indirect cooling, which are characteristic of a sector. (See table IND).

---

[10] Given quantities of goods can be cooled down with high installed capacity in short time or with low installed capacity in longer time. The refrigerant quantity depends on the installed capacity in kW, not on the actually used capacity in kWh.

[11] Méthode de calcul de la puissance frigorifique por l'industrie agroalimentaire. Annexe 3 to [INV 01]. The ratios have recently been updated in [INV 07]. INV 07 = Inventaires des émissions des fluides frigorigènes et de leurs émissions, France, année 2007 et leurs prévisions d'évolution jusqu'en 2022 - Rapport final - Février 2010. Document 2 Données de base, Cenerg (Stéphanie Barrault, Sabine Saba, Denis Clodic), Février 2010.

[12] For instance Öko-Recherche: Emissions, Activity Data, and Emission Factors of Fluorinated Greenhouse Gases (F-Gases) in Germany 1995-2002 - Adaptation to the Requirements of International Reporting und Implementation of Data into the Centralised System of Emissions (ZSE)". For the German EPA, No 201 41 261/01, June 2004.

4. At that stage of the method, the refrigerant quantities in a sector are defined by mass, not by type. Most important refrigerant in industrial applications is ammonia (NH_3), not only in new systems but also in the bank. Less than half of the total bank consists of fluorinated refrigerants. Typical fluorinated refrigerant before 2000 was the HCFC R-22, which was superseded in new equipment by the HFC-blend R-404A, from 2000 onwards when R-22 was no longer allowed in new equipment. Given the long lifetime of industrial refrigeration equipment of 20 to 30 years, R-22 is still the most common fluorinated refrigerant in industrial use. The CFC refrigerant R-12 had never played a major role in industrial refrigeration, while the HCFC/CFC blend R-502 had been used extensively in some sectors (e.g. cold storage).

5. Assumptions on sector-specific refrigerant compositions of new equipment from 1960 onwards have recently been presented by Clodic et al. [INV 07]. Based on these data, by means of a static simulation model which runs the same number of new systems per year over the equipment lifetime, from the refrigerant composition of new equipment the refrigerant composition of the bank can be calculated, for each sector and for every year of concern.

It must be pointed out that industrial refrigeration is traditionally the only refrigeration sector in which natural refrigerants, i.e. NH_3, prevails. From this it results that size of bank and emissions of F-gases largely depend on the share of NH_3 in this sector[13]. As the NH_3 share varies not only from sector to sector but also from country to country, the establishment of the NH_3 shares is of high importance for the model. In the model not only data from Clodic et al. are used. Two other experts for ammonia-based refrigeration assisted in modelling[14]. The work resulted in the generation of a number of static simulation models and is presented in the following.

6. The NH_3 shares vary by sectors and by countries.

For **meat industry** four simulation models were generated:

- The base model for most countries presumes a rate of 30 % of ammonia in 1985 in new cooling installations. The rate remains unchanged until 2050.
- For Austria, Italy and Luxembourg a share of 50 % of ammonia has been assumed in the year 1985, increasing from 1995 to 60 % in the year 2000 (constancy then).
- The same applies to Germany, where additionally the one-year-earlier ban on R-22 is accounted for[15].
- For Denmark, Finland, Portugal, Spain and Sweden the NH_3 share in 1985 was 60 %, increasing to 70 % since 2000, in Denmark increasing since 2001 to 100 % in 2007[16].

---

[13] If the NH_3 share is 90%, F-gas bank and emissions are half as much compared with 80% NH_3 share. F-gas emissions are estimated a multiple or a fraction of its actual amount if the NH_3 share is not estimated correctly.

[14] Anders Lindborg, Sweden, who is a member of this project team, and Alexander Cohr-Pachai, Denmark, from the company Johnson-Controls.

[15] The deadline for the R-22 phase-out in new refrigeration equipment was Jan 1, 2000 also in Finland, Denmark, Austria. The deadline in Netherlands was Jan 1, 1999. In Sweden the phase-out was already in 1995, with service allowed until 2002.

[16] In Sweden the limitation of direct F-gas systems to 20/33 kg strongly supported the application of NH_3. In Denmark from 2007 onwards, F-gases are no longer allowed for use in any refrigeration system charged over 10 kg (see task 1).

For **dairy industry** four simulation models were generated:

- The base model for most countries presumes a rate of 30 % of ammonia in 1985 in new cooling installations, increasing from 1995 to 35 % in the year 2000.
- For Austria, Italy and Luxembourg a share of 50 % of ammonia has been assumed in the year 1985, increasing from 1995 to 65 % in the year 2000 (Constancy then).
- The same applies to Germany, where additionally the one-year-earlier ban on R-22 is accounted for.
- For Denmark, Finland, Portugal, Spain and Sweden the NH_3 share in 1985 was 60 %, increasing to 75 % since 2000, in Denmark increasing since 2001 to 100 % in 2007.

For **frozen food** three static models were generated:

- The base model for most countries assumes a constant rate of 40 % of ammonia for the whole time period for new cooling installations.
- For Austria, Germany, Italy and Luxembourg a higher rate of 55 % of ammonia has been assumed for the whole time period.
- For Denmark, Finland, Portugal, Spain and Sweden a rate of 60 % of ammonia has been assumed for the whole time period, in Denmark increasing since 2001 to 100 %.

For **cold storages** three static models were generated:

- The base model for most countries assumes a constant rate of 30 % of ammonia for the whole time period for new cooling installations.
- For Austria, Germany, Italy and Luxembourg a higher rate of 40 % of ammonia has been assumed for the whole time period.
- For Denmark, Finland, Portugal, Spain and Sweden a rate of 50 % of ammonia has been assumed for the whole time period, in Denmark increasing since 2001 to 100 %.

For **beer** three static models had to be generated:

- The base model for most countries presumes a rate of 30 % of ammonia for new cooling installations in the year 1985, steadily increasing to 40 % in the year 2005.
- For Austria, Denmark, Finland, Italy, Luxembourg, Portugal, Spain and Sweden a rate of 70 % of NH_3 is assumed for 1985, increasing from 1995 to 90 % in 2000. In Denmark the rate of ammonia in new installations is increasing since 2001 to 100 %.
- The same NH_3 rate is assumed for Germany, but R-22 is prohibited one year earlier.

For **ice rinks and other industries** three static models had to be generated:

- The base model for most countries presumes a constant rate of 15 % of ammonia for new cooling installations for the whole time period.
- For Austria, Germany, Italy and Luxembourg a higher rate of 30 % of ammonia has been assumed for the whole time period.
- For Denmark, Finland, Portugal, Spain and Sweden a rate of 40 % of ammonia has been assumed for the whole time period, in Denmark increasing since 2001 to 100 %.

7. The static models are used to calculate the shares of refrigerants for each sector and country group from the year 1985 on. Since the model focuses on F-gases only until now, the only refrigerant for which emissions have been calculated is R-404A. .Emissions estimation follows the equations below.

$$EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}$$
$$EM_{Disposal,n} = Disposal_n * EF_{Disposal,n}$$
$$Bank_n = Installed\_Cooling\_Capacities_n * Charge * Percentage\_of\_gas_n$$
$$Installed\_Cooling\_Capacities_n = Production\_data_n * Specific\_cooling\_consumption$$
$$Disposal_n = \frac{Bank_{n-Lifetime}}{Lifetime}$$

Emission parameters

Lifetime = 20 years for milk farm cooling, ice rinks and other industry
Lifetime = 30 years for all other sectors
$EF_{Lifetime,n}$ = 8 % for milk farms, production of chocolate, fruit juice, and wine.
= 9% for Cold storage, frozen food, industry of meat, beer, dairy industry, ice rinks.
= 12% for other (non-food) industry.
$EF_{Disposal,n}$ = 30 %

WM scenario

With a few exemptions, equipment in industrial refrigeration is higher charged than 3 kg; in most sectors (cold store, chemical industry, breweries) charges over 100 kg are typical. As a consequence, industrial refrigeration is addressed by all measures of the F-gas Regulation.

As a result of successful application of the F-gas Regulation, the leakage rates, i.e. the lifetime emission factor will be reduced to 60 % of the current levels from 2015 onwards (decreasing gradually in 2010-2015). Only the emissions factors for milk cooling on farms is not expected to decrease because the typical charges are below 3kg and thus below the threshold value for application of the leak checks foreseen in Art 3(2) of the F-gas Regulation.

Recovery efficiency at end-of-life is assumed to rise generally. The default emission factor for disposal will be reduced from 30 % in 2010 to 20 % in the year 2015. Between these years emission factors are interpolated, afterwards they are kept constant.

III.3 Commercial Refrigeration

For detailed modelling of the commercial refrigeration sector the information provided by CRF tables or NIRs is too general. Therefore, the model approach does not rely on national reporting even though it can draw upon information from selected NIRs in some cases.

Usually, commercial refrigeration is divided in two sectors.

(1) Supermarket refrigeration for which large on-site erected centralised systems are typical.

(2) Small commercial applications for which prefabricated condensing units are typical, together with hermetically operating stand-alone-systems and vending equipment.

The model approach to supermarket refrigeration differs from that of small commercial refrigeration.

In the small commercial sector the number of operators ("shops") in a sub sector is estimated, and the typical refrigerant charge of their equipment (condensing units, hermetics) is estimated by expert judgement or from literature. The total refrigerant bank is the product of number of units with the average charge of the operated equipment. It must be noted that in the model discount markets and small food retail stores (<400 m^2) are included in small commercial applications. This is because the refrigeration equipment is not completely of the centralized type but mainly consists of condensing units, even though the refrigerant charges in discount markets are high, averaging 130 kg (France) and 80 kg (Germany), respectively.

In the supermarket sector (excluding discount markets), which covers ca. two thirds of the sector refrigerants, starting point of the bank estimate is not the number of shops but the food sales area in a country. From a typical, average sized supermarket and its refrigerant quantity for low and medium cooling stage, the ratio of refrigerant (kg) per sales area (m^2) is derived, and serves as key factor for the assessment of the refrigerant bank in the whole sector. For France, Clodic et al. use the ratio 0.262 kg/m^2 for large supermarkets (hypermarchés), and 0.287 kg/m^2 for normal-sized supermarkets. For Germany, the data from a recent supermarket study for EPEE[17] are used, resulting in a similar ratio of 0.230 kg/m^2 for all supermarkets >400 m^2. (See table COM).

Based on these ratios, the refrigerant bank in the French and the German supermarket sector can be estimated. With growth or decline in sales area, the installed refrigerant quantity grows or declines at the same pace. Forecast or recalculations of the bank can be made by means of historical or projected food sales area data.

In commercial refrigeration natural fluids like NH_3 or CO_2 so far play a marginal role. In this context, in the model only ODS or HFC refrigerants are considered, with R-404A being the only HFC refrigerant in Europe outside Germany, Austria, Czech Republic and Slovenia. In these countries, R-404A is also used for low temperatures, but in a considerable number of cases (20%) R-134a is the refrigerant for medium temperatures.

---

[17] SKM Enviros, Eco-Efficiency Study of Supermarket Refrigeration, for the European Partnership for Energy and Environment (EPEE), March 2010. In this study a typical ("conventional") European supermarket is described: 1,000 m^2 sales floor area, medium temperature: 75 kW (160 kg), low temperature: 20 kW (70 kg); refrigerant 404A ("The vast majority of existing European supermarket systems use R404A refrigerant", p 34); leakage rate 15%.

Estimates of the refrigerant composition of new supermarket equipment from 1960 onwards have been presented by Clodic et al. [INV 07]. Based on these data, by means of a static simulation model which runs the same number of new systems per year over the whole equipment lifetime, from the refrigerant composition of new equipment the refrigerant composition of the bank can be calculated. R-22 was allowed in new systems until 2001 (in Germany, Finland, Denmark, Austria until 2000, in The Netherlands until 1999). Given 12 years average lifetime of supermarket equipment, in 2008 or even 2010 still considerable amounts of R-22 should be banked. R-404A, which has been filled into new systems from 1995 onwards (until 2000 R-22 was also used), is dominating the supermarket sector.

The refrigerant composition of the bank in small commercial refrigeration is determined by the refrigerant in condensing units. This applies also to discount markets in France, while refrigeration of discount markets in Germany mostly relies on centralised systems for medium temperature and on plug-in hermetics for low temperature. In the model, R-22 is assumed to be the only refrigerant before 2001 (2000 in Germany), which has been replaced by R-404A in new condensing systems. Hermetic units and vending machines had been filled with R-12 before 1995. From then, R-134a is the only refrigerant.

Table COM Parameters for Commercial refrigeration in the reference countries France and Germany

	Specific amount of Refrigerants			1995	2008	2020	2030	2040	2050
	Central systems	Conden-sing units	Hermetics						
	kg / m^2	kg/shop		million m^2					
Germany - Model									
SB Warenhaus (> 5000 m2)	0,230			4,9	6,0	7,1	7,9	8,8	9,6
SB Warenhaus (2500-5000 m2)	0,230			2,4	3,1	3,7	4,2	4,8	5,3
Kleiner Supermarkt (400-2500 m2)	0,230			8,3	8,3	8,4	8,4	8,4	8,5
				Number of shops					
Discounter (kg / shop)	*80kg/shop*		5,0	10.630	15.490	19.945	23.658	27.371	31.084
kl. Lebensmittel EZH Geschäfte (<400 m2)		4	1,0	54.010	23.048	17.000	12.000	7.400	4.400
Kleinhandel									
Getränkeabholmärkte		3	0,5	8.900	12.600	15.960	18.760	21.560	24.360
Kiosks			0,5	52.000	39.000	27.000	18.600	16.600	14.600
Bahhof-Outlets			0,5	1.600	2.800	2.800	2.800	2.800	2.800
Facheinzelhandel mit Nahrungsmitteln		3	0,5	30.000	30.000	30.000	30.000	30.000	30.000
Tankstellenshops		2	0,5	1.000	11.000	11.000	11.000	11.000	11.000
Handwerk									
Fleischer incl. Filialen		12	1,0						
Bäckereihandwerk		11	1,0	33.982	27.137	20.819	15.554	10.289	5.024
Bäckereifilialen		5	1,0	21.932	15.337	9.811	7.600	5.800	4.800
Hotel/Restaurants		3	1,0	27.214	30.000	32.571	34.714	36.857	39.000
Getränkeautomaten			0,2	23.000	235.000	235.000	235.000	235.000	235.000
France - Model				million m^2					
Hypermarché	0,262			5,8	8,3	10,4	12,2	14,0	15,8
Supermarchés	0,287			6,5	7,0	7,0	7,0	7,0	7,0
				Number of shops					
Maxidiscomptes		130		1.470	4.349	6.869	8.969	11.069	13.169
Supérettes		130		2.161	2.633	2.633	2.633	2.633	2.633
Alimentation générale		4	1,0	19.841	17.116	14.602	12.506	10.411	8.315
Commerce de detail									
CD produits surgelés		16	18,0	280	112	78	68	58	48
CD poissons		8		3.046	2.222	2.145	2.082	2.019	1.955
CD boissons		3	1,0	3.068	4.958	5.133	5.278	5.424	5.569
CD produit laitiers		10	2,0	1.659	970	906	853	800	747
Stations service		2	0,5	800	9.000	9.000	9.000	9.000	9.000
Artisanat commercial									
Charcuterie		12		11.242	5.615	5.120	4.708	4.295	3.883
CD viandes et produit à base de viande		8		20.691	15.191	14.683	14.260	13.837	13.414
Boulangerie, pâtisserie		11	1,0	43.321	44.586	44.733	44.855	44.978	45.100
Hôtels et restaurants		3	1,0	182.342	164.764	163.141	161.789	160.437	159.085
Distributeur automatique			0,2	15.000	185.000	185.000	185.000	185.000	185.000

Extrapolation to other Member States

Basic assumption is that the food sales area per inhabitant is similar amongst all European countries. Given size and composition of refrigerant banks in the whole sector of commercial refrigeration in France and Germany, the banks in the other countries are calculated as percentage shares of their population compared to the population of France or Germany. Germany is the projection basis for Austria, Czech Republic and Slovenia, who show refrigerant split similar to that in Germany. In all other countries centralized systems rely much more on R-404A, thus the refrigerant banks are estimated with the French bank as the basis.[18]

Emissions equations for commercial refrigeration

$$EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}$$

$$EM_{Disposal,n} = Disposal_n * EF_{Disposal,n}$$

$$Bank_{Country,n} = German\_or\_French\_Bank_n * \frac{Population_{Country,n}}{Population_{Germany/France,n}}$$

$$Disposal_n = \frac{Bank_{n-Lifetime}}{Lifetime}$$

First years of disposal have been calculated as the difference of banks of the years n-lifetime and n-lifetime-1.

Emission parameters (WOM)

Lifetime:	Centralized systems = 12 years
	Condensing units = 15 years
	Hermetics incl. vending machines = 15 years
$EF_{Lifetime}$:	Centralized systems = 15% (as of 2010). [2005: 20%, 2006; 19%, 2007; 18%, 2008: 17%, 2009: 16%].
	Condensing units = 10%
	Hermetics incl. vending machines = 1%
$EF_{Disposal}$:	Centralized systems = 30%
	Condensing units = 50%
	Hermetics incl. vending machines = 70%

Projection 2050

For the projection until 2050 it is assumed that food sales areas, and thus refrigerant bank and emissions, show strong growth in large supermarkets (hypermarchés, supermarkets > 2500 m^2) and discount markets (maxidiscomptes). Until 2050 doubling is forecasted there, extrapolating the high historical growth rates of these market formats in Europe. Unlike large supermarkets, small supermarkets will be unaltered in selling area, and small food retail stores will significantly decrease in number. In the remaining sub sector of small commercial refrigeration, the number of shops of bakers and butchers is forecast to decline while the

[18] It is conceded national food sales areas would be a more appropriate extrapolation parameter than population. Statistical data on supermarket sales areas are available only from very few countries.

number of hotels and restaurants is likely to be constant in the future. Likewise, the number of vending machines should be unchanged.

WM Scenario

Refrigeration equipment in supermarkets incl. discount markets over 400 m^2 is generally charged with more than 50 kg, and thus subject to the key measures of Art 3 and 4 of the F-gas Regulation. The majority of equipment in the small commercial refrigeration sector is at least charged over 3 kg, and thus also subject to containment and recovery measures acc to F-gas Regulation. Some sectors like the catering industry or convenience shops run equipment below 3 kg or hermetic systems, which are not subject to the key containment measures (e.g. leak checks, records, leakage detection systems) according to the F-gas Regulation. In the scenario it is assumed that the lifetime emission factors of centralised equipment and condensing units decrease during 2010-2015 from 15% to 9% and from 10% to 6%, respectively. Emission factors of hermetic systems and vending machines are considered to remain unchanged. Recovery efficiency is assumed to generally increase, resulting in a decrease of the disposal emission factor 2010-2015 from 30% to 20% for centralised equipments, from 50 % to 25 % for condensing units and from 70 % to 35 % for hermetics.

References

[INV 07] Inventaires 2007, Inventaires des émissions des fluides frigorigènes et de leurs émissions, France, année 2007 et leurs prévisions d'évolution jusqu'en 2022 - Rapport final - Février 2010. Document 2 Données de base, Cenerg (Stéphanie Barrault, Sabine Saba, Denis Clodic), Février 2010.

IRI (Information Resources GmbH), Grundgesamtheiten Deutschland 2009, Nürnberg 2009.

IRI (Information Resources GmbH). Situación y Evolución de los Mercados, Nürnberg 2008.

Ministère de l'Économie, de l'industrie et de l'emploi – DGCIS, Chiffres clés du commerce - 10/2009 http://www.pme.gouv.fr/economie/chiffresclefs/chiff_commerce.php

Ministère des Petites et Moyennes Entreprises, du Commerce, de l'Artisanat et des Professions libérales, 22/05/2001, Chapitre 1 : Les principales caractéristiques du commerce. http://www.pme.gouv.fr/economie/onc/chap1.htm#haut

Bord Bia, Irish Food Board, Overview of the Belgium Retail & Food Service market, November 2008.

Lebensministerium Austria, Lebensmittelbericht 2008, Wien 2008 http://www.lebensmittelnet.at/filemanager/download/27446/

KPMG - EHI Retail Institute, CONSUMER MARKETS & RETAIL Status quo und Perspektiven im deutschen Lebensmitteleinzelhandel 2006.

Wabe Institut Berlin/Ver.di, Fachbereich Handel, Bereich Branchenpolitik, Teilbranchenanalyse Lebensmitteleinzelhandel, Branchenüberblick und Konzerndaten, Januar 2010.

Department for Environment, Food and Rural Affairs, Implementation of Fluorinated Greenhouse Gases and Ozone-Depleting Substances Regulations. Initial Market Intelligence Work and Risk-Based Implementation Model, London November 2007.

VDMA, Allgemeine Lufttechnik (Guntram Preuß): Branchenbericht Deutscher Markt für Kältetechnik 2009. Bestand an Kältesystemen in Deutschland nach Einsatzgebieten. Marktvolumen für kältetechnische Anwendungen, Frankfurt am Main, 15.12.2009.

European Vending Association (Rozenn Maréchal), Brussels, Letter to Öko-Recherche, 10 Septemer, 2010.

Consultancy Rob Jans, Onderzoek naar de koudemiddellekkage van HFK's in 2009 bij Nederlandse supermarkten. Agentschap NL. Ministerie van Economische Zaken. Status 06-01-2011.

III.4 Refrigerated Road Vehicles

In the model three categories of vehicles are distinguished: vans, trucks and trailers. While trucks >3.5 t and trailers cool their load by a motorized aggregate mounted to the vehicle box, the compressor of vans (<3.5 t) is driven by the vehicle engine, similar to air conditioning systems. Often the aggregate is fitted to the van roof top. Refrigerant types and charges, and emission factors of vans differ from those of trucks and trailers. In the model, trucks and trailers do not differ from each other, and are considered together.

Emissions equations for refrigerated road vehicles

$$EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}$$
$$EM_{Disposal,n} = Disposal_n * EF_{Disposal,n}$$
$$Bank_n = Stock\_of\_vehicles_n * Charge * Percentage\_of\_gases_{Stock,n}$$
$$Disposal_n = \frac{Bank(n - Lifetime)}{Lifetime}$$

Standard refrigerant of vans had been R-12, which was replaced in new systems by HFC-134a after 1995. Common refrigerant of trucks and trailers was R-22; new systems run with R-404A, from 2001 onwards, at the latest. R-410A plays a minor role in refrigerated road vehicles and is not reflected in the model.

Transfrigoroute, which is a federation that promotes the development of the transport of temperature-controlled foodstuffs and goods made data available on the 2008 stock of refrigerated vans, trucks and trailers in Europe, covering the 12 largest national parks, representing 85% of the total EU-27 vehicles fleet. The stock data for the missing countries are taken from NIRs (Estonia, Portugal, Austria), from a study for the European Commission by RPA (Belgium, Cyprus, Greece, Hungary, Ireland, Latvia, Lithuania, Luxembourg, Malta, Slovenia), and from own estimates (Bulgaria, Romania). In 2008, the total EU fleet includes 400,000 vans, 200,000 trailers, and 220,000 trucks.

Starting from stock data bypasses the difficulties associated with annual sales as starting point. The latter approach can hardly account for the fact that the actual fleet size in high-industrialised MS is systematically lower than the accumulated total of annual registrations because of the used-vehicles shift to MS under economic transition in Eastern Europe where the reverse problem arises.

The refrigerant shares in the vehicle stock are calculated with a static simulation model which runs the same number of new systems per year over the equipment lifetime. From the refrigerant composition of new registrations (for which data are available in Öko-Recherche archives) the refrigerant composition of the stock is derived. See table REV.

Table REV Refrigerant split of stock of refrigerated vans, trucks& trailers

	1995	1997	1999	2001	2003	2005	2006	2007	2008
R-12 Vans	88%	63%	38%	13%	0%	0%	0%	0%	0%
R-134a Vans	13%	38%	63%	88%	100%	100%	100%	100%	100%
R-22 Trucks	100%	100%	91%	69%	44%	19%	9%	3%	0%
R-404A Trucks	0%	0%	9%	31%	56%	81%	91%	98%	100%

From 2008 onwards, the refrigerant split remains unaltered until 2050.

Emission parameters (WOM)

Lifetime: 10 years

Charges: Vans = 1.5 kg
Trucks and trailers = 6.5 kg

$EF_{Lifetime}$: Vans = 30 %
Trucks and trailers = 20 %

$EF_{Disposal}$: 30 %

The stock data on vans, trailers, and trucks for the missing years 1995-2007 rely on the stock growth rates for Germany for which the data are available in the Centralized Systems Emissions (ZSE) of the German EPA (Umweltbundesamt). The German 1995-2007 growth rates range ~ 3%/y, and are applied to all other MS irrespective of national situations.

The forecast of the vehicles stock for 2009-2050 is based on the assumption of average growth rates of ~ 3.3% per year, for each MS and for each vehicle category. As a result, the total EU-27 fleet increases from 820,000 vehicles (2008) to 1.6 million units (2050).

While the use-phase emissions per year and by individual MS are estimated by application of the emission factor to the banked HFCs in the vehicle stock, the estimation of the disposal emissions of HFCs, which arise from 2005 onwards (lifetime 10 years) requires knowledge of the retired units per year. For year n, these are identical with the number of units sold in year n - lifetime. In the model number and refrigerant split of the units for disposal are calculated in the first years of disposal as the difference of banks of the years (n - lifetime) and (n-lifetime - 1), afterwards by division of the stock in year (n – lifetime) by 10 (= lifetime years).

WM scenario

The WM scenario follows the WOM scenario because mobile refrigeration systems are not subject to Art 3 or Art 4(1) of the F-Gas Regulation. The model considers that the general provision of Art 4(3) for recovery by “appropriately qualified personnel” does not impact quantitatively the disposal emission factor.

References

Transfrigoroute (Joe Grealy), Communication to Öko-Recherche, 17 May, 2010.

RPA, Analysis of the costs and the impact on emissions of regulatory measures for reducing emissions of hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride in foams and mobile refrigeration in the road transport sector, prepared for the European Commission, DG Environment, final report, December 2005.

III.5 Refrigeration in fishing vessels

The vast majority, namely 91%, of the 89,000 fishing vessels in the EU (2007) are small boats of length below 18 metres (EUSTA 09). These vessels are used for coastal fishing. If there is ice aboard, it is produced ashore, often by means of ammonia systems. This land-based refrigeration equipment is not considered her because it belongs to industrial refrigeration. The model includes ca. 7,400 vessels over 18 metres length, equipped with refrigeration or with refrigeration plus freezing system, which are distinguished into five types. These differ by typical refrigerant charges from <17 kg to > 8,000 kg. Ship systems built before 2000 run R-22, which has to be replaced by 2015 at the latest when recycled R-22 is not longer allowed for refilling; new systems from 2000 onwards run HFCs (R-404A).

The following types of vessels and their typical charges have been considered in the model.

1. Factory-ship new >70 m: 1,500 kg charge (indirect systems).
2. Factory-ship from before 2000 >70 m: 8,000 kg charge (direct systems).
3. Freezer trawler >42 m: 900 kg charge.
4. Freezer trawler 36-42 m: 210 kg charge.
5. Medium sized vessels >18 m: 17 kg charge.

Emission calculation follows the equation in the box below.

$$EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}$$
$$EM_{Disposal,n} = Disposal_n * EF_{Disposal,n}$$
$$Bank_n = Stock\_of\_ships_n * Charge$$
$$Disposal_n = Disposed\_ships_n * Charge$$

For each ship type, and for each MS assumptions are made about the vessels built between 2001 and 2006, built from 2007 to 2014, and the number of older ships from before 2001, whose refrigeration/freezing system has to be converted from R-22 to HFCs (R-404A) by end of 2014 at the latest.

Ships built before 2001 and operated in 2015 are assumed to fulfil the law and will be converted from R-22 (to R404A) in the time period 2011-2014, irrespective of their life expectancy. Given average lifetime of 30 years, in 2015 no ship built after 1985 will run ODS refrigerant any longer. All vessels below 70 m length will use HFC refrigerants then.

Ships over 70 m length (factory ships) show the important feature that from 2001 onwards new-builts are not equipped with HFCs but with natural refrigerants (ammonia, CO_2). Until 2015, only old factory ships with R-22 will be converted to HFC refrigerants. Reaching end of life, they will be replaced by vessels with natural refrigerants, too.

Table FISH shows the numbers of ships concerned.

Table FISH Assumptions for ship refrigeration - ships with HFC-based refrigeration

	Factory ship					Trawler 42-70m			Trawler 36-42m			Medium Vessel 18-36m		
	Natural Refr.2001-2006	Conversion 2011-14 to nat. ref.	New 2003+ 2004 HFC	New Natural 2007-14	Conversion 2011-14 to HFC	New 2001-06	New 2007-14	Conversion 2011-14	New 2001-06	New 2007-14	Conversion 2011-14	New 2001-06	New 2007-14	Conversion 2011-14
Austria														
Belgium										13	14	10	15	39
Bulgaria											1	5	10	26
Cyprus												3	6	11
Czech Republic														
Denmark	1			1		4	8	11	4	9	11	27	50	100
Estonia					1		3	4		1		5	10	25
Finland							1			2	3	5	9	15
France	3	3		4		6	12	24		7	8	92	160	363
Germany	1				4		4	5		6	8	23	40	77
Greece							3	4		1		75	130	295
Hungary														
Ireland		1		1		7	10	3	6	7		27	48	95
Italy					2		11	15		7	11	200	400	846
Latvia					3		4	4				14	30	53
Lithuania					10		2	1		1	2	4	8	18
Luxembourg														
Malta							1			1		5	12	22
Netherlands	3	9		4	1	11	16	17	12	35	53	50	108	157
Poland					12		1	2				14	30	67
Portugal						2	5	6	2	3	5	50	90	227
Romania												1	4	4
Slovakia														
Slovenia												1	1	1
Spain	6	5	2	7	5	17	34	64	25	40	51	260	500	977
Sweden							4	5	1	7	11	20	30	64
United Kingdom	6	5	1	6		8	11	16	6	12	23	72	120	289
Total	**20**	**23**	**3**	**23**	**38**	**55**	**130**	**181**	**56**	**152**	**201**	**963**	**1811**	**3771**

No growth in total fleet is assumed. Over the entire time period from 2007 to 2050 new ships do not increase the overall number but replace old ships. Decommissioning of ships originally equipped with HFC refrigeration/freezing system takes place from 2030, decommissioning of R-22 converted ships begins 2015.

Emission parameters (WOM)

Lifetime : 30 years

$EF_{Lifetime}$: 40 %

$EF_{Disposal}$: 30 %

WM scenario

The WM scenario follows the WOM scenario because mobile refrigeration systems are not subject to Art 3 or Art 4(1) of the F-Gas Regulation. The model considers that the general provision of Art 4(3) for recovery by “appropriately qualified personnel” does not impact quantitatively the disposal emission factor.

References

EUSTA 09 = Eurostat, Statistics in focus 2009, Agriculture and fisheries, The EU-27 fishing fleet continued to decline in 2008, Author Franco Zampogna.

Schwarz, W., The analysis of the emissions of fluorinated greenhouse gases from refrigeration and air conditioning equipment used in the transport sector other than road transport and options for reducing these emissions (07010401/2006/445124/MAR/C4).

For the European Commission (DG Environment), Brussels 2007.

Schwarz, W., Measures to reduce the climate impact of refrigerant emissions, in: CE Delft, DLR, Fearnley Consultants, Per Kageson, David Lee, MARINTEK, Norton Rose, Öko-Institut, Öko-Recherche, with assistance from DNV on some issues: Technical support for European action to reducing Greenhouse Gas Emissions from international maritime transport (DG ENV.C3/ATA/2008/0016). For the European Commission (DG Environment), Delft, October 2009.

III.6 Room Air Conditioners

Emissions calculation is based on stock assumptions for split and factory-sealed moveable air conditioning devices which are taken from a recent study for the European Commission[19] (Ecodesign study) for all 27 Member States, for the years 2005, 2010, 2015, 2020, 2025 and 2030. The five-year stock data involve all systems with cooling capacity <12 kW, thus also including most part of small multisplit devices. We follow that study in the assumption that saturation will be reached in all MS by 2030. Room air conditioners include systems of the reversible type to be used also for heating (air-to-air heat pumps). These systems are not considered in the model sector on heat pumps.

Between the years given from the Ecodesign study, linear interpolation is applied, for the years 2000 to 2004 the average growth rate from between 2005 and 2010 is assumed.

Emissions equations for room air conditioners

$$EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}$$
$$EM_{Disposal,n} = Disposal_n * EF_{Disposal,n}$$
$$Bank_n = Stock_n * Charge * Percentage\_of\_gases_{Stock,n}$$
$$Disposal_n = \frac{Stock_{n-Lifetime}}{Lifetime} * Charge$$

Emission parameters (WOM)

Charges:
Moveable systems = 0.75 kg
Split systems = 1.5 kg

Lifetime	10 years	
Moveable	$EF_{Lifetime}$	3%
Split	$EF_{Lifetime}$	5%
$EF_{Disposal}$:	70%	

Since 2000, the former standard refrigerant R-22 has been replaced continuously in the stock of room air conditioners by R-407C and, increasingly, R-410A. From the year 2018, only R-410A will be in use in room air conditioners. According to Daikin, the following percentages of refrigerants are assumed to constitute the HFC bank in equipment stock[20].

[19] ECODESIGN Lot 10 Draft of Chapter 2, Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation) Contract TREN/D1/40-2005/LOT10/S07.56606, Draft report of Task 2, July 2008, Economic and Market analysis. Co-ordinator: Philippe Riviere, Armines, France.

[20] In a meeting with Öko-Recherche, Daikin gave their own estimates for new units, retired units, and installed units for total Europe, by the three refrigerants, for each year from 1995 to 2030.

Table RAC Percentage of refrigerants in stock of room air conditioners 2000-2020

	2000	2005	2010	2015	2020
R22	97%	56%	27%	0%	0%
407C	2%	16%	13%	8%	0%
410A	1%	28%	60%	91%	100%

The use-phase emissions per year and by individual MS are estimated by application of the emission factors to the banked refrigerants in the installed equipment stock.

The estimation of the HFC disposal emissions, which arise from 2010 onwards (lifetime 10 years) requires knowledge of the retired units per year. In the model number and refrigerant split of the units for disposal are calculated by division of the stock in year (n – lifetime) by the lifetime years.

Saturation of the equipment stock is assumed from 2030 onwards. Until then, stock and emissions are rising at high growth rates.

WM scenario

Charges of room air conditioners are lower than 3 kg hence the more substantial measures of Art 3 of the F-gas Regulation do not apply to this sector. Art 4(1) on recovery, which applies to all stationary F-gas containing equipment irrespective of their charge, stipulates “proper recovery by certified personnel” to ensure recycling, reclamation or destruction. In the model, Art 4 is not considered to affect the use phase emissions but the end-of-life emissions. Disposal emissions are assumed to be reduced compared with the WOM scenario. The disposal emission factor decreases from 70% to 35%, 2010-2015.

References

BSRIA report. Worldwide Air Conditioning. Europe. Report 50570/A, Bracknell (UK) April 2009. This report presents annual sales data for 2007 and 2008 with forecast for 2009-2012 for all types of stationary air conditioning for the nine most important EU markets: Austria, Czech Republic, France, Germany, Greece, Italy, Poland, Spain, United Kingdom.

BSRIA. World Air Conditioning Overview 2008, edition March 2009, for 2007 and 2008 including forecast until 2012” by 14 EU countries.

Daikin meeting. Meeting of Öko-Recherche (W. Schwarz, B. Gschrey) and Daniel Colbourne (Re-phridge) with Daikin Europe NV, Oostende (Hilde Dhont, Environment Readiness Section; Martin Dieryckk, Assistant Director Environment Readiness Center), Oostende 19 May, 2010.

III.7 Multi split (VRF) and Rooftop Air Conditioners

Multisplit (VRF) systems

Multisplit systems, in particular those of the VRF (Variable Refrigerant Flow) type, which came in relevant quantities onto the EU market in 2003, show significantly higher refrigerant charges than single split and moveable devices, exceeding the threshold value of 3 kg for application of leak checks and record maintenance provided in Art 3 of the F-gas Regulation. Therefore they are considered separately from split and multisplit systems < 12 kW, the more so as in the model the bank and emissions calculation of multisplit devices differs from other stationary air conditioning systems. The emissions calculation is not based on direct stock estimates but on data on the annual sales of units sold to the Member States. Banks are considered accumulated annual sales minus retired units (= annual sales in year n – lifetime).

For the year 2009, break-down of equipment sales to all 27 countries is available, estimated by Daikin for EU-27. In the model, this break-down is kept constant over the entire time-period from 2003 to 2050.

The company's estimate includes also historical and projected sales figures into the EU as a whole, from 2003 to 2050. In the model, this sales trend is applied to all 27 MS. Based on this trend data and the 2009 breakdown by countries, the number of annually sold systems have been calculated for each Member State. In the model, the only refrigerant is R-410A.

Saturation of the market is projected for the year 2026, with a constant number of 140,000 units sold to the entire EU, until 2050.

Emissions equations for air conditioners of VRF type

$$EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}$$
$$EM_{Disposal,n} = Disposal_n * EF_{Disposal,n}$$
$$Bank_n = Bank_{n-1} + Sales\_of\_VRF_n * Charge - Disposal_n$$
$$Disposal_n = Sales\_of\_VRF_{n-Lifetime} * Charge$$

Emission parameters (WOM)

Charge :	13.5 kg (acc to Daikin)
Lifetime:	10 years
$EF_{Lifetime}$:	8 %
$EF_{Disposal}$:	30 %

WM-Scenario

Multisplit (VRF) systems contain more than 3 kg refrigerant, and thus are subject to all containment and recovery measures according to Art 3 and 4 of the F-gas Regulation. It is assumed that as a result of the application of the law, both the lifetime emission factor and the disposal emission factor will decrease significantly from 2010 to 2015. The use phase emission factor will decrease by 40%, from 8% to 5.6%. In the same time span the disposal emission factor will be reduced from 30% to 20%.

Packaged systems (rooftop)

Packaged air conditioning systems means units with combined compressor, condenser, and evaporator, mounted outdoor, mostly on rooftops. The spread of packaged systems over Europe widely differs by countries. There are only few markets of relevance, with Spain accounting for 60% of the total market, followed by UK, Italy and France.

Not in design, but in refrigerant charge rooftop systems are similar to multisplit (VRF) systems and thus considered separately from single split devices. Like emission calculation for multisplit, emissions calculation of packaged systems is based on annual sales figures. Two HFC refrigerants come into question for new systems: Starting in 2001, R-407C was used exclusively, but was replaced soon by R-410A, which is the only refrigerant in new systems as of 2006.

Emissions equations for packaged air conditioning systems

$$EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}$$
$$EM_{Disposal,n} = Disposal_n * EF_{Disposal,n}$$
$$Bank_n = Bank_{n-1} + Sales\_of\_packaged\_systems_n * Charge - Disposal_n$$
$$Disposal_n = Sales\_of\_packaged\_systems_{n-Lifetime} * Charge$$

Emission parameters (WOM)

Charge:	10.5 kg (acc to Daikin)
Lifetime:	10 years (acc to Daikin)
$EF_{Lifetime}$:	5 %
$EF_{Disposal}$:	30 %

From two BSRIA reports (see references) sales figures for the 13 Member States with some market relevance are available for 2007-2008 with projections until 2012. For the years before and after, sales figures estimated by Daikin for Europe as a whole are applied. Each individual Member State market is assumed to follow this overall growth trend.

Saturation of the markets is assumed for the year 2016, with a constant number of 80,000 sold systems per year in the EU-27, until 2050.

WM-Scenario

Like mulitsplit systems, packaged systems contain more than 3 kg refrigerant, and thus are subject to all containment and recovery measures according to Art 3 and 4 of the F-gas Regulation. It is assumed that as a result of the application of the law, both the lifetime and the disposal emission factor will decrease significantly during 2010 and 2015. The use phase emission factor will decrease by 40%, from 5% to 3%. In the same time span the disposal emission factor will be reduced from 30% to 20%. These emission factors are the same as those for multisplit systems.

References

BSRIA report. Worldwide Air Conditioning. Europe. Report 50570/A, Bracknell (UK) April 2009. This report presents annual sales data for 2007 and 2008 with forecast for 2009-2012 for all types of stationary air conditioning for the nine most important EU markets: Austria, Czech Republic, France, Germany, Greece, Italy, Poland, Spain, United Kingdom.

BSRIA. World Air Conditioning Overview 2008, edition March 2009, for 2007 and 2008 including forecast until 2012" by 14 EU countries.

Daikin meeting. Meeting of Öko-Recherche (W. Schwarz, B. Gschrey) and Daniel Colbourne (Re-phridge) with Daikin Europe NV, Oostende (Hilde Dhont, Environment Readiness Section; Martin Dieryckk, Assistant Director Environment Readiness Center), 19 May, 2010.

III.8 Chillers (displacement and centrifugal)

For air-conditioning of whole buildings (department stores, factories, hotels) or large halls (cinemas, sports complexes, computer centres) mostly centrally positioned systems are used which work indirectly. The refrigeration circuit cools a liquid (mostly water) down to +5 or +6°C, which is pipelined through the building as a coolant. Such systems are called chillers.

Chillers are not only used for air conditioning but also for cooling of liquids for industrial processes. To avoid double counting, in the model industrial chillers are not considered under industrial refrigeration but together with the technically identical air conditioning systems under stationary air conditioning.

Most chillers are used for cooling capacities higher than those which are provided by directly evaporating systems. The refrigeration capacities range from 15 kW to over 3,000 kW.

Chillers can be divided according to their compressors in reciprocating/scroll chillers, screw chillers, and centrifugal chillers. They show large differences in refrigerant charges and in lifetime. They also differ by the HFC refrigerant R-407C, R-410A, or R-134a. Standard refrigerant for piston, scroll, and screw chillers before 2000 was R-22. Centrifugal chillers had used R-11 or R-12 before 1995, when fully halogenated ODS were replaced by HFC-134a[21]. In addition to the common chillers, in a few countries (France, Italy) so-called mini-chillers are used.

Details for the different types of chillers are shown in table CHI.

Table CHI Model assumptions for Chillers

	F-Gas	Lifetime [years]	Charge [kg]
Minichillers < 15 kW	410 A	12	2
Chillers < 100 kW	407 C and 410 A	15	10
Chillers > 100 kW	407 C and 134a	15	95
Centrifugals	134a	25	630

Identical emission factors are used for all types of chillers.

Emission parameters (WOM)

$EF_{Lifetime}$: 4 %
$EF_{Disposal}$: 30 %

In the model, the refrigerant composition of chillers (annual sales) is fairly constant. For chillers >100 kW a constant ratio of 33% of R-134a to 67% of R-407C is applied over the entire time period from 2001 to 2050. Centrifugal chillers run with HFC-134a from 1995 to 2050. Mini chillers use R-410A. Only chillers <100 kW show changing refrigerant composition. From 2001 to 2011 the initially dominating R-407C (80% in 2001) is completely replaced by R-410A.

[21] In centrifugal chillers only "one-molecular" refrigerants can be used, no blends. Apart from HFC-134a, as replacement for R-11 or R12 the HCFC-refrigerant R-123 was also used, however in much smaller extent than in USA. R-123 is not considered in the model.

Like the emission calculation of multisplit and rooftop air conditioning systems, the emission modelling for chillers is not directly based on stock data but on data on annual sales to the individual Member States. Stocks are considered accumulated annual sales minus retired units (= annual sales in year n – lifetime), banks are calculated per multiplication with charges.

From two BSRIA reports (see references) sales figures are available for the 13 Member States with market relevance, for 2007-2008, with projections until 2012. The remaining 14 national markets are considered of negligible size. For the years before and after 2008-2012, for the 13 relevant countries assumptions on the annual sales have been made based on estimates from industry experts.

Generally, after a growth of almost 4% per year from 2001 to 2007, the chillers market is considered to be rather stable in the period from 2010 to 2050, with ca. 86,500 units sold per year. From 2015 onwards, new systems are installed only to replace retired old ones[22].

WM-Scenario

The vast majority of chillers contain more than 3 kg refrigerants, most chillers are charged with more than 30 kg, and large screw compressor chillers and all centrifugal chillers contain over 300 kg refrigerant. As a consequence, they are subject to all containment and recovery measures acc to Art 3 and 4 of the F-gas Regulation including, where the charge exceeds 300 kg, installation of leakage detection systems. It is assumed that as a result of the application of the law, both the lifetime emission factor and the disposal emission factor will decrease significantly between 2010 and 2015. The use phase emission factor will decrease by 40%, from 4% to 2.4%. In the same time the disposal emission factor will be reduced from 30% to 20%.

References

BSRIA report. Worldwide Air Conditioning. Europe. Report 50570/A, Bracknell (UK) April 2009. This report presents annual sales data for 2007 and 2008 with forecast for 2009-2012 for all types of stationary air conditioning for the nine most important EU markets: Austria, Czech Republic, France, Germany, Greece, Italy, Poland, Spain, United Kingdom.

BSRIA. World Air Conditioning Overview 2008, edition March 2009, for 2007 and 2008 including forecast until 2012" by 14 EU countries.

Johnson Controls. Meeting of Öko-Recherche (W. Schwarz, B. Gschrey) with Johnson Controls (Adam Mc Carthy and William F. McQuade), Frankfurt/Main, 11 June, 2010.

[22] It should be noted that the market projections of the model, which indicates constant levels, is not undisputed. There are industry experts who project a long-term market growth of 2% per year for non-centrifugal chillers.

III.9 Heat pumps

The model includes only residential heat pumps in the strict sense, i.e. systems for space heating only, which use ambient air or the heat in the ground for inside hot water circulation. Tap water heat pumps and reversible air-to-air heat pumps are not reflected. The latter are identical with - reversible - air conditioning systems, and are already considered there. Heat pumps of the heating only type are common in central and northern Europe while in southern parts of Europe often reversible air conditioners are used temporarily for heating. Heat pumps rank among so-called renewable energy users. This is one of the reasons why a strong increase in heat pump installations is projected for the foreseeable future. (See chapter 3.3 on policy interactions).

Standard refrigerant for heat pumps that exploit ground sources (GSHP) or ambient air (air-water) had been R-22 for a long time. From 2000 onwards, HFC blends are used: R-407C, R-404A (before 2008), and, increasingly, R-410A. In the model the following refrigerant split is used for new installations of both heat pump types.

Table HEP Refrigerant split for new-installed heat pumps, 2000-2009

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
407C	80%	77%	75%	70%	60%	55%	50%	45%	40%	30%
410A	0%	3%	5%	10%	30%	40%	45%	50%	60%	70%
404A	20%	20%	20%	20%	10%	5%	5%	5%	0%	0%

From 2009 onwards, the refrigerant split remains constant. In the model, GSHP and air-water heat pumps are not considered separately. As their refrigerant charges do not substantially differ, a common value for the average charge (2.6 kg) is used.

Emission parameters (WOM)

Charge: 2.6 kg
Lifetime: 15 years
$EF_{Lifetime}$: 3.5 %
$EF_{Disposal}$: 70 %

Emission equations for heat pumps

$$EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}$$
$$EM_{Disposal,n} = Disposal_n * EF_{Disposal,n}$$
$$Bank_n = Bank_{n-1} + HFC\_in\_heat\_pumps\_sold_n - Disposal_n$$
$$Disposal_n = HFC\_in\_heat\_pumps\_sold_{n-Lifetime}$$

The calculation starts with data about annual heat pump sales from 2000-2009, which are collected and published by EHPA (European Heat Pump Association). F-gas banks are accumulated annual sales minus retired units (= annual sales in year n – lifetime). Time series dating back to 2000 and beyond are available for the “classic” EU heat pump countries Austria, Finland, France, Germany, and Sweden. Market data on the countries where considerable use of heat pumps started after 2005 are given for Belgium (2006), Czech Republic (2005), Hungary (2007), Ireland (2006), Italy (2008), Lithuania (2006), United

Kingdom (2006). EHPA states that so far not all countries with use “heating only” heat pumps are included in their statistics. The remainder, however, is considered negligible. EHPA data are in some cases compared with or supplemented by national studies (e.g. Germany, UK, Austria).

From 2010 until 2030 the annual numbers of heat pumps sold is estimated, assuming saturation in 2030. In literature there are many different national and international projections of the possible growth of heat pump installations until 2015 or even 2030, with results far apart from each other. Our model follows the projection communicated by EHPA (Thomas Nowak) that saturation sets in when the national heat pumps stocks reach 4 % of the country’s population. This will be almost 10 times the current stock in EU-27. It should rise from 1.5 million units containing HFCs in 2010 to 13 million units. This might seem to be very high. However, existing and additional financial incentives are expected to accelerate the installation numbers because heat pumps are considered climate friendly devices for space heat production. It should be noted that Sweden has already reached the 4% share in 2009.

The market size for heat pumps in the individual years 2010-2030 is calculated by linear interpolation between the 2009 value and the 2030 target. From 2030 to 2050 the national markets will be unaltered, new units will only replace old units.

WM scenario

Charges of heat pumps are assumed to average 2.6 kg, with a small percentage of systems charged higher than 3 kg. Generally, the key measures of Art 3 of the F-gas Regulation do not apply to this sector. Art 4 on recovery, which applies to all stationary F-gas containing equipment disregarding their charge, stipulates “proper recovery by certified personnel” to ensure recycling, reclamation or destruction. In the model, Art 4 is not considered to affect the use phase emissions but the end-of-life emissions. Disposal emissions are assumed to drop compared with the WOM scenario. The disposal emission factor decreases from 70% to 35%, from 2010 to 2015.

References

Thomas Nowak, The European Heat Pump Association, Brussels, discussion with Öko-Recherche, April and June, 2010.

EHPA (European Heat Pump Association), Outlook 2010. European Heat Pump Statistics, Summary, Brussels 2010.

EHPA (European Heat Pump Association), Outlook 2009. European Heat Pump Statistics, Brussels 2009.

NERA Economic Consulting/AEA, The UK Supply Curve for Renewable Heat. Study for the Department of Energy and Climate Change. Ref: URN 09D/689 (DEC), July 2009.

Peter Biermayr et al. Erneuerbare Energie in Österreich. Marktentwicklung 2008. Photovoltaik, Solarthermie und Wärmepumpen. Erhebung für die Internationale Energie-Agentur (IEA), Im Auftrag des Bundesministeriums für Verkehr, Innovation und Technologie. Berichte aus Energie- und Umweltforschung16/2009.

Les Pompes a chaleur Residentielles. Chapter 7 of [INV 07], Document 2. Paris 2010.

Bundesverband Wärmepumpe, Berlin. BWP-Branchenstudie 2009. Szenarien und politische Handlungsempfehlungen, Stand September 2009.

III.10 Mobile air conditioning of passenger cars

Starting point of bank and emission calculations are UNECE data on the number of registered cars (stock) in the 27 Member States from 1993 to 2008. Statistics on Mobile Air Conditioning (MAC) equipment quotas of these stocks are not available. For the German EPA, Öko-Recherche has surveyed average MAC quotas and refrigerant charges of the new registrations in Germany from 1993 onwards. The share of vehicles equipped with MAC systems of the total of new registrations has significantly increased from 1993 to 2008. In contrast, the refrigerant charge decreased in the same time (see table PAC1).

In the model, the German values for charges and MAC quotas are applied to all EU countries. Considering the high share of German makes in all national fleets, the error of the approach is considered acceptable. Concerns might arise from the high share of used cars from Western Europe in the fleets of Eastern Europe, which could result in significantly lower MAC quotas. A recent survey, presented in the Bulgarian 2010 NIR (p. 173/174), proves the contrary. MAC quotas of imported second hand cars in the country show high values which are not lower than those of cars in Germany.

Emissions equations for passenger car MACs

$$EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}$$
$$EM_{Disposal,n} = Disposal_n * EF_{Disposal,n}$$
$$Bank_n = Stock\_of\_cars_n * MAC\_Quota_{Stock} * Average\_Charge_{Stock}$$
$$Disposal_n = \frac{Stock\_of\_cars_{n-Lifetime}}{Lifetime} * MAC\_Quota_{new,n-Lifetime} * Charge_{new,n-Lifetime}$$

In a static stock simulation model which runs the same number of new systems per year over the whole equipment lifetime, the stock values can be derived from the values of new registrations, as to MAC quotas and refrigerant charges (see table PAC1). Given the equipment lifetime (12 years), MAC quota and refrigerant charge of the annually disposed vehicles (which are identical to MAC quota and charge of the equipment at the start of its lifetime) can be calculated as well.

For projections until 2050 a variable growth rate for the national car stocks is applied. From 2008 the passenger car fleet in a country increases at the same rate as the GDP of this country until a vehicle density of 750 cars/1000 persons is reached, which is assumed to be the maximum or saturation rate for passenger cars in each EU country. Once saturation is reached, the fleet size follows the population in a country.

Table PAC1 MAC values for new registrations and stock in the model (WOM)

		1993	1994	1995	2000	2005	2010	2015	2020	2030	2040	2050
MAC quota of new registered vehicles	%	9%	18%	25%	80%	94%	96%	96%	96%	96%	96%	96%
MAC quota of stock	%	1%	2%	4%	30%	66%	90%	96%	96%	96%	96%	96%
Charge of new MAC	kg	0.94	0.88	0.88	0.76	0.66	0.63	0.63	0.63	0.63	0.63	0.63
Average charge of MAC in stock	kg	0.94	0.90	0.89	0.81	0.74	0.67	0.63	0.63	0.63	0.63	0.63

In the WOM scenario, MAC quota, refrigerant charge, lifetime, emission factor, disposal emission factor, and the lifetime itself are kept constant until 2050.

Emission parameters (WOM)

Lifetime: 12 years
$EF_{Lifetime}$: 10 %
$EF_{Disposal}$: 70 %
MAC quota: 96% (since 2006)
MAC charge: 625 g (since 2007)

The maximum MAC quota of new registrations is assumed to remain 96%, which was already reached in 2006. Assuming constant MAC quota in the future, the 96% quota of the stock is reached in 2017. The same applies to the refrigerant charge contained in MAC for which the 2006 value of 625 g is assumed the long-term minimum. It will be stock value in 2018.

WM Scenario

As a consequence of the MAC Directive, in the WM scenario HFC-134a is expected to be replaced by unsaturated HFC (HFO) refrigerant gradually in the time period 2011 to 2017 (alternatively, calculation with the refrigerant CO_2 can be carried out). The quota of MACs containing HFC-134a is decreasing; the quota of MACs containing an alternative refrigerant is increasing at the same pace. All other parameters are the same as in the WOM scenario. The general provision of Art 4(3) for recovery by "appropriately qualified personnel" is not considered to impact the disposal emissions quantitatively. As a consequence, the WM scenario for HFC emissions and demand 2010-2050 does not differ from the WOM scenario.

Table PAC2 MAC values for new registrations and stock in the model (WM)

		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2030	2040	2050
HFC-MAC Quota of new registered vehicles	%	96%	100%	85%	70%	55%	40%	25%	0%	0%	0%	0%	0%	0%	0%
HFO-MAC Quota of new registered vehicles	%	0%	0%	15%	30%	45%	60%	75%	96%	96%	96%	96%	96%	96%	96%
HFC-MAC quota of stock	%	90%	92%	93%	92%	89%	85%	79%	71%	63%	55%	47%	0%	0%	0%
HFO-MAC quota of stock	%	0%	0%	1%	4%	8%	13%	19%	27%	35%	43%	51%	96%	96%	96%
Charge of new MAC	kg	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Average charge of MAC in stock	kg	0.67	0.66	0.65	0.64	0.64	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63

References

UNECE UN Economic Commission for Europe, Transport Statistics 2010. http://w3.unece.org/pxweb/DATABASE/Stat/Statistics.asp.

Schwarz, W./J. Harnisch, Establishing the Leakage Rates of Mobile Air Conditioners. (B4-3040/2002/337136/MAR/C1) Prepared for the European Commission (DG Environment). April 2003.

Emissions, Activity Data, and Emission Factors of Fluorinated Greenhouse Gases (F-Gases) in Germany 1995-2002 - Adaptation to the Requirements of International Reporting und Implementation of Data into the Centralised System of Emissions (ZSE). For the German EPA, No 201 41 261/01, June 2004.

Data of HFCs, PFCs and SF_6 for national emission reporting under the UNFCCC, for the reporting years 2006 and 2007, and study for applicability of databases in the sector of refrigeration, for the F-gas inventory, For the German EPA, No 3707 42 300, January 2009.

III.11 Mobile air conditioning of trucks

Starting point of bank and emission calculations are UNECE statistical data on the stock of trucks and trailers in the 27 MS from 1993 to 2008. Statistics on MAC quotas are not available. For the German EPA, Öko-Recherche has surveyed average MAC quotas and refrigerant charges of the new registrations in Germany from 1993 onwards, divided by the load capacity classes N 1 (trucks of van type <1.5 t), N 2 (medium trucks 1.5-7 t), N 3 (heavy trucks incl. road tractors >7 t)[23]. The break-down is of relevance because MAC quotas and charges differ widely between these three categories.

The share of MAC equipped vehicles in the total of new registrations has rapidly increased from 1993 to 2008, most of all in class N1 (van type). In N3 class the quota is constant at high level since several years.

Emissions equations for truck MACs

$$EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}$$
$$EM_{Disposal,n} = Disposal_n * EF_{Disposal,n}$$
$$Bank_n = Stock\_of\_trucks_n * MAC\_Quota_{Stock} * Average\_Charge_{Stock}$$
$$Disposal_n = \frac{Stock\_of\_trucks_{n-Lifetime}}{Lifetime} * MAC\_Quota_{new,n-Lifetime} * Charge_{new,n-Lifetime}$$

Starting from the stock bypasses the problem associated with so-called vintage models in which the actual fleet size in high-industrialised countries is systematically lower than the accumulated total of annual registrations because of the used-vehicles shift to EU countries in economic transition. In Eastern Europe arises the reverse problem.

In the stock model, the German values for charges and MAC quotas are applied to all EU countries. Considering the high share of German makes in all national fleets, the error of the approach is considered acceptable.

In a static simulation model which runs the same number of new systems per year over the whole lifetime, the stock values can be derived from new registrations, as to MAC quotas and refrigerant charges (see tables TRK1-TRK3). Given the equipment lifetime (10 years), MAC quota and refrigerant charge of the annually disposed vehicles (which are identical to MAC quota and charge of the equipment at the start of its lifetime) can be calculated as well.

The MAC quotas and charges are given in the tables below for three types of trucks.

Table TRK1 MAC data in the model for trucks N1 of van type (<1.5t)

		1993	1994	1995	2000	2005	2010	2015	2020	2030	2040	2050
MAC Quota of New registered vehicles	%	1%	3%	4%	13%	31%	45%	45%	45%	45%	45%	45%
MAC Quota of stock	%	0%	0%	1%	6%	17%	34%	44%	45%	45%	45%	45%
Charge of new MAC	kg	1,0	0,9	0,9	0,9	0,9	0,8	0,8	0,8	0,8	0,8	0,8
Average charge of MAC in stock	kg	1,0	0,9	0,9	0,9	0,9	0,8	0,8	0,8	0,8	0,8	0,8

[23] N1 values are based on the MAC quotas of Mercedes Sprinter, Mercedes Vito, VW Transporter, VW Crafter, VW Caddy, Renault Kangoo, and Renault Master. N2 values are those of Mercedes Atego (light), and N3 values are those of Mercedes Actros, Mercedes Axor, and Mercedes Atego (heavy).

Table TRK2 MAC data in the model for medium trucks N2 (1.5-7t)

		1993	1994	1995	2000	2005	2010	2015	2020	2030	2040	2050
MAC Quota of New registered vehicles	%	2%	4%	8%	20%	36%	43%	43%	43%	43%	43%	43%
MAC Quota of stock	%	0%	1%	1%	8%	21%	35%	42%	43%	43%	43%	43%
Charge of new MAC	kg	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Average charge of MAC in stock	kg	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0

Table TRK3 MAC data in the model for trucks N3 (>7t, Road tractors and heave and good vehicles)

		1993	1994	1995	2000	2005	2010	2015	2020	2030	2040	2050
MAC Quota of New registered vehicles	%	5%	20%	36%	74%	88%	90%	90%	90%	90%	90%	90%
MAC Quota of stock	%	1%	3%	6%	36%	73%	87%	90%	90%	90%	90%	90%
Charge of new MAC	kg	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2
Average charge of MAC in stock	kg	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2

Emission parameters (WOM)

Lifetime: 10 years

$EF_{Lifetime}$: trucks N1 = 10 %

trucks N2 and N3 = 15 %

$EF_{Disposal}$: 70 %

Projection 2050

For projections until 2050 the growth rates of the national GDP is applied to N1 trucks and N3 road tractors, until 2030. For the period 2030 to 2050 the stock is assumed to be constant. Stocks of N2 trucks and of heavy trucks of type N3 are constant from the year 2008 onwards.

WM scenario

The WM scenario follows the WOM scenario because the MAC Directive does not apply to truck MACs, so far, and the F-gas Regulation applies to truck MACs only with the general recovery provision of Art 4(3) which is not considered to impact the emissions quantitatively. As a consequence, the WM scenario for HFC emissions and demand 2010-2050 does not differ from the WOM scenario.

Reference

UNECE UN Economic Commission for Europe, Transport Statistics 2010. http://w3.unece.org/pxweb/DATABASE/Stat/Statistics.asp.

Schwarz, W., Establishing the leakage rates of mobile air conditioners in heavy duty vehicles (070501/2005/422963/MAR/C1). For the European Commission (DG Environment), part I trucks, and part II buses, Brussels 2007.

III.12 Mobile air conditioning of buses

For buses the same calculation approach as for trucks is used (see previous section), however with different MAC Quotas for three types of countries. EU Member States have been classified into South, Central/North and East European countries (including UK because of their low rate of air-conditioned buses). The assumptions for MAC quotas and charges are shown in the table below.

Table BUS MAC data in the static model for buses

		1993	1994	1995	2000	2005	2010	2015	2020	2030	2040	2050
MAC Quota of New registered vehicles												
Central/North Europe	%	36%	43%	49%	65%	76%	80%	80%	80%	80%	80%	80%
East Europe/ UK	%	34%	40%	44%	54%	57%	57%	57%	57%	57%	57%	57%
South Europe	%	38%	48%	56%	88%	96%	96%	96%	96%	96%	96%	96%
MAC Quota of stock												
Central/North Europe	%	4%	8%	13%	42%	66%	76%	80%	80%	80%	80%	80%
East Europe/ UK	%	3%	7%	12%	37%	53%	57%	57%	57%	57%	57%	57%
South Europe	%	4%	9%	14%	52%	85%	96%	96%	96%	96%	96%	96%
Charge of new MAC	kg	12,0	12,0	12,0	12,0	11,0	10,4	10,4	10,4	10,4	10,4	10,4
Average charge of MAC in stock	kg	12,0	12,0	12,0	12,0	11,7	10,9	10,5	10,4	10,4	10,4	10,4

Emission parameters (WOM)

Lifetime: 10 years
$EF_{Lifetime}$: 15 %
$EF_{Disposal}$: 70 %

Projection 2050

Based on the very low historical growth rates of numbers of buses no growth is assumed until 2050. The stock of 2008 (or of the last available year) is kept unchanged in all MS. This also applies to MAC quotas and refrigerant charges.

WM scenario

The WM scenario follows the WOM scenario because F-gas Regulation or MAC Directive does not apply to bus MACs, with the exception of Art 4(3) of the F-gas Regulation. This general provision for recovery by “appropriately qualified personnel” is not considered to impact the disposal emissions quantitatively.

References

Schwarz, W., Establishing the leakage rates of mobile air conditioners in heavy duty vehicles (070501/2005/422963/MAR/C1). For the European Commission (DG Environment), part I trucks, and part II buses, Brussels 2007.

III.13 Mobile air conditioning of ships

Merchant ships over 100 GT are considered to be air conditioned. Although most refrigerant emissions arise in international waters, the model includes all sea-going ships >100 GT in one of the registers of the EU-27 Member States, which were in service in 2006. Ships in other registers operated by EU based owners are excluded because EU law can only be applied to EU registered ships. According to Lloyd's Register Fairplay, the EU registered merchant fleet includes ca. 9,000 vessels, which are distinguished in four types. These differ by typical refrigerant charges. AC systems on ships built before 2001 use R-22, from 2001 HFC-134a is used.

1. Cruise ships: 6,400 kg charge.
2. Passenger ships: 520 kg charge.
3. Container ships: 160 kg.
4. Other cargo ships: 160 kg.

Emission calculation follows the equations in box below.

$$EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}$$
$$EM_{Disposal,n} = Disposal_n * EF_{Disposal,n}$$
$$Bank_n = Stock\_of\_ships_n * Charge$$
$$Disposal_n = Disposed\_Ships_n * Charge$$

For each ship type, and for each MS assumptions are made about the number of ships built between 2001 and 2006, built from 2007 to 2014, and the number of older ships from before 2001, whose air conditioning system has to be converted from R-22 to HFCs (R-134a) by end of 2014 at the latest.

Ships built before 2001 and operated in 2015 are assumed to keep the law and will be converted from R-22 (to HFC-134a) in the time period 2011-2014, irrespective of their life expectancy. Given average lifetime of 30 years, in 2015 no ship built after 1985 will run ODS refrigerant any longer.

No growth in total fleet is assumed, except for container ships, based on the high historical growth rates of this category. Growth of container ships is assumed to last until 2020.

Over the entire time period from 2007 to 2050, other new ships do not increase the overall number but replace old ships. Decommissioning of ships originally equipped with HFC air conditioning systems takes place from 2030, decommissioning of converted R-22 ships already begins 2015.

Table SHP shows the numbers of ships concerned.

Table SHP Number of ships with air conditioning by ship register country

	Cruise			Passenger			Cargo Ships			Container		
	New 2001-06	New 2007-14	Converted 2011-14	New 2001-06	New 2007-14	Converted 2011-14	New 2001-06	New 2007-14	Converted 2011-14	New 2001-06	New 2007-14	Converted 2011-14
Austria												
Belgium		1	1	1	2	3	26	28	2	3	5	2
Bulgaria					5	5	1	32	32		3	3
Cyprus		4	3	4	19	22	182	200	266	73	90	57
Czech Republic												
Denmark		1	1	16	28	44	73	85	98	44	52	32
Estonia				6	10	15		7	7			
Finland		1	2	4	37	41	4	35	39	1	2	0
France		1	1	20	24	36	69	80	64	24	30	6
Germany		0	1	5	50	68	33	60	93	122	165	89
Greece	1	4	3	52	137	189	271	320	185	23	30	15
Hungary												
Ireland				3	3	6	17	20	8	0	1	0
Italy	7	9	0	79	145	225	155	180	157	8	10	10
Latvia					4	4	1	8	8			
Lithuania				2	1	3	0	18	18		1	0
Luxembourg	1	2	1	2	3	2	17	20	9	3	4	1
Malta	3	5	4	10	22	31	225	304	529	9	22	31
Netherlands	5	8	11	23	32	9	225	250	115	31	38	3
Poland					15	16		11	11		3	2
Portugal	1	4	5		27	27	18	25	43		1	1
Romania					4	3	1	26	25			
Slovakia							1	26	25			
Slovenia												
Spain				33	40	35	36	50	14	3	10	13
Sweden		1	1	28	72	100	40	50	66			
United Kingdom	2	4	5	62	70	82	332	370	236	105	150	54
Total	**20**	**45**	**39**	**350**	**750**	**966**	**1727**	**2205**	**2050**	**449**	**617**	**319**

Emission parameters (WOM)

Lifetime: 30 years

$EF_{Lifetime}$: 40 %

$EF_{Disposal}$: 30 %

WM scenario

The WM scenario follows the WOM scenario because F-gas Regulation or MAC Directive does not apply to ship MACs, with the exception of Art 4(3) of the F-gas Regulation.

References

Schwarz, W., The analysis of the emissions of fluorinated greenhouse gases from refrigeration and air conditioning equipment used in the transport sector other than road transport and options for reducing these emissions (07010401/2006/445124/MAR/C4). For the European Commission (DG Environment), Brussels 2007.

Schwarz, W., Measures to reduce the climate impact of refrigerant emissions, in: CE Delft, DLR, Fearnley Consultants, Per Kageson, David Lee, MARINTEK, Norton Rose, Öko-Institut, Öko-Recherche, with assistance from DNV on some issues: Technical support for European action to reducing Greenhouse Gas Emissions from international maritime transport (DG ENV.C3/ATA/2008/0016). For the European Commission (DG Environment), Delft, October 2009.

III.14 Mobile air conditioning of rail vehicles

For almost 20 years, new railway cars (railway, metros, trams) have been equipped with air conditioning. Before 1995, the standard refrigerant was R-22 in southern Europe, while in other parts of Europe mostly R-12 was used. Since 2000, only HFCs are filled in new systems and are applied for the conversion of existing equipment. Standard is HFC-134a, whereas in southern countries often R-407C is used. In the model, R-134a is the only HFC refrigerant in the model, for simplicity. Considering the small difference in GWP, the effect of this assumption is insignificant.

In the 2007 Öko-Recherche study for the European Commission both the total 2006 number of rail cars ("rolling stock") and the total 2006 number of air-conditioned vehicles had been estimated, by all the 25 Member States with rail traffic (excl. Cyprus and Malta). In addition, the refrigerant charges of various rail vehicle types (coaches, diesel and electric train-sets, locomotives, restaurant cars, etc.) had been identified. The model utilizes all these data; however applies an average value of 8 kg refrigerant charge to all air conditioned railway cars in Europe. The charge of metro cars is 10 kg, the charge of tram cars is 30 kg). The use-phase emission factor of the model (7%) is an average of the lower value of electrically driven air conditioning systems and the higher value of systems driven by the diesel engine of the vehicle.

Emission calculation follows the equation in the box below.

$$EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}$$
$$EM_{Disposal,n} = Disposal_n * EF_{Disposal,n}$$
$$Bank_n = Stock\_of\_vehicles_n * Charge$$
$$Disposal_n = Disposed\_vehicles_n * Charge$$

While the 2006 lifetime emissions can be calculated by application of the emission factor to the HFC bank in the air conditioned rolling stock of a country, the estimation of lifetime emissions before 2006 and of the disposal emissions after 2020 (given 25-year-lifetime) requires the knowledge of the number of air conditioned vehicles annually put into service since the 1990s. The model simplifies the identification of the number of new vehicles per year, by division of the number of air conditioned vehicles in 2006 by the number of years since introduction of rail car air conditioning in a country. The first year of rail car air conditioning differs by geographic regions: 1990 for Italy, Portugal, and Spain, 1997 for the new MS and 1992 for all other countries of the EU-27. The annual number of new systems, calculated this way, is a constant value which does not account for annual variations.

Projection 2050

The calculation of the air conditioned rolling stock in the period from 2007 to 2050 likewise starts from the constant number of new vehicles calculated for the period 1990-2006. The stock remains the same in number of vehicles until 2050. New systems per year are constant in number after 2006 until first decommissioning of systems (which is 30 years after introduction of air conditioning). From then onwards, the number of new systems per year doubles in order to compensate for the retired systems. The MAC quota of the stock is constantly growing, until saturation of 100% is achieved. Once the 100% is reached, the number of new systems per year is the same as the number of annually decommissioned systems.

Emission parameters (WOM)

Charge: 8 kg
Lifetime: 25 years
$EF_{Lifetime}$: 7 % (not differing by diesel or electric drive)
$EF_{Disposal}$: 30 %

WM scenario

The WM scenario follows the WOM scenario because F-gas Regulation or MAC Directive does not apply to rail vehicle MACs, with the exception of Art 4(3) of the F-gas Regulation This general provision recovery by “appropriately qualified personnel” is not considered to impact the disposal emissions quantitatively.

References

Schwarz, W., The analysis of the emissions of fluorinated greenhouse gases from refrigeration and air conditioning equipment used in the transport sector other than road transport and options for reducing these emissions (07010401/2006/445124/MAR/C4). For the European Commission (DG Environment), Brussels 2007.

Lutz Boeck, Faiveley Transport Leipzig, discussion with Öko-Recherche, 24 February 2011.

III.15 One Component Foam (OCF)

The propellant gas in canned one-component PU foam (including so-called two-component PU foam) can contain HFCs which have replaced HCFC-22 from 2002 at the latest. The gas expels the foam from the aerosol cans; on application, it is completely released to the atmosphere.

In 2006 about 110 million OCF cans of an average weight of 660 g were sold to the EU-27 market, containing ca. 110 g of propellant gas per can. The majority of cans contained hydrocarbon gases, approximately 10-13% contained HFCs. According to manufacturers, the formulation of several special foam types (fire safe foam, winter foam, mega foam) still relied on high shares of HFC-134a[24] in the gas mixture (up to 110 g per can).

Emission equation for one component foam

$$EM_{Lifetime,n} = Consumption_n$$
$$Consumption_n = Cans\_sold_n * Percentage\_of\_cans_{HFC134a} * Charge_{can}$$

The emissions estimation in the model is based on data on the number of OCF cans, irrespective the gas content, sold in 2006 to each individual MS. This information was provided by the leading European OCF manufacturer Polypag.

Sales data 2002-2005, and 2007-2008 are likewise based on estimates by this manufacturer; they refer to the EU market as a whole. Individual MS markets in the missing years are estimated by application of the 2006 breakdown. The share of HFC containing cans in the total annual sales is not constant but decreases significantly from 2002 to 2008. In addition, the shares in Germany are higher than in other countries as a result of particular fire safety requirements in that MS[25]. This data are taken from a recent Öko-Recherche study for the German EPA (see table).

Table OCF Share of OCF-cans with HFCs (134a) in the total OCF market

	2002	2003	2004	2005	2006	2007	2008
GER	30%	25%	21%	17%	13%	11%	11%
EU-26	20%	18%	16%	13%	10%	9%	9%

Projection 2050

In the WOM scenario it is assumed that the HFC-134a share in the annual sales of OCF cans remains unaltered at the level of 2008. This is the last calendar year in which HFC emissions are not yet really affected by the relevant prohibition of the F-gas Regulation, as of July. This is because cans, legally bought before the prohibition, might be used later.

In Austria and Denmark the use of HFC containing OCF cans ceased in 2006, in consequence of national legal prohibition. The discontinuation is reflected in the WOM

[24] The model does not account for pure HFC-152a which was used only for a short time of quantitative importance. From 2008 onwards some manufacturers use HFC-152a in a propellant gas mixture.

[25] In Germany, the so-called Building Material Class 2 (B 2) must be complied with. This construction norm requires a high degree of fire resistance of PU foam, which could only be achieved by high dosage of HFCs. For a long time, the required quantity of flame retardants could not be solved in fluids other than HFC-134a.

scenario, not in the WM scenario because these prohibition measures date back to March 2001 (Denmark) and December 2002 (Austria), respectively. In the model AnaFgas this approach is applied to all sectors concerned.

In the model, for 2009-2030, a 2% growth rate of annual OCF sales is assumed, and for 2031-2050 an annual growth rate of 1%. As a consequence, the sales of HFC containing cans, and with that the emissions of HFC-134a from application, rise by 90% from 2009 to 2050, increasing from 10 million to 19 million cans and from 1,100 to 2,100 t HFC-134a, respectively.

WM Scenario

The F-gas Regulation (Art 9) interdicts sales of OCF containing HFCs to the market “except when required to meet national safety standards”, since July 2008.

In the WM scenario HFC emissions do not drop to zero. Safety standards in Germany require, according to the Öko-Recherche study, annual use of 50,000 cans containing HFC-134a as propellant for coal mining in the long run. For the other EU Member States a long-term use of 100,000 OCF cans containing HFCs is assumed, based on the assumption that comparable standards exist (not yet checked). The share of cans containing HFCs in the total markets drops to 0.2% (Germany) and 0.12% (other MS), respectively.

References

Winfried Schwarz, Estimation of the reduction potential of emissions from OCF with regard to a clarification of the provisions given in §9(1) of Regulation (EC) 842/2006. Report for German EPA, No 363 01 196, Dessau, January 2009.

Achim Niemeyer (Polypag AG, Switzerland). Estimation of the OCF market 2006 for all 27 Member States, Communication to Öko-Recherche, 23 March, 2010.

III.16 Extruded polystyrene foam (XPS)

Insulation boards made of XPS are produced with HFC-134a or HFC-152a, from 2001 when the HCFC-142b and HCFC-22 were banned. Emissions of HFCs as blowing agents for XPS foam arise both on manufacturing of the insulation boards (in countries with own production) and in the use-phase from installed foam (in all countries that use self-produced or imported XPS products). The lifetime of XPS boards is estimated 50 years. Therefore, disposal emissions are not estimated during the timeframe covered by the model.

Emissions equations for XPS foam

$$EM_{Manu,n} = Consumption_{Manu,n} * EF_{Manu,n}$$
$$EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}$$
$$Bank_n = Bank_{n-1} + Installed\_XPS_{HFC,n} - EM_{Lifetime,n-1}$$
$$Installed\_XPS_{HFC,n} = Total\_Installed\_XPS_{HFC,n} * Percentage_{country}$$
$$Total\_Installed\_XPS_{HFC,n} = (1 - EF_{Manu,n}) * Total\_Manufacturing\_consumption_n$$

Emission parameters

EF_{Manu}: 30 % for HFC-134a
100 % for HFC-152a
$EF_{Lifetime}$: 0.75 % for HFC-134a

1. Manufacturing emissions

The estimation is based on CRF or NIR data about quantities for manufacturing in 11 XPS producing Member States (Austria, Belgium, Bulgaria, France, Germany, Greece, Italy, Portugal, Spain, Sweden, UK). All these countries report the amounts of HFC-134a and HFC-152a for "hard foam"; however, in most cases do not distinguish between XPS foam, PU rigid foam, or OCF. Diligent interpretation of NIRs from the period 2003 to 2010 finally allowed the attribution to XPS in case of Austria[26], Bulgaria, France, Greece, Sweden, and Spain; with further research data for Belgium, Germany, Italy, Portugal, UK[27] could be estimated.

The total of the 12 individual quantities does not significantly deviate from the overall EU quantities that provided the European association of XPS manufacturers EXIBA to Öko-Recherche for 2002-2005 (134a and 152a), and for 2009 (152a). The differences are in a range of -4% to +17% and are considered acceptable.

The model uses a standardized emission factor of 30% for 134a and 100% for 152a.

EXIBA estimated 30% manufacturing emissions for HFC-134a. This value is used in the model, irrespective of differences in MS reporting, where the factors range from 10% to 35%. Uniformity is justified because technology does not differ substantially between MS.

---

[26] For Austria a new study was used: Öko-Recherche, Assessment of the Consumption and the Real Emissions of Fluorinated Greenhouse Gases in Austria 2000-2008, study on behalf of the Austrian Environmental Protection Agency/Umweltbundesamt GmbH, Wien, May 2010.

[27] The authors thank especially Mr Mike Jeffs for his estimation of the HFC breakdown of the UK reports on (unspecified) HFC use for foam blowing.

For 152a, the nationally applied EFs range from 10% to 100%. The IPCC-GL 2006 recommend as default value 50%, assuming that the remainder emits the next following two years in equal parts. This emission distribution is applied only by few MS because the second 50% (2 x 25%) must be calculated from use-phase, what is difficult, the more so as a result of foreign trade significant parts of these manufacturing emissions arise from use phase abroad. A correct application of the GL default factor could not be found in the national submissions. For simplicity, the model uses 100% for all countries.

2. Use-phase emissions

The model uses a standard emission factor of 0.75% of the banked HFCs for XPS boards containing HFC-134a. This is default value of the IPCC-GL 2006 (table 7.6). An emission factor for HFC-152a is not necessary because of complete emission on manufacturing.

The estimates of the HFC-134a bank in XPS boards installed in the 27 EU Member States is based on sales data provided by EXIBA to Öko-Recherche for 2009. This data include the sales of all XPS foam (in cubic metres) blown with HFCs or with CO_2. In the model it is assumed that the quantitative split between CO_2 and HFC blown foam products is the same for each individual MS. The 2009 breakdown is also applied to all years before 2009.

Projection 2050

No growth of current production and of market of HFC blown XPS foam is assumed based on the trend in the years 2003-2008. For the time after 2008 all parameters of 2008 are kept constant until 2050. This includes not only the emissions factors but also all quantities for manufacturing and all annual sales to the individual MS. Constant sales result in a constant increase in the HFC-134a bank, and thus in HFC-134a use-phase emissions, until 2050. Disposal is not assumed before 2050.

The WM scenario resembles the WOM scenario because the current F-gas Regulation does not apply to XPS foam.

References

EXIBA (European Extruded Polystyrene Insulation Board Association), Blowing Agents – Year 2009. Confidential aggregated statistical results for 2009, issued on: 8.04.10.

Nadine Rauscher (EXIBA), Communication to Öko-Recherche, 19 April 2010.

III.17 PU Rigid and PU Integral foam

PU rigid foam exists in a great diversity of product types, including continuous and discontinuous panels or blocks, laminate, appliances, pipe-in-pipe foam, or spray foam. There are three HFC types in use. HFC-134a replaced ODS in a variety of products in the 1990s. The most widespread ODS blowing was HCFC-141b, which was replaced by new-developed HFCs like HFC-245fa and HFC-365mfc[28], from 2003 onwards. In addition to PU rigid foam, PU integral foam is blown with HFCs.

1. Emission factors

Emissions of HFCs as blowing agents arise both on manufacturing and on use. The emission factors for rigid foam, as presented in the IPCC GL 2006, differ by foam sub sectors from 4% to 45% (manufacturing), and from 0.25 to 1.5 (use-phase). There are no data available on the sub-sector breakdown by individual MS. However, the association of the European producers of PU raw material, ISOPA, gave estimates of the HFC usage by ten sub sectors for the entire EU, for 2002, 2004 and 2008.

Emissions equations for PU foam

$$EM_{Manu,total,n} = EM_{Manu,Rigid,n} + EM_{Manu,Integral,n}$$
$$EM_{Manu,Rigid,n} = Manufacturing_{Rigid,n} * EF_{Manu,n}$$
$$EM_{Manu,Integral,n} = Manufacturing_{Integral,n}$$
$$EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}$$
$$Bank_n = Bank_{n-1} + Manufacturing_{Rigid,n} - EM_{Lifetime,n-1} - EM_{Manu,Rigid,n}$$

Based on the ISOPA data, an average, uniform manufacturing emission factor of 10% for all sub sectors and all MS except Spain is estimated; for Spain, for which wide application of spray foam is typical, a higher manufacturing emission factor of 15% is applied[29 30]. For the use-phase emissions, the country-specific factors from the CRF tables are applied; for missing countries, the default value of the model is 1%.

Emission parameters for HFCs in PU foam blowing

$EF_{\mathbf{Manu}}$**:** 10 % for rigid foam (15% in Spain)
100 % for integral skin
$EF_{\text{Life}\mathbf{time}}$**:** 1 % for rigid foam (default)

The model manufacturing emission factor for integral skin is 100%. Hence, use phase emissions do not occur.

Lifetime of the typical HFC blown PU rigid foam products in the EU is estimated 50 years. Therefore, disposal emissions are not calculated in the model. Blowing agents for PU integral skin emit completely on manufacturing.

---

[28] The latter is blended with 5-10% HFC-227ea to reduce the flammability of the pure fluid.
[29] Basis breakdown assumptions for Europe: HFC-demand: 50% for spray foam (Spain 90%), 13% for discontinuous panel, 12% for continuous panel, 25% for appliance and other. Emission factors manufacture/use: spray 15%/1.5%, disc panel 12%/0.5%, cont panel 5%/0.5%, appliance 4%/0.25%.
[30] In Estonia, the emission factor is also 15% because spray foam is the main use of HFC blowing agent there. The absolute amount of HFCs in that country is, however, very small.

2. Activity data

The data on annual use and banks of HFC-134a, as well as the application split into rigid foam or integral skin are taken from national submissions (CRF, NIR). For countries that do not report HFC-134a own estimates are made.

HFC-245fa and HFC-365mfc are not yet subject to UNFCCC reporting obligations. Manufacturing and stock data are not reported, with the exception of France[31]. The model estimates are based on sales data for 2003-2009 provided confidentially by the only producers Honeywell (245fa) and Solvay (365mfc), for individual Member States.

From the sales data, the data on manufacturing emissions, domestic banks and use-phase emissions are derived for each Member State (except for France, for which the CRF data could be used)[32].

Projection 2050

The market for HFC blowing agents is small compared with former quantities of HCFC blowing agents. Standard blowing agents for PU rigid foam are hydrocarbons. The use of HFCs for integral skin is rapidly decreasing and of almost negligible size.

The model projection assumes that all growth in PU rigid foam products will be realised without HFCs. The demand of all HFC types for manufacture of PU foam is kept constant on the 2008 level, until 2050. Constant sales result in a constant increase in the HFC bank, and thus HFC use-phase emissions. Disposal is not assumed before 2050.

WM scenario

The WM scenario resembles the WOM scenario because the current F-gas Regulation does not apply to PU foam.

Important notice

For confidentiality, the model presents any data on HFC-245fa and 365mfc together, to prevent conclusion to the sales figures of one of the two only producers.

References

Meeting Honeywell. Discussion of Öko-Recherche (Winfried Schwarz and Barbara Gschrey) with Honeywell Fluorine Products Europe BV (Tim Vink and Michelle O'Neill), Brussels, 19 May, 2010.

Meeting Solvay. Discussion of Öko-Recherche (Winfried Schwarz and Barbara Gschrey) with Solvay Fluor (Felix Flohr, Hans-Jürgen Korte, Carsten Frank, and Norman Solheid), Hannover, 10 March, 2010.

Tim Vink (Honeywell Fluorine), Confidential communication of sales data for 245fa in the EU, to Öko-Recherche, 30 April, 2010.

Meeting ISOPA. Discussion of Öko-Recherche (Winfried Schwarz and Barbara Gschrey) with Wolfram Frank (ISOPA), 19 March 2010 Frankfurt.

Wolfram Frank (ISOPA), Estimates of consumption of Polyurethane for spray in Spain 2007-2012, communication to Öko-Recherche 7 May, 2010.

---

[31] In addition, Germany indicates in CRF table 9(b) an "unspecified mix of HFCs", expressed in GWP.

[32] In Denmark and Austria HFCs are prohibited for domestic use as of 2002 and 2006, respectively. Danish HFC imports are used for the production of PU foam systems, which are exported, completely. Emissions of 0.5% from the mixing process are considered.

III.18 Metered Dose Inhalers (MDI)

HFC are used as propellants in aerosol sprays for drug application in asthma therapy. The quantity of HFCs in a country, sold in MDIs and emitted the same year, compared to another country is based on the product of (1) prevalence of asthma (number of persons suffering from asthma per 1000 persons), (2) spray quota (share of MDI vs. powder devices in the total of inhaled therapy), (3) population of the country. Reference quantity for all MS is Germany, for which the quantity of HFCs in annually sold (and used) spray cans has empirically been surveyed by a renowned market research company (IMS Health) in the years 2004, 2005, and 2006.[33]

Prevalence values are taken from literature[34] where figures for 21 MS could be found. For the missing countries Bulgaria, Lithuania, Luxembourg, Netherlands, Slovakia and Slovenia the prevalence values of comparable MS are used.

Spray quotas for the individual countries are spread across various studies, *inter alia* in TEAP ATOC reports. In addition, experts from pharmaceutical companies have been consulted[35].

Two types of F-gases (HFC-134a and HFC-227ea) are used for MDIs: Ca. 88% of HFC-134a and ca. 12% of HFC-227ea in 2006. This ratio is assumed to be identical for all Member States, and is kept constant until 2050 in the WOM scenario.

WOM scenario

The prevalence values from 2004 are kept constant until 2010. From the year 2011 onwards a growth rate of 0.5 % per year is assumed.

Population projection is derived from Eurostat.

WM scenario

The WM scenario resembles the WOM scenario because the current F-gas Regulation does not apply to MDI aerosols.

---

[33] Schwarz, W., Inventory of F-gases 2008 – data of HFCs, PFCs and SF_6 for national emission reporting under the UNFCCC, for the reporting year 2008. For the German EPA, No 360 16 026, February 2010.

[34] Global Initiative for Asthma – GINA: Global Burden of Asthma, Authors: Matthew Masoli, Denise Fabian, Shaun Holt, Richard Beasley (Medical Research Institute of New Zealand, Wellington, New Zealand; University of Southampton, Southampton, United Kingdom), 2004.

[35] Dr. Peter De Biasi, AstraZeneca GmbH, Wedel, Germany, pers. comm 23 March 2010. Ruth Christophel, former PR Manager Corporate Affairs & Business Support, GlaxoSmithKline GmbH & Co. KG, München, Germany, pers comm., 24 March 2010. In addition, several members of the former Working group Powder Inhalation Germany (API-AZA) were contacted.

III.19 General and Novelty Aerosols

Eleven Member States report HFC quantities for aerosols in CRF tables from 2000 onwards. However, there is no breakdown into General (technical) and Novelty aerosols, which is necessary for the identification of HFC quantities for Novelty aerosols which are the only aerosol category subject to market prohibition according to the F-Gas Regulation.

Aggregated data on the total HFC demand of EU based fillers for technical and Novelty aerosols were provided by FEA (European Aerosol Federation), in terms of CO_2 eq. They decreased from 5.83 MT to 3.87 MT in the period 2001-2008. On condition that almost all aerosol propellants consist of HFC-134a (GWP 1,300), the recalculation in metric tons results in a total amount of HFCs of ca. 4,485 t to 2,977 t.

In 2002, FEA had surveyed the HFC quantities filled in Novelties alone by European fillers, amounting to 940 t. From this time, use of HFCs for Novelties has continuously decreased. The number of cans remained constant, but the HFC share in the propellant gas preparation has changed and has been reduced below GWP 150 (F-Gas Regulation Art 2(5)). From this it follows that approximately 10% of HFC-134a are still contained in the propellant gas mixture of Novelties. This applies to ca. half of the annually sold cans, while the other half have been changed to completely HFC free formulations.

FEA estimates that the EU wide quantity of HFC-134a in Novelty aerosols has decreased from 940 t in year 2001 to less than 100 t in 2009 and to 46 t in 2010. This quantity is assumed to be constant in future.

The HFC quantity for General aerosols in the EU-27 is estimated as the difference between the quantity for all aerosols and the quantity for Novelties only, for 2001-2008 (both data from FEA).

The EU wide split between General and Novelty aerosols for 2001-2008 is applied to the HFC use in aerosols of the individual Member States, of both the 11 countries that report sales of HFCs in aerosols with their national CRF tables, and of the remaining 16 countries for which Öko-Recherche estimated their HFC use (in cans sold to the market).

Emission equation

Emissions in year n = quantity of HFC-134a in cans sold in the same year n.

This equation deviates from the recommendation of the IPCC GL to distribute the emissions from sold cans over two years, 50% in year n-1, the other 50% in year n. As the difference in emissions is negligible in size, we apply the "one-year" 100% emission factor for simplicity.

In the WOM scenario the 2008 amount of HFCs for both types of aerosols is kept constant for the future, with 2,720 t of HFC-134a in General Aerosols, and 260 t of HFC-134a in Novelty aerosols. 2008 is the last year before the prohibition of HFCs in novelty Aerosols.

WM Scenario

In the WM scenario, Novelty Aerosols are regulated from July 2009 (preparations must show GWP < 150), resulting in a reduced amount of HFC-134a of 46 t in the total of sold cans. This quantity is kept constant until 2050.

For General aerosols the WM follows the WOM scenario because the F-gas Regulation does not apply to these applications.

References

Meeting FEA. Discussion of Öko-Recherche (Winfried Schwarz and Barbara Gschrey) with FEA (European Aerosol Federation): Alain D-Haese, Secretary General, and Virginie Fourneau, Ad-hoc group HFCs, Brussels, 16th April, 2010.

FEA (European Aerosol Federation). Code of practice of HFCs use in aerosols, last update 12 August 2010.

III.20 Solvents

For some parts, data on use and (identical) emissions of solvents could be applied from national CRF tables. 4 Member States report a complete time series until 2008 (Austria, Germany, France, and UK[36]). Another 3 Member States report small quantities for individual years before 2006 (Hungary, Romania, and Slovakia). All reports include HFC-43-10mee; some include small amounts of HFC-134a. HFC-365mfc or HFC-145fa have not been reported so far. The total reported quantity of HFC solvents has been growing from 1995 and reached ca. 300 t in 2008.

No reporting means either no use in a country or lack of data on actual use.

The manufacturer of the main HFC solvent 43-10mee, DuPont, confidentially communicated his 2008 sales to 9 Member States. This total includes 5 countries more than the abovementioned Member States but the company sales, which are considered reliable, were even lower than the CRF reported quantity. The explanation might be that the biggest EU user (France) reports the whole solvent and not only the HFC component in the blend. The HFCs is the quantity the manufacturer's data refer to, counting for only one third of the blend[37]. In this model, only the manufacturer's data is used although this approach requires further research.

Emissions equation

Emissions in year n = quantity of F-gases sold in the same year n

This equation deviates from the recommendation of the IPCC GL to distribute the emissions from sold quantities over 2 years, 50% in year n-1, the other 50% in year n. As the difference in emissions is negligible in size, we apply the "one-year" 100% emission factor for simplicity.

Recovery of used solvents for recycling or reclamation outside the cleaning equipment is not assumed in the model. All new application is considered to offset solvent loss by cleaned parts or by direct release to the atmosphere. Only a small residue of highly contaminated solvent is recovered for external destruction. The very low amount of recovery (for destruction only) is the main reason why the MS cannot give information about the application of Art 4(1)b of the F-gas Regulation (see section 4.4.5).

Projection 2050

It is assumed that the use of 2008 continues at the same level until 2050.

WM scenario

A WM scenario is not calculated because it is not assumed that the F-gas Regulation (Art 4.1 (b)) significantly impacts the solvent emissions.

References

Meeting of DuPont, Öko-Recherche and HEAT GmbH. Frankfurt/Main 27 April 2010.

---

[36] UK usually indicates F-gas quantities in CO_2 equivalents of an "unspecified HFC mix". By recalculation with plausible GWP values, the metric mass could be estimated.

[37] This might also be the case with UK where Defra stated a solvent quantity ("around 100 tonnes") which is much higher than the manufacturer's indication for this country. (Defra, Impact Assessment of the Fluorinated Greenhouse Gases Regulations 2009, November 2008). See also task 2.3, chapter on practice of training and certification in the solvent sector.

III.21 Fire protection systems and fire extinguishers

The calculation of F-gas emissions from fixed fire extinguishing equipment and portable fire extinguishers is based on information derived from CRF tables from the Member States; 18 of the 25 tables (Cyprus and Malta are not obliged to report) could be used directly. Missing country information[38] were estimated based on data of reporting countries deemed to be similar. This applies to the Netherlands, Hungary, Lithuania, Bulgaria, Romania, and Luxembourg.

The usable CRF data could be compared with data on the 2008 sales of the manufacturers DuPont and Solvay to Europe, communicated confidentially to Öko-Recherche[39 40]. It was found that the overall sales largely match the total of the data from the reports. This sales data, however, was of limited use to identify the F-gas quantities of individual MS. The Chemical companies do not know the end users of their product because they directly supply the manufacturers of fire protection equipment who sell extinguishing agents together with equipment all over Europe. As most big equipment manufacturers are based in UK, UK sales data are much higher than the country uses itself. Another country who fills imported fire-extinguishing F-gases into containers for use in other countries is the Netherlands.

Six F-gas species are reported by the MS: HFC-227ea, HFC-23, HFC-125, HFC-236fa, HFC-134a and C_4F_{10}. The use of PFC C_4F_{10} has been stopped in 2005, two years before placing on the market of PFC containing equipment was prohibited by Art 9 of the F-gas Regulation. After 2005, emissions of PFCs occur only from non-converted banks, lowering the bank size year by year.

In general the following equations have been used:

$$\boxed{\begin{aligned}
&EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}\\
&EM_{Disposal,n} = Disposal_n * EF_{Lifetime,n}\\
&Bank_n = Bank_{n-1} + Filling_extinguisher_n - Disposal_n\\
&Disposal_n = Filling_extinguisher_{n-Lifetime}
\end{aligned}}$$

Emission parameters

Lifetime: 20 years

$EF_{Lifetime,\, n}$: Country and gas specific, taken from CRF tables (ranging from 0.2% to 5%, sometimes decreasing over the time). Default value for fixed systems: 2.5%.

$EF_{Disposal}$: 10 % (default)

---

[38] Denmark, who does not report HFCs for fire extinguishing, claims not to use them: "As in previous years, there have been no reports of consumption of HFCs for … fire extinguishing equipment …". See: Tomas Sander Poulsen, Ida Bode (PlanMiljø): The greenhouse gases HFCs, PFCs and SF_6. Danish consumption and emissions, 2008, December 2009, p. 21.

[39] Meeting DuPont. Öko-Recherche conference with DuPont de Nemours: Pascal Faidy (Sales & Marketing Manager EMEA), Jorge Dièguez (Government & Regulatory Affairs Director Fluoropoducts – EMEA), Dr. Frank Rinne (Technical Programmes Manager Fluorochemical Refrigerants), Jürgen Usinger (HEAT GmbH), Dietram Oppelt (HEAT GmbH), Linda Ederberg (HEAT GmbH), Frankfurt/Main 27 April 2010.

[40] Peter Jannick, Solvay Fluor GmbH, Hannover, personal comm. to Öko-Recherche, 5 May 2010.

It must be noted that most disposal emissions i.e. end-of-life emissions do not arise on site when old equipment is decommissioned because the F-gas containing bottles are simply removed from the piping and returned for off-site reclamation. This implies that end-of-life emissions are mainly reclamation emissions. Not many MS run reclamation plants so that most disposal emissions arise in a few countries, and cannot really be assigned to those MS where the fire suppression equipment had been installed. However, for simplicity the model assumes all disposal emission to arise in the user countries.

Projection 2050

For the projections it is assumed that in consequence of the strong competition from other (e.g. fluoroketone-based) fire extinguishing agents, only until 2015 HFC based fluids are filled in additional new systems, increasing the equipment stock. From then onwards, new HFC based equipment only replaces retired installations, keeping the banks at the 2015 level until 2050.

WM-Scenario

Fixed fire protection systems are subject to the measures prescribed in Art 3 and 4 of the F-gas Regulation.

It is characteristic of the sector that the equipment must satisfy very high safety requirements and standards so that regular control measures have always been common practice. Only in a minority of cases increase in intensity and frequency of equipment check will be necessary. The containment and recovery measures by certified personnel acc to Art 3 and 4 of the F-gas Regulation are therefore not assumed to show substantial additional reduction effects to the existing use phase emissions. As a consequence, in the model AnaFgas the use-phase emission factor decreases from 2.5% to 2.3 %.

From 2011 onwards, the lifetime emission factors for HFC-227ea, HFC-125, HFC-23, and C_4F_{10} decrease from 2.5 % in 2010 to 2.3 % in 2015. They remain unchanged until 2050. The emission factors for HFC-236fa and HFC-134a, which are mainly used in portable systems, are kept constant at 4%.

Most disposal emissions i.e. end-of-life emissions do not arise on site when old equipment is decommissioned because the F-gas containing bottles are simply removed from the piping and returned for off-site reclamation. End-of-life emissions are mainly reclamation emissions. As the reclamation plants are not subject to the provisions of the F-gas Regulation, a specific reduction effect from that law cannot be assumed. In AnaFgas, the disposal emission factor decreases from 10% to 9%.

References

Meeting DuPont. Öko-Recherche conference with DuPont de Nemours: Pascal Faidy (Sales & Marketing Manager EMEA), Jorge Dièguez (Government & Regulatory Affairs Director Fluoropoducts – EMEA), Dr. Frank Rinne (Technical Programmes Manager Fluorochemical Refrigerants), Jürgen Usinger (HEAT GmbH), Dietram Oppelt (HEAT GmbH), Linda Ederberg (HEAT GmbH), Frankfurt/Main, 27 April 2010.

Meeting 3M. Öko-Recherche conference (Winfried Schwarz and Barbara Gschrey) with 3M Europe (Cynthia Sanfilippo, Government Affairs Manager) and 3M Belgium N.V. (Bart Goeman), Brussels 16 May 2010.

III.22 Electrical equipment for transmission and distribution of electricity (switchgear)

Data on banks of SF_6 in switchgear for the years 1995 to 2008 could be used from 9 CRF tables: Austria, Denmark, France, Germany, Italy, Latvia, Spain, Sweden and UK. For the other 18 countries, data from CAPIEL[41] have been used for the years 2005 and 2007. The average annual growth between 2005 and 2007 was applied for calculation of the banks in the years 1995 to 2005. The annual growth rates, established for both, the 9 reporting and the 18 non-reporting countries are applied to the time after 2008 until the year of saturation.

In AnaFgas, the switchgear stock is not broken into high voltage in the strict sense (voltage > 50 kV) using “closed systems” and in medium voltage (1 – 50 kV) using “sealed for life systems”. This is because only two countries provided data, including Germany and Spain[42].

The saturation year is earlier for Western than Eastern countries, because SF_6 had been introduced in Western Europe already in 1970-1975. In the view of the long equipment lifetime of 40 years, it is assumed that from 2015 onwards only replacement of existing equipment will take place[43]. In Eastern Europe the stock will increase five years longer, until 2020. Even if additional equipment should be put into service after 2015/2020, the SF_6 bank is unlikely to further increase because new equipment is lower charged than old systems.

Emissions equations for switchgear

$$EM_{Manu,n} = SF6_{Manu,n} * EF_{Manu,n}$$
$$EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}$$
$$EM_{Disposal,n} = Disposal_n * EF_{Lifetime,n}$$
$$Bank_n = Assumption_{Country,n}$$
$$Disposal_n = \frac{Bank_n}{Lifetime}$$

Bank emissions differ slightly between the reporting MS, varying from 0.5 to 2%. Default value for non-reporting countries is 1%. This value is kept constant until 2050, in the WOM scenario.

For modelling of disposal emissions it is assumed that switchgear is decommissioned after 40 years lifetime. As SF_6 in switchgear came up in the 1970s in Western countries and 20 years later in Eastern countries the calculated disposal of switchgear starts in 2010, respectively 2030. The quantity for disposal in year n is calculated bank in year n divided by lifetime years. Default disposal emission factor is 5%. For Germany only 1.5% is used, according to the 2005 voluntary agreement of the German switchgear industry.

---

[41] CAPIEL = Coordinating Committee for the Associations of Manufacturers of Industrial Electrical Switchgear and Control gear in the European Union, now: T&D Europe. Former representatives of this association, in particular Mr Friedrich Plöger (Siemens) and Mr Roland Büscher (AREVA), provided Öko-Recherche with background data for a study of Ecofys: Reductions of SF_6 emissions from high and medium voltage electrical equipment in Europe, Final Report to CAPIEL, 28 June 2005. The background data had not been published in that report.

[42] Data on the subset of medium voltage switchgear which includes so-called secondary distribution switchgear have been provided by the manufacturers’ association T&D Europe. These are discussed in chapter 6.11 of this report, and in annex V (EU sector sheet 27)..

[43] This is the position of T&D Europe (successor of CAPIEL) on the meeting with Öko-Recherche, Frankfurt/Main, 4 May 2010.

Manufacturing of SF_6 containing switchgear takes place in 11 countries: Czech Republic, France, Germany, Hungary, Italy, Poland, Portugal, Slovenia, Spain, Sweden, and UK. Five countries report the annual SF_6 use of the switchgear industry, and estimate the emissions on manufacturing; the mostly used emission factor is 5%. This value is also applied to the six non-reporting countries with own switchgear industry. In the WOM scenario quantities for manufacturing and manufacturing emissions are kept constant at the 2008 level until 2050.

Emission estimation parameters (WOM)

Lifetime : 40 years

$EF_{Lifetime}$: 1 % (default). Country-specific variation from 0.2% to 2% in 9 reporting MS.

$EF_{Disposal}$: 5 %, except for Germany: 1.5 %

$EF_{Manufacturing}$: Country-specific for 5 reporting countries. The values of 2008 are kept constant until 2050. Default value for non-reporting countries is 5%.

WM-Scenario

Operators of high-voltage switchgear are subject to Art 4(1) of F-gas Regulation. As a consequence, from 2010 to 2015 the bank emission factor is reduced in all MS to 0.7%, which is the present value in Germany but still higher than reported from Sweden for 2008 (0.5%).

The disposal emission factor is generally reduced from 5% to 1.5% (current German value), in the time from 2010 to 2015.

Manufacturing emissions are not affected because manufacture is not addressed by the measures in the F-gas Regulation.

References

Meeting T&D Europe. Discussion of Öko-Recherche (André Leisewitz, Barbara Gschrey, and Winfried Schwarz) with T&D Europe, Frankfurt/Main, 4th May 2010. Participants from T&D Europe: Jean-Marc Biasse (head), Thor Endre (ABB), David Crawley (EURELECTRIC), Guillermo Amann (Ormazabal), Bernhard Tilwitz von Keiser (Siemens).

Meeting Eaton. Discussion of Öko-Recherche (Winfried Schwarz and Barbara Gschrey) with EATON Electric B.V: Wim Porte (Manager Product Manager), Ton de Haan (Marketing Communications Director), Frankfurt/Main 28 April 2010.

Meeting Working Group SF_6. Discussion of Öko-Recherche with Roland Büscher (AREVA), head of the working group SF_6 of the German switchgear industry. Frankfurt/Main 16 March 2010.

Roland Büscher (AREVA), Communication to Öko-Recherche, 14 March 2010, 14 July 2010.

III.23 SF_6 in car tyres

SF_6 shows a low permeability through rubber (cf. IPCC GL 2006, p. 8.31). A German tyre manufacturer exploited this property and offered in the 1990s tyres with SF_6 as filling gas instead of air.

Emissions equation for car tyres

$$\boxed{EM_{Disposal,n} = SF6\_Consumption\_for\_filling_{n-Lifetime}}$$

Lifetime = 3 years

According to IPCC GL 2006 it is assumed that SF_6 completely emits from car tyres with their disposal three years after filling. Filling emissions are regarded to be insignificant. The SF_6 quantity for filling equates disposal emissions three years later.

Within the EU, 80% of SF_6 filling in car tyres occurred in Germany, the remainder in Austria, Belgium, the Netherlands and France.

In the WOM scenario it is assumed that the SF_6 quantity for car tyres remains at the level of 2006 (year of enforcement of F-gas Regulation) until 2050.

In Austria, the use of SF_6 for tyres was prohibited by the Austrian Industriegas Verordnung as of 1.1.2003. The resulting reduction of SF_6 emissions in Austria is included in the WOM scenario.

WM Scenario

The F-gas Regulation prohibits placing on the market of F-gases in tyres as of 4 July 2007. SF_6 is not used any longer for filling of car tyres from the year 2008 onwards.

References

Schwarz, W., Inventory of F-gases 2008 – data of HFCs, PFCs and SF_6 for national emission reporting under the UNFCCC, for the reporting year 2008. For the German EPA, No 360 16 026, February 2010.

Linde 2009: Linde Gas GmbH, Graz, Erich Weissensteiner, Verkauf Sondergase, comm. to Öko-Recherche, 13.08.2009.

UBA-AT (2001): Umweltbundesamt GmbH, Wien (Hrg.), Abschätzung der tatsächlichen und potentiellen treibhauswirksamen Emissionen von H-FKW, P-FKW und SF6 für Österreich

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). Report for the European Commission (DG ENV) by Jochen Harnisch (Ecofys) & Winfried Schwarz (Öko-Recherche), February 4, 2003, pp. 12-14.

Öko-Recherche, Assessment of the Consumption and the Real Emissions of Fluorinated Greenhouse Gases in Austria 2000-2008. Study on behalf of the Austrian EPA, Wien, May 2010

III.24 Sound proof glazing

Emissions from the application of SF_6 to soundproof glazing arise in three ways. 1. Emissions on manufacturing (ca. 33% of the annual application). 2. Emissions from the stock over the lifetime (1% per year). 3. Emissions on disposal after the lifetime of 25 years (100% of the remainder).

The model is identical to that used in the German ZSE, described in ÖR 2004[44] and in the IPCC GL 1999 and 2006. This means that there is only one input parameter to be entered every year, for each country: quantity of SF_6 for new soundproof windows. All further data derive from this input variable: emissions on manufacturing; increase of the stock before stock emissions; stock emissions; stock after stock emissions; quantity for disposal after 25 years lifetime; disposal emissions after lifetime.

The emission estimates in each country follow the equations in the box below.

$$EM_{Manu,n} = Consumption_n * EF_{Manu,n}$$
$$EM_{Lifetime,n} = Bank_n * EF_{Lifetime,n}$$
$$EM_{Disposal,n} = Disposal_n * EF_{Lifetime,n}$$
$$Bank_n = Bank_{n-1} + Consumption_n - EM_{Manu,n} - EM_{Disposal,n}$$
$$Disposal_n = (Consumption_{n-Lifetime} - EM_{Manu,n-Lifetime}) * (1 - EM_{Lifetime,n})^{Lifetime}$$

In the EU, in 10 MS SF_6 had been filled into soundproof window-panes: Austria, Belgium, Czech Republic, Denmark, France, Germany, Luxembourg, Netherlands, Poland, Sweden. CRF or NIR data are available from all these countries except for France, Netherlands, and Poland. As a substitute for the Netherlands the Belgian data, and for Poland the Czech data are applied. Data on France are available in the Öko-Recherche archives: background material for the 2003 study[45] for the European Commission.

In the model the SF_6 use had to be recalculated back to the first application year, in order to estimate the current disposal emissions which arise 25 years after filling. This recalculation was carried out by Öko-Recherche for all 10 MS, based on the own data base for Germany, which was the biggest SF_6 user for soundproof glazing, by far.

The EU F-gas Regulation prohibits the use of SF_6 for window panes as of July 2007 (domestic use), and as of July 2008 for the remaining buildings (other use).

2007 is the last year of legally unlimited use of SF_6 for soundproof windows. Therefore, in the projection of the WOM scenario it is assumed that the SF_6 quantity for filling remains constant at the 2007 level until 2050. The emissions (from disposal) will peak in 2020 (25 years after the filling peak 1995). In Austria and Denmark the use of SF_6 for soundproof

[44] Öko-Recherche: Emissions, Activity Data, and Emission Factors of Fluorinated Greenhouse Gases (F-Gases) in Germany 1995-2002 - Adaptation to the Requirements of International Reporting und Implementation of Data into the Centralised System of Emissions (ZSE)". For the German EPA, No 201 41 261/01, June 2004.

[45] 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). Report for the European Commission (DG ENV) by Jochen Harnisch (Ecofys) & Winfried Schwarz (Öko-Recherche), February 4, 2003, pp. 12-14.

windows had been banned as of 2003 and 2002, respectively. These measures are included in the WOM scenario because they are not caused by EU F-gas legislation.

Emission estimation parameters (WOM)

Lifetime: 25 years

$EF_{Lifetime}$: 1 %
$EF_{Manufacturing}$: 33 %
$EF_{Disposal}$: 100%

WM-Scenario

The WM Scenario includes the final prohibition of placing on the market of SF_6 filled windows from 2009 onwards. The last emissions from bank and disposal are expected to occur in 2033. So far, there is no equipment available which could recover used SF_6 gas from the pane interspaces on disposal of old windows. Therefore, the disposal emission factor of 100% is not reduced in the WM scenario.

III.25 Sport Shoe Soles

SF_6 until 2003

A sports equipment manufacturer introduced a series of sport shoes using soles containing gas cushions filled with SF_6 in the early 1990's. The company reduced its global SF_6 usage annually since the 1997 calendar year high of 277 t. In 2004 no new shoe soles were filled with SF_6 anymore.

World consumption of SF_6 for sport shoe soles

Year	1997	1998	1999	2000	2001	2002	2003	2004
tons	277	148	105	87	53	47	24	0

Source: Öko-Recherche 2004.

Manufacturing of SF_6 filled shoe soles took place outside Europe. The annual sales of shoe soles containing SF_6 to the EU are estimated 35% of the world production, and the break down by individual MS correlates with the population.

SF_6 Emissions follow the equation

$$\boxed{EM_{Disposal,n} = SF6\_Sales\_shoes_{n-Lifetime}}$$

Lifetime = 3 years

According to IPCC GL 2006 it is assumed that SF_6 completely emits from sport shoe soles with their disposal three years after manufacture (purchase). As a consequence, the final SF_6 emissions occurred 2006, everywhere in Europe.

The F-gas Regulation prohibits placing on the market of F-gases in sport shoe soles as of 4 July 2007. In our model the company's SF_6 phase-out is not considered a result of the EU F-gas legislation. The decision to stop the use of SF_6 had been taken already before 2000.

In the WOM scenario SF_6 emissions do no longer arise after 2006. The WM scenario follows the WOM scenario.

PFC-218 from 2003 to 2006

PFC-218 (C_3F_8) was selected the shoe-sole gas in the transition to complete elimination of greenhouse gases in products imported into Europe. According to the concerned company, PFC-218 had the lowest GWP of any gas that could maintain the product performance during the transition period.

There are data available on the sales to Europe. The metric tons of PFC-218 in footwear imported into the European market in 2003-2006 period by calendar year is estimated as follows: 2003: 8.25 t; 2004: 6.7 t; 2005: 4.23 t. By spring 2006 the shoes sold in EU were free of PFP. (2006 sales are 2005 times 0.5).

The break down by individual Member States correlates with the population.

PFC-Emissions follow the equation

$$\boxed{EM_{Disposal,n} = PFC\_218\_Sales\_shoes_{n-Lifetime}}$$

Lifetime = 3 years

The final sales of PFC-containing sport shoes in Europe took place in the year 2006. As a consequence, the last (disposal) emissions arise in 2009.

The F-gas Regulation prohibits placing on the market of F-gases in sport shoe soles as of 4 July 2007. In our model the company's F-gas phase-out is not considered a result of the EU F-gas legislation. The decision to use temporarily PFCs as replacement for SF_6 had been taken already before 2000.

In the WOM scenario PFC-218 emissions do no longer arise after 2009. The WM scenario follows the WOM scenario.

References

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). Report for the European Commission (DG ENV) by Jochen Harnisch (Ecofys) & Winfried Schwarz (Öko-Recherche), February 4, 2003, pp. 22-23.

Öko-Recherche: Emissions, Activity Data, and Emission Factors of Fluorinated Greenhouse Gases (F-Gases) in Germany 1995-2002 - Adaptation to the Requirements of International Reporting und Implementation of Data into the Centralised System of Emissions (ZSE)". For the German EPA, No 201 41 261/01, June 2004.

Luha, Kristjan (Nike Estonia), Communication to Öko-Recherche on Nike sportshoes with SF_6, PFC etc. in Estonia, 26 February, 2008.

III.26 Non ferrous metal industry

SF_6 in the magnesium industry

In a global perspective, magnesium casting is the second largest application sector of SF_6, after switchgear equipment. In magnesium casting SF_6 is used as a cover gas to prevent the hot molten metal from burning. All gas applied is considered to be released to the atmosphere (manufacturing emission factor = 100%).

Emission equation Magnesium casting

$$\boxed{EM_{Manu,n} = Consumption\_SF6_n * EF_{Manu,n}}$$

Three technologies are applied in Europe: Die casting (large scale production), sand casting (prototypes and small scale production), and recycling.

In 2006, magnesium production with SF_6 took place in Germany, France, Italy, Romania, Spain, Sweden, UK. Total SF_6 use amounted to 52 t/a[46].

Four of these countries reported their quantities by CRF. France, Spain, Romania, and UK did not. Before 2004 magnesium casting with SF_6 took place also in Austria, Sweden, and Denmark. The three countries had reported by CRF.

In the WOM scenario the 2006 SF_6 use is starting point. SF_6 is assumed to be used unaffected by the Regulation until 2050, at the same technological ratio of SF_6 per t Mg cast. An annual growth rate of 1% is assumed for the use of SF_6 in die casting and sand casting between 2006 and 2030, for recycling plants constancy is assumed. From 2030 the absolute increase from 2006 to 2030 in magnesium casting (die and sand casting) is used as basis for the calculation of the increase 2030-2050. The SF_6 amount for recycling remains constant over the whole time period.

WM scenario

The F-gas Regulation (Art 8) prohibited the use of SF_6 for die casting plants with annual SF_6 application of more than 850 kg, as of 2008. This measure almost halved the SF_6 demand of the European magnesium industry and limits SF_6 use to smaller die casters, to sand casters and to recycling plants. In the WM scenario it is assumed that these three sectors continue applying SF_6, at unchanged ratio per t Mg produced or recycled. For these sectors, the same growth assumptions as in the WOM scenario are made.

Nine of the ten big die casting plants, affected by the F-gas Regulation, have replaced SF_6 by HFCs as the new cover gas. One has changed to SO_2. The quantity of HFCs used by these nine die casters is of the same size as the replaced quantity of SF_6, and has to be taken in account when estimating the consequences of the F-gas Regulation for the entire Mg sector.

The modelled WM scenario assumes for the demand for the alternative cover gas HFC-134a the same growth rates and technological parameters as for SF_6 in the WOM and WM

---

[46] Öko-Recherche 2009: Study to assess the feasibility of options to reduce emissions of SF_6 from the EU non-ferrous metal industry and analyse their potential impacts (ENV.C.4/SER/2008/0059rl). For the European Commission (DG ENV).

scenarios. The emission factor of HFC-134a is the same as that of SF_6: 100%[47]. Compared with SF_6, the emission factor for HFC-134a is 6.3% (GWP 1,430 to GWP 22,800).

SF_6 in aluminium cleaning

SF_6 is currently used for cleaning aluminium melt in Austria and Germany only. Data is available for Germany 1999 (start of use) until 2009 and for Austria 2006 (start of use) until 2008.

Emission equation Aluminium cleaning

$$\boxed{EM_{Manu,n} = Consumption\_SF6_n * EF_{Manu,n}}$$

In projections 2050 it is assumed that the used quantities will remain constant in Austria 2009-2050 at the 2008 level. This applies to Germany only to 2009 and 2015. The German operator has decided to phase-out SF_6 by 2015 at the latest. Therefore the phase-out is included in the WOM scenario, although the company's decision might be substantially be influenced by the EU F-gas legislation. This assumption is based on the fact that in 2008 the gas feeding equipment was changed in order to reduce the SF_6 quantity per t aluminium alloy. Therefore, in the model the WOM emission factor is reduced from 3% to 1.5%, as of 2008.

$EF_{\textbf{Manufacturing}}$: 3 %
$EF_{\textbf{Manufacturing}}$: 1.5 % (from 2008 onwards for Germany)

References

Salzburger Aluminium AG, Lend, Andreas Kraly, written communication to Öko-Recherche, 25.11.2009.

Rheinfelden ALLOYS GmbH & Co. KG, D-79618 Rheinfelden, Germany. Willi Glück, personal communication to Öko-Recherche, 25.05.2010.

Schwarz, W., Gschrey, Barbara, Study to assess the feasibility of options to reduce emissions of SF_6 from the EU non-ferrous metal industry and analyse their potential impacts (ENV.C.4/SER/2008/0059rl). For the European Commission (DG ENV), Brussels, November 2009.

[47] For discussion of the extent of decomposition of cover gases on use, see the aforementioned study for the European Commission. There, further details can be found on SF_6 use and its regulation in EU Mg industry.

III.27 Semiconductors and Photovoltaic

Semiconductor industry

In the EU semiconductor industries the following fluorinated greenhouse gases are applied: SF_6, PFC (CF_4, CHF_3, C_2F_6, C_3F_8, c-C_4F_8), which are usually referred to as “PFCs” and HFC-23.

Apart from these gases, for cleaning of deposition chambers NF_3 is increasingly used, both in semiconductor and photovoltaic industry. This gas is neither subject to UNFCCC reporting nor is currently included in the basket of greenhouse gases under the Kyoto Protocol. However, it might be covered by a post-2012 framework. In chapter 5.4 of this report use and emissions data on NF_3 are presented and it is discussed whether NF_3 should be included in the scope of the F-gas Regulation (see there).

The emission factor for each individual F-gas, i.e. the amount of emissions in relation to the input into the manufacturing process basically depends on both the utilisation efficiency in plasma and the efficiency of the emission control technology, both of which vary from plant to plant. As a consequence, estimation of a general emission factor is not advisable. The model considers absolute amounts of emissions for each gas, each country, and each year.

Most emission data in the model are from CRF tables. There are nine EU countries with own semiconductor manufacture. Italy, France, and Austria report annual application and emissions 1995-2008 so that implied country specific emission factors can be calculated. Germany, Czech Republic and Ireland report emissions for the same time period. Netherlands, Finland and United Kingdom do not report at all.

The European Semiconductor Industry Association EECA-ESIA, who monitor and report the European aggregate emissions in the frame of a worldwide voluntary agreement on PFC emission reduction[48], could not provide data on the missing countries because the association surveys company-specific data, irrespective of the countries where the companies' manufacturing plants are operated[49]. As a consequence, the missing country-data are estimates by the authors of the model for the time being[50].

Projection 2050

Emissions from semiconductor manufacturing constantly decreased in the period 2000-2008 reflecting commitment to the voluntary agreement on PFC emission reductions and improved abatement technologies. As new plants (“fabs”) are hardly erected in Europe, no growth of F-gas emissions is assumed until 2050. The annual emissions are kept constant at the average of the last four years (2005-2008).

The WM scenario resembles the WOM scenario because the current F-gas Regulation does not apply to semiconductor manufacture.

---

[48] EECA-ESIA: Memorandum of Agreement (http://www.eeca.eu/index.php/esh_pfc/en/)
[49] Meeting ESIA. Discussion of Öko-Recherche (Winfried Schwarz and Barbara Gschrey) with EECA-ESIA (Shane Harte), Brussels, 16 April, 2010.
[50] Netherlands is estimated half Germany, UK is estimated Austria, Finland a quarter of Austria.

Photovoltaic industry

In the production of photovoltaic cells, F-gases are used within the silicon-based thin film technology which represents approximately 5% of the globally installed manufacturing capacity for photovoltaic cells. In Europe, before 2008 this technology had only been applied in Germany which is the world second largest producer of photovoltaic cells, after China. Recently solar cell production with the silicon-thin-film technology started also in Spain and in Italy. Similar to the manufacture of semiconductors or liquid crystal displays (LCD), in the manufacture of silicon-based thin film cells SF_6 or – increasingly – NF_3 is used for cleaning silicon off the chemical vapour deposition chambers, which has not been properly deposited on the substrate but onto the walls, electrodes, and product carriers inside the reactor chamber instead.

Presently (April 2010) the model AnaFgas does not include NF_3.

In Germany, in thin film technology SF_6 has been used since the 1990s (small scale) with a sudden increase to large scale use from 2006 onwards. The SF_6 demand increased from 2 t a year (before 2006) to over 50 t in 2008. In Spain and Italy, SF_6 has not been used[51].

$EF_{\mathbf{Manufacturing}}$: 4%

All data and emission parameters for the model are taken from a recent study by Öko-Recherche for the German EPA[52].

Projection 2050

For the time after 2008, no growth in the use of SF_6 is assumed because it is no longer used for new equipment but only for existing. New installations use NF_3 or – alternatively – elemental fluorine. The demand for SF_6 will remain constant until 2050 at its 2008 level.

The WM scenario resembles the WOM scenario because the current F-gas Regulation does not apply to photovoltaic manufacture.

[51] The two plants in Spain use NF_3. The first plant in Italy starts 2010; elemental fluorine is used there.
[52] Öko-Recherche (Winfried Schwarz): SF_6 and NF_3 in the German Photovoltaic Industry (German), FuE Vorhaben 36016027, October 2010.

III.28 Aluminium production

Historical and new figures on annual metal production and PFC emissions 1995-2008 are taken from the national UNFCCC submissions of the 13 countries with domestic production of primary aluminium. The time series are almost complete, only in two cases the metal output is kept confidential and had to be supplemented by data from elsewhere.

The calculation method is not the same in all countries. Nevertheless, the coefficients "kg CF_4 / t Al" are rather close to each other, except for Poland (14 times higher than in most other countries), and, to lesser degree, Sweden (8 times) and Romania (6 times).

Assumptions for projection 2050

It is assumed that in the long term the EU wide production of primary aluminium remains at the same level as in the 1995-2008 period (1995: 2.47 million t; 2000: 2.86 million t; 2005: 3.10 million t; 2008: 2.82 million t). The 1995-2008 time periods show a quasi constant metal output of averaging 2.8 million t per year in the EU-27. In the same time the world capacity has doubled, rapidly growing outside Europe, especially in China and Russia. It is assumed that all global growth in capacity will take place outside the EU.

In the EU, the coefficient "kg CF_4 / t Al" has been decreasing significantly in the same time periods, in consequence of the almost general spread of point fed prebake anode types, replacing Soederberg and side worked prebake anodes. As a result, the CF_4 emissions per t aluminium dropped from typical 0.500 kg to less than 0.100 kg in modern facilities (C_2F_6 emissions counting generally 1/10 of CF_4 emissions).

Up to 2008, in some EU facilities point feeding has not yet become the only alumina feeding technology, leading to an EU average coefficient of 0.093 kg CF_4 / t Al. Model assumption is that by 2030 all facilities will have switched to point feeding prebake anodes, thus lowering the technical coefficient to 40 g CF_4 (4.0 g C_2F_6).

This reduction is considered realistic because the inclusion of PFC emissions from aluminium production in the EU Emissions Trading System from 2013 onwards will support the technological trend (see section on legal interactions).

The 40 g value is considered the technical optimum in the long run (until 2050).

III.29 Production of Halocarbons

In seven countries of the EU-27 halocarbons are manufactured and fugitive or by-product emissions arise.

1. By-product emissions

HFC-23 by-product emissions arise from the production of HCFC-22 or HFC-32 in Germany, Spain, Italy, France, and Netherlands. In UK and Greece the HCFC-22 plants were closed in 2009 and 2006 respectively, a further plant was closed 2010 in Germany. While in the mid-1990s, HFC-23 by-product caused emissions of more than 40 million t CO_2 eq, due to the installation of abatement equipment the 2008 emissions have been reduced to less than 2 million t CO_2 eq (for details see chapter 5.4 of this report).

In addition to the production of HCFC-22, the production of Trifluoroacetic acid (TFA) in France causes by-product emissions of HFC-125 and CF_4.

By-product emissions are reported in CRF from 1995 onwards by Spain, France, the Netherlands, and Greece. The HFC-23 emissions of UK, Italy and Germany are based on expert estimates.

2. Fugitive emissions

In the EU two plants exist which produce PFCs, one in Belgium, another in UK. The emissions from the Belgian plant have been reported from 1995 onwards, while the data on the UK plant had to be estimated.

Today, HFCs are produced in four countries: France, Germany, Spain, and UK. The production of 134a, 125, and 143a in Italy ceased in 2008.

The fugitive HFC emissions of France, Spain, and Italy have been reported by CRF (or NIR) from the beginning. The emissions in UK and Germany have been kept confidential. The model data on the latter are based on expert estimates.

Projection 2050

The model does not assume growth in the EU halocarbon production until 2050 (see section on F-gas markets in chapter 3.1 of this report). Emissions are kept constant on the 2008 or 2009 level.

References

Meeting Honeywell. Discussion of Öko-Recherche (Winfried Schwarz and Barbara Gschrey) with Honeywell Fluorine Products Europe BV (Tim Vink and Michelle O'Neill), Brussels, 19 May, 2010.

Meeting Solvay. Discussion of Öko-Recherche (Winfried Schwarz and Barbara Gschrey) with Solvay Fluor (Felix Flohr, Hans-Jürgen Korte, Carsten Frank, Norman Solheid), Hannover, 10 March, 2010.

Meeting DuPont. Öko-Recherche conference with DuPont de Nemours: Pascal Faidy (Sales & Marketing Manager EMEA), Jorge Dièguez (Government & Regulatory Affairs Director Fluoropoducts – EMEA), Dr. Frank Rinne (Technical Programmes Manager Fluorochemical Refrigerants), Jürgen Usinger (HEAT GmbH), Dietram Oppelt (HEAT GmbH), Linda Ederberg (HEAT GmbH), Frankfurt/Main 27 April 2010.

Meeting Mexichem. Discussion of Öko-Recherche (Winfried Schwarz) with Karsten Schwennesen from Mexichem Fluor (former Ineos Fluor), Frankfurt/Main, 26 February 2010.

Andrew Lindley, Regulatory Affairs Manager Mexichem Fluor, written communications to Öko-Recherche, May and June 2010.

III.30 F-gas applications not included in the model AnaFgas

By CRF some Member States report F-gas applications which are not reported by other MS. Amongst these individual applications are

- HFC-152a for thermometers (DNK)
- SF_6 for particle accelerators (GER)
- SF_6 in medical applications (IRL)
- CF_4 and c-C_4F_8 in fiber optics (DNK)
- SF_6 in fiber optics (GER)
- SF_6 in laboratories (DK)
- C_6F_{14} as dielectric medium and heat transfer fluid (FRA).

Although we are convinced that the listed applications are not limited to only one MS, we could not identify such countries or quantify the used F-gases.

F-gas demand for Organic Rankine Cycles (ORC; i.e. generation of power from heat recovery) and for tumble dryers shows growing importance. So far no MS reports these applications.

After all, we do not hold the opinion that the omitted applications substantially affect the overall emission assessment for the EU or for individual Member States.

III.31 Calculation of F-gas demand in AnaFgas and the prefilled equipment

In addition to emissions, the model AnaFgas calculates the annual demand of F-gases for the EU as a whole, for each Member States, for each year. While emissions include both use-phase and disposal at end-of-life, demand does not take into account disposal but includes re-fill during use-phase and the first fill into equipment. Only in sectors where import or export of equipment is of minor importance in terms of F-gas quantities, e.g. stationary refrigeration, the first fill is identical with the F-gas quantity in new units sold to the domestic market. (For further discussion of the term demand see chapter 2.2.4 of the report).

Emission calculation in most sectors relies on the annual sales of new units containing F-gases to the domestic markets of EU-27 as a whole or of individual Member States. As stock of equipment annually increases (or decreases) by the number of new units sold, emissions from the F-gas bank in that stock are calculated by application of sector specific use-phase emission factors. It does not matter for emissions estimation in which country the new units are manufactured and whether they are charged with F-gases within the EU-27 or somewhere else in the world. All new equipment contributes to emissions within the EU. In the terms of UNFCCC reporting the equivalent denomination for the total of domestically and abroad filled equipment for use in a particular country is “potential emissions”.

In contrast, for mobile systems like motor vehicles, small air conditioning equipment, MDI aerosols, or electrical switchgear, the country of manufacture can significantly differ from the country of use to which the equipment is sold.

If one wants to know the F-gas demand of a country or of the EU-27 as a whole for domestic use only (domestic first fill plus domestic re-fill), which means F-gases supplied in bulk, containers, cylinders, bottles, etc. one has first to identify the F-gas quantity in pre-filled equipment from import and in pre-filled equipment for export. Imported pre-filled equipment increases, and exported pre-filled equipment decreases the F-gas quantity that annually adds to the in the existing domestic bank[53].

In the model AnaFgas, the sectors of concern are

1. One-component foam (OCF) and MDI aerosols (export surplus).
2. Moveable, single split, multi-split, and rooftop air conditioners (excess of imports).
3. Mobile air conditioning of passenger cars, trucks, and buses (usually excess of exports).
4. Electrical switchgear (export surplus).

The following table DEM indicates the Member States where first fill of equipment is carried out for the sectors with significant deviation between F-gas demand for first fill and F-gas quantity in new sold units.

[53] In chapter 2.2.4 of the report, the “second extension” of the term demand accounts for imported equipment first filled in third countries and for domestic first fill into equipment for export to third countries.

Table DEM: F-gas applications with significant deviation between F-gas demand for first fill and F-gas quantity in new sold units, by MS

	OCF	MDI	Aero-sols	Stationary AC				MAC in road vehicles					El. switch gear
				Move able	Split	Multi split	Roof top	Pass cars	N1	N2	N3	Bus	
Austria								o		o	o		
Belgium	o	o	o		o	o		o		o	o	o	
Bulgaria													
Cyprus													
Czech Republic	o				o			o	o	o	o	o	o
Denmark													
Estonia	o												
Finland	o							o		o	o		
France		o	o	o			o	o	o	o	o	o	o
Germany	o	o	o					o	o	o	o	o	o
Greece													
Hungary		o						o		o	o	o	o
Ireland		o											
Italy		o	o	o	o		o	o	o	o	o	o	o
Latvia													
Lithuania													
Luxembourg													
Malta													
Netherlands	o		o					o		o	o	o	
Poland	o							o	o	o	o	o	o
Portugal								o	o	o	o	o	o
Romania	o							o	o	o	o	o	
Slovakia								o					
Slovenia	o							o	o				o
Spain		o	o	o	o		o	o	o	o	o	o	o
Sweden								o		o	o	o	o
United Kingdom		o	o	o	o	o	o	o	o	o	o	o	o

In each sector, the calculation of the demand for first fill has to account for sector-specific conditions. In the following, the sectoral approaches in the model AnaFgas are discussed.

1. Sectors with high imports

Moveable air conditioners

Factory-filled moveable systems which are sold to the Member States (new sales units) are charged with 0.75 kg HFCs. Approx. 90% of new units are imported from outside of the EU (Asia). The remaining 10% are manufactured and factory filled in 4 Member States.

Single-split room air conditioners

Single-split systems which are sold to the Member States (new sales units) are pre-charged with 1.375 kg of F-gas. On-site, the systems are topped up with 0.125 kg for the piping. Approx. 75% of new units are imported from outside of the EU (Asia). In 5 Member States the remaining 25% are manufactured and factory filled with an average of 1.375 kg of refrigerant. Total first fill includes 0.125 kg for each new installation in the 27 Member States plus 1.375 kg for the domestically manufactured 25% of the total number of units in 5 Member States.

Multi split room air conditioners (VRF type).

Multisplit air conditioning systems which are sold to the Member States (new sales units) are pre-charged with 8.5 kg of F-gas. On-site, the systems are topped up with 5.0 kg for the piping. Approx. 78% of new units are imported from outside of the EU (Asia). The remaining 22% of new units are manufactured and factory filled with an average refrigerant charge of 8.5 kg in 2 Member States. Total first fill includes 5.0 kg for each new installation in the 27 Member States plus 8.5 kg of F-gas for domestically manufactured 22% of new units.

Rooftop room air conditioners

Rooftop air systems which are sold to the Member States (new sales units) are pre-charged with 9.3 kg of F-gas. On-site, the systems are topped up with 1.2 kg for the piping. Approx. 33% of new units are imported from outside of the EU. In 4 Member States the remaining 67% are manufactured and factory filled with an average refrigerant charge of 9.3 kg. Total first fill includes 1.2 kg for each new installation in the 27 Member States plus 9.3 kg of F-gas for 67% of new units domestically manufactured in 4 Member States.

2. Sectors with high exports

OCF

The European producers of canned PU foam (OCF) are based in 9 Member States and Switzerland. After the ban of placing on the market of HFC containing propellant mixtures with GWP >150 (Art 9 of the F-gas Regulation), most HFC-products are filled for markets outside the EU, primarily in Eastern Europe and the Middle East. Therefore, demand for first fill significantly exceeds the domestic use of HFCs in EU-27.

MDI

In Europe, MDIs are filled for more than 50% of the world market. Demand for first fill ranges at 5,000 t whereas approx. 2,500 t are used by patients within EU-27. MDIs are manufactured and filled with HFC-134a (8 MS) or HFC-227ea (1 MS) in 8 Member States.

Aerosols

Demand/supply and emissions of HFCs in aerosols are almost equal. Imports are negligible. Relevant HFC demand for the filling of aerosols occurs in 7 Member States. Novelty aerosols are filled in 3 of these 7 Member States.

Electrical switchgear

Europe is the world's largest producer and exporter of electrical switchgear for power transmission and distribution. Every year ca. 1,500 t of SF_6 are filled into new equipment for high voltage (>50 kV) and for medium voltage (1 - 50 kV) switchgear. Two thirds of the high voltage equipment containing SF_6 and manufactured in EU are exported to countries outside of the EU, while 50% of the medium voltage equipment are exported to thired countries.

SF_6 contained in containers for on-site replenishment of equipment to operation pressure are included in the exported quantities of SF_6.

3. Sectors where usually exports exceed imports

Passenger cars, trucks, and buses

EU-27 is the world's largest vehicle producer with an output of over 15 million passenger cars, vans, trucks and buses per year (25% of worldwide vehicle production). Although the share of EU-27 (as a total) in the new registrations is of the same size (~ 25%), considerable deviation between production and new registrations by vehicle types (passenger cars, light and heavy commercial vehicles, and buses) and by Member States are to be noted. The deviation between domestic production and new registrations (which includes certain shares of domestic production and imports) applies also to the refrigerant quantities in the air conditioning systems of the relevant motor vehicles.

For passenger cars an export surplus occurs in most years; for buses an export surplus exists in all years; light commercial vehicles (N 1 vehicles) show mostly import surplus, while heavy vehicles (N2 and N3) usually show balanced import and export.

The calculation basis for use-phase emissions in AnaFgas is the vehicle stock which is built up by annual new registrations. The calculated use-phase emissions form part of the demand (for refill), which additionally includes first fill into domestically manufactured air-conditioned motor vehicles. Table DEM shows the EU MS in which HFC demand for first fill takes place, by vehicle type passenger car, truck of N1, N2, and N3 class, and bus.

General assumption for the demand estimation is that MAC quotas and refrigerant charges for domestically manufactured vehicles are the same as those for domestic new registrations.

After the phase-out of HFC-134a in air conditioners of passenger cars (2011-2017 for new models used in the EU), in the WM scenario the HFC-134a demand is reduced to first fill into systems of cars which are exported to third countries. This remaining quantity is assumed to range ca. 25% of the annual first fill before the MAC Directive. In one option in the WAM scenario (quantitative limits for placing on the market of HFCs) HFC phase-down in mobile air conditioning of trucks and buses is assumed. The demand for the remaining first fill is likewise estimated at 25% of the WOM demand for first fill.

III.32 Overview of Model Assumptions

AnaFGas 1.2			Refrigeration				
			Domestic	Commercial	Industrial	Road transport	Ship (fisheries)
General assumptions							
	Gases concerned		HFC 134a	134a; 404A	404A	134a; 404A	404A
	Charges	kg	0.12	n.e.	different for each sector	1.5 for vans; 6.5 for trucks and trailers	from 17 (medium vessels) to 8,000 (fish factories converted
	Lifetime	years	15	Central systems: 12; condensing units: 15; hermetic units: 10	20 for ice rinks and other industry; 30 for all other sectors	10	40
WOM Scenario							
	Emission factors						
	EF Manufacturing	% / year	Country specific; Min: 0.6; Max: 5.0				
	EF Lifetime	% / year	0.3	Central systems: 15; condensing units: 10; hermetic units: 1	8 for wine, fruit juice, milk farm and chocolate production; 12 for other industry; 9 for all other sectors	30 for vans; 20 for trucks and trailers	40
	EF Disposal	% / year	40; SE: 5	Central systems: 30; condensing units: 50; hermetic units: 70	30	30	30
	EF By-product	% / year					
Different values for WM Scenario (with linear interpolation from WOM value in year 2010 to WM value in 2015)							
	Emission factors						
	EF Manufacturing	% / year					
	EF Lifetime	% / year		Central systems: 9; condensing units: 6; hermetic units: 1	4.8 for wine, fruit juice, milk farm and chocolate production; 7.2 for other industry; 5.4 for all other sectors		
	EF Disposal	% / year	30; SE: 5	Central systems: 20; condensing units: 25; hermetic units: 35	20		
	Other Gases						
	Other Reduction measures						

AnaFGas 1.2			Stationary A/C and heat pumps			
			Moveable & Single split	Multisplit & Rooftops	Chillers	Heat pumps
General assumptions						
	Gases concerned		407C; 410A	Multisplit: 410A; Rooftop: 407C; 410A	407C; 410A; 134a	404A; 407C; 410A
	Charges	kg	Moveables: 0.75; Split: 1.5	Multisplit: 13.5; Rooftop: 10.5	minichillers: 2; <100 kW: 10; >100 kW: 95; centrifugal: 630	2.6
	Lifetime	years	10	Multisplit 13; Rooftop 10	minichillers: 12; centrifugals: 25; other: 15	15
WOM Scenario						
	Emission factors					
	EF Manufacturing	% / year				
	EF Lifetime	% / year	3 & 5	8 & 5	4	3.5
	EF Disposal	% / year	70	30	30	70
	EF By-product	% / year				
Different values for WM Scenario (with linear interpolation from WOM value in year 2010 to WM value in 2015)						
	Emission factors					
	EF Manufacturing	% / year				
	EF Lifetime	% / year		4.8 & 3	2.4	
	EF Disposal	% / year	35	20	20	35
	Other Gases					
	Other Reduction measures					

AnaFGas 1.2			**Mobile Air Conditioning**				
			Passenger Car A/C	Bus A/C	Truck A/C	Ship A/C	Rail A/C
General assumptions							
	Gases concerned		134a; 1234yf	HFC 134a	HFC 134a	HFC 134a	HFC 134a
	Charges	kg	1993: 0.943; decreasing until 2007 to: 0.625	1993: 12; decreasing until 2016 to: 10.4	N1:1993: 1.0; decreasing until 2016 to: 0.81; N2: 1.0; N2: 1.2	Cruise: 6,400; Passenger: 520; Cargo+Container: 160	Rail: 8; Tram: 30; Metro: 10
	Lifetime	years	12	10	10	40	25
WOM Scenario							
	Emission factors						
	EF Manufacturing	% / year					
	EF Lifetime	% / year	10	15	N1:10; N2+N3: 15	40	7
	EF Disposal	% / year	70	30	70	30	30
	EF By-product	% / year					
Different values for WM Scenario (with linear interpolation from WOM value in year 2010 to WM value in 2015)							
	Emission factors						
	EF Manufacturing	% / year					
	EF Lifetime	% / year					
	EF Disposal	% / year					
	Other Gases		1234yf or CO_2 in 2012, from 2017 on the only refrigerant				
	Other Reduction measures						

AnaFGas 1.2			**Foams**		
			One Component Foam	PU foam	XPS
General assumptions					
	Gases concerned		HFC 134a	HFC 365mfc, 245fa, 134a, 152a	HFC 134a, 152a
	Charges	kg	0.11	n.e.	n.e.
	Lifetime	years	1	50	50
WOM Scenario					
	Emission factors				
	EF Manufacturing	% / year	100	Default: 10 Sprayfoam 15	HFC 134a: 30; HFC 152a: 100
	EF Lifetime	% / year		Country specific or default: 1	HFC 134a: 0.75; HFC 152a: n.a
	EF Disposal	% / year		n.e.	n.e.
	EF By-product	% / year			
Different values for WM Scenario (with linear interpolation from WOM value in year 2010 to WM value in 2015)					
	Emission factors				
	EF Manufacturing	% / year			
	EF Lifetime	% / year			
	EF Disposal	% / year			
	Other Gases				
	Other Reduction measures		Prohibition of placing on the market except for safety standards as of July 2008		

AnaFGas 1.2			**Other HFC**			
			Aerosols	Metered Dose Inhalers	Solvents	Fire Extinguishers
General assumptions						
	Gases concerned		HFC 134a	HFC 134a, 227ea	HFC 43-10mee, 134a, C_6F_{14}, CF_4	HFC 134a, 227ea, 23, 125, 236fa; C_4F_{10}
	Charges	kg	n.e.	80 g HFC / Person with Asthma using spray inhalers	n.e.	n.e.
	Lifetime	years	1	1	1	20
WOM Scenario						
	Emission factors					
	EF Manufacturing	% / year				
	EF Lifetime	% / year	100	100	100	2.5
	EF Disposal	% / year				10
	EF By-product	% / year				
Different values for WM Scenario (with linear interpolation from WOM value in year 2010 to WM value in 2015)						
	Emission factors					
	EF Manufacturing	% / year				
	EF Lifetime	% / year				2.3
	EF Disposal	% / year				9
	Other Gases					
	Other Reduction measures		Prohibition of placing on the market for novelty aerosols as of July 2009			Prohibition of placing on the market for PFC as of July 2007

AnaFGas 1.2			**SF6**				
			Electrical Equipment	Car tyres	Soundproof Glazing	Sport Shoe Soles	Magnesium Casting Secondary Aluminium
General assumptions							
	Gases concerned		SF6	SF6	SF6	SF6, C3F8	SF6; HFC 134a, 125
	Charges	kg	n.e.	n.e.	n.e.	n.e.	n.a.
	Lifetime	years	40	3	25	3	n.a.
WOM Scenario							
	Emission factors						
	EF Manufacturing	% / year	Default 5		33		Aluminium: 3.0-1.5; Magnesium: 100
	EF Lifetime	% / year	Default 1		1		
	EF Disposal	% / year	Germany: 1.5; other MS: 5	100	100	100	
	EF By-product	% / year					
Different values for WM Scenario (with linear interpolation from WOM value in year 2010 to WM value in 2015)							
	Emission factors						
	EF Manufacturing	% / year					
	EF Lifetime	% / year	Country specific reduction since 2008				
	EF Disposal	% / year	1.5				
	Other Gases						Since 2008: HFC 134a, 125, SO_2 in die casting > 850 kg
	Other Reduction measures			No SF6 in car tyres as of July 2007	No SF6 in windows as of July 2008		No SF6 in large die casting as of 2008

AnaFGas 1.2			PFC and other Halocarbons		
			Seminconductors and Photovoltaics	Primary Aluminium Production	Halocarbon Production
General assumptions					
	Gases concerned		SF6, HFC 23; CF4, C2F6, C3F8, c-C4F8	CF4, C2F6	HFC 23, 32, 125, 134a, 143a, 227ea, 365mfc,CF4, C4F10, C5F12, C6F14, SF6
	Charges	kg	n.a.	n.a.	n.a.
	Lifetime	years	n.a.	n.a.	n.a.
WOM Scenario					
	Emission factors				
	EF Manufacturing	% / year	absolute values		
	EF Lifetime	% / year			
	EF Disposal	% / year			
	EF By-product	% / year		CF4: 0.140 decreasing to 0.045 kg CF4/ t Al; C2F6: 0.014 decr. to 0.004 kg C2F6 / t Al	By-product and Fugitive Emissions: abs. values
Different values for WM Scenario (with linear interpolation from WOM value in year 2010 to WM value in 2015)					
	Emission factors				
	EF Manufacturing	% / year			
	EF Lifetime	% / year			
	EF Disposal	% / year			
	Other Gases				
	Other Reduction measures				

Annex IV: Global Data Input Sheets

IV.1 Refrigeration and Air Conditioning

Data Input Sheet – Domestic refrigeration

Business as Usual

Region	A2	A5
New units per year (Total 102.9m for 2008)	47.2m (46% of total) (RTOC 2010)	55.2m (54% of total) (RTOC 2010)
Total stock	709m (RTOC, 2010)	721m (RTOC, 2010)
Consumption	HFC (2008): 3,770 t (RTOC, 2010)	HFC (2008): 7,690 t (RTOC, 2010)
Bank	CFC (2006): 16,188 t (RTOC, 2010) HFC: (2006) 47,175 t (RTOC, 2010)	CFC (2006): 43,433 t (RTOC, 2010) HFC (2006): 34,381 t (RTOC, 2010)
Annual growth	+4.3% to 2015 +4.4% to 2020 +4.0% to 2030 (RTOC 2010, extrapolated from 1992 – 2008 data)	+5.3% to 2015 +5.1% to 2020 +4.3% to 2030 (RTOC 2010, extrapolated from 1992 – 2008 data)
Refrigerant type (BAU) 2010 2015 2020 2030	45% HFC 134a, 55% HC 600a (RTOC 2010) 43% HFC 134a, 57% AO 39% HFC 134a, 61% AO 32% HFC 134a, 68% AO	72% HFC 134a, 28% HC 600a (RTOC 2010) 68% HFC 134a, 32% AO 65% HFC 134a, 35% AO 57% HFC 134a, 43% AO
Average unit data:		
Refrigerant charge	Average 0.175 kg	Average 0.175 kg
Lifetime	15 years	20 years
Leakage rate	0.3% p.a. (RTOC 2010)	0.5% p.a. (RTOC 2010)
Rated capacity	Average 200 W	Average 200 W
Annual energy use	250 kWh	250 kWh
Cost of unit	€ 400	€ 350
Operation Cost per unit (maintenance +refill, excl electricity cost)		

Abatement Options

Abate-ment option	Year	Max. technical penetration rate in new units		Capital investment costs per unit †	Unit investment costs per unit	Additional operating costs
		A2	A5			
R600a	2015 2020 2030	95% 95% 95%	95% 95% 95%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +0% onto product cost (10 year reference period). (Equates to €0.3m per 500,000 units annual production)	A2 and A5 the same. For same efficiency rating, product costs marginally more because material (compressor) costs slightly higher than for R134a; +2% per unit; 50% charge reduction	A2 and A5 the same. -1.5 % (manufacturers state that R600a has approx 10% higher efficiency than R134a, but value is fixed because of energy labelling). Additional operating cost 0% per unit
R744‡	2015 2020 2030	10% 20% 30%	10% 20% 30%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, approx +0.1% onto product cost for first year. (Equates to €1m per 500,000 units annual production)	A2 and A5 the same. For same efficiency rating, product costs more because of more material weight costs; approx. double compared to R134a systems; +20% per unit	A2 and A5 the same. Same energy consumption. Additional operating cost 0% per unit
Unsat. HFCs ‡ (R1234yf)	2015 2020 2030	1% 50% 100%	0% 50% 100%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +0.1% onto product cost (10 year reference period). (Equates to €1 m per 500,000 units annual production)	A2 and A5 the same. For same efficiency rating, product costs more because of much greater refrigerant costs and marginally higher material costs; +1% per system	A2 and A5 the same. Same energy consumption. Additional operating cost 0% per unit

† Assumes costs to be identical in A2 and A5 countries since, 80% of manufacturing is centralised in very few manufacturing sites within a small number of A5 countries.

‡ Approximations because (a) no manufacturer currently using this AO and (b) no feedback information on R1234yf.

Data Input Sheet – Commercial refrigeration – centralized systems

Business as Usual

Region	A2	A5
New units per year	17,500 = 12.5% of 140,000 (10 to 15% of total stock in A2 annually with equipment lifetime of 7 to 12 years /UNEP2010/)	14,000 = 10% of 140,000 (4 to 6% of total stock in A5 annually – but probably more (maybe 10%) due to shift from small outlets to larger supermarkets lifetime in A5 between 15 and 25 years /UNEP2010/)
Total stock	140,000 A2 + A5: 280,000[54] in 2006 from 400 m^2 to 20,000 m^2/UNEP2010/, estimated 140,000 in A2 based on UNEP2006 figures, which included also smaller supermarkets (for comparison: 2009: Germany 27,910 over 400 m^2, growth from 2008 1.5% /IRI2010/; 2009: Spain 8,650 over 400 m^2, growth from 2008 5% /IRI2010/ 2006: USA 34,000 – average size 4530m^2 /FMI2010/)	140,000 A2 + A5: 280,000 in 2006 from 400 m^2 to 20,000 m^2/UNEP2010/, estimated 140,000 in A5 based on UNEP2006 figures which included also smaller supermarkets
Consumption	8,900 t HFC (17,500*230 + 140,000*230*15%)/1000 kg/t	11,300 t CFC+HCFC+HFC (14,000*230 + 140,000*230*25%)/1000 kg/ t
Bank	32,200 t HCFC+HFC = 140,000*230kg Worldwide 156,400 t - CFC+HCFC+HFC; approx. 36,000 t HFC mainly in A2 /UNEP2010/	32,200 t CFC+HCFC+HFC = 140,000*230kg
Annual growth	+1.5% to 2015 (Growth due to East Europe's development) +1.5% to 2020 +1.5% to 2030	+1% to 2015 +1.5% to 2020 +4% to 2030
Refrigerant type (BAU) new systems 2010	92% R404A, 5% R407C, 2% R134a, 1% all AOs (R290+R744+R717)	95% R22 (RTOC 2006), remainder R404A and to a lesser extent R134a
2015	87% R404A, 10% R134a, 3% AO	90% R22, 10% R404A, R134a, 0% AO
2020	70% R404A, 18% R134a, 12% AO	96% R404A, R134a, 4% AO
2030	40% R404A, 30% R134a, 25% AO	89% R404A, R134a, 11% AO

[54] RTOC2006 presents on page 63 a table with all supermarkets in the world by regions/countries – without mentioning the minimum size, i.e. TOTAL 462,034 + 14,925 = 476,959, which, looking at the IRI and FMI figures, seem to be more realistic than 280,000 in the 2010 draft.

Average unit data:		
Refrigerant charge	Average 230 kg, ranging from 40 to 3,000 kg (UNEP2010 numbers yield 560 kg as average charge which seems to be too high).	Average 230 kg, ranging from 40 to 3,000 kg (UNEP2010 numbers yield 560 kg as average charge which seems to be too high); majority of existing systems in A5 countries use R22.
Lifetime	12 years /UNEP2010/	Av. 20 (15 to 25 years /UNEP2010/)
Leakage rate	15% p.a. (5 – 35% p.a.) /UNEP2010/	25% p.a. (more than 5 – 35% p.a.) /UNEP2010/
Rated capacity	Average 100 kW, ranging from 20 kW to > 1,000 kW /UNEP2010/	Average 100 kW, ranging from 20 kW to > 1,000 kW /UNEP2010/.
Annual energy use	175,200 kWh (COP = 3; 50% run time)	175,200 kWh (COP 3; 50% run time)
Cost of unit	€340,000	€300,000

Abatement Options

Abate-ment option	Year	Max. technical penetration rate in new units		Capital investment costs per unit	Unit investment costs per unit	Additional operating costs[55]
		A2	A5			
CO_2 transcritical [56]	2015 2020 2030	5% 15% 30%	0% 2.5% 5%	Tooling is estimated to be €250,000 for a company building approx. 1,000 supermarkets a year, so one could say that it will be €250 per supermarket with a threshold value, i.e. a company cannot buy tooling for building only 4 supermarkets for 1,000 €.	25 % additional costs for in 2015 2020: +15% 2030: +0%	-7,5 % energy consumption; numbers only valid for moderate climates, i.e. north of Frankfurt/Main. Service cost similar to those for HFC systems.

[55] Climate: A2 50% moderate climate, 50% warm climate, A5 : 75% warm climate

[56] R744 is so far only installed in moderate climates due to lower energy efficiency at high ambient temperatures when compared to HFC systems.

HC + CO_2 as evap. Second-ary [57][58]	2015 2020 2030	20% 40% 90%	5% 20% 80%		50% additional costs for small supermarkets, 20% additional cost for large supermarkets; (assumed investment costs reduction to 20% additional cost (small) to 0% (large) additional cost in 2020 and 0% in 2030) Charge reduction: 75%	Should use av 7.5 (5 to 10%) less energy than comparable HFC systems in all climates. This difference is expected to remain also in 2020 and 2030
HC + liqu. sec for MT and CO_2 cascade for LT	2015 2020 2030	20% 40% 90%	5% 20% 80%		30% additional costs for small supermarkets, 15% additional cost for large supermarkets; (assumed investment cost reduction to 5% additional cost (small) to 0% (large) additional cost in 2020 and 0% in 2030) Charge reduction 90%	Same energy consumption.
Unsat. HFC + CO_2	2015 2020 2030	1% 30% 90%	0% 2.5% 5%		30 % additional costs in 2015 2020: +10% 2030: +0% Charge reduction 66%	-3 % energy consumption

R717 is not seen as a commercially viable alternative for centralized commercial systems due to the high investment cost and the training level of the refrigeration technicians.
Currently, discussed unsaturated HFCs are not seen as a viable alternative due to their flammability, even if their flammability index is lower (flame propagation, minimum ignition energy,etc.); if flammable refrigerants are to be used in indirect supermarket systems, HCs will be more cost efficient and probably also more energy efficient.

Melting secondary refrigerant does not seem to be a viable alternative for centralized commercial systems in the next 20 years.

---

[57] HC/R744 cascade system for LT with pump circulation of CO_2 for MT seems to be a viable alternative for warmer climates. Only pilot installations exist today. No experience for cost figures.

[58] R134a/R744 cascade systems with R134a as DX system for MT are marketed by several companies as a lower GWP option. According to our AOs, this is not an AO and therefore is not included in the MACCs.

Data Input Sheet – Commercial refrigeration – condensing units

Business as Usual

Region	A2	A5
New units per year	1 to 1.5m units (7 to 10% of total stock in A2 annually at equipment lifetime 10 to 15 years) (UNEP2010)	0.8 to 1.2m units (4 to 6% of total stock in A5 annually at equipment lifetime in A5 between 15 and 25 years) (UNEP2010)
Total stock	Assumed 14m units in A2 In 2006, 34m condensing units worldwide Majority of systems installed in A5 countries /UNEP2010/.(estimated 1m in Europe /DKV2002/)	Assumed split between A2 and A5: 40%/60%, i.e. 14m units in A2 and 20m units in A5.
Consumption	26,800 t = 1.25m*8kg+14 m*8kg*15%	20,400 t =1.1m*4kg+20m*4kg*20%
Bank	112,000 t =14m*10 kg	80,000 t =20m units x 5 kg
Annual growth	+1.5% to 2015 +1.5% to 2020 +1.5% to 2030 (all based on 2010) (Number of supermarkets is expected to decrease in many A2 countries; shift towards larger markets)	+4.5% to 2015 +3% to 2020 +1.5% to 2030 (all based on 2010) (decrease because of shift to centralized systems)
Refrigerant type (BAU) new units 2010 2015 2020 2030	92% R404A, 5% R407C, 2% R134a, 1% all AOs (R290+R744+low GWP HFCs) 87% R404A, 10% R134a, 3% AO 70% R404A, 16% R134a, 14% AO 35% R404A, 20% R134a, 30% AO	95% HCFC R22 (RTOC 2006), remainder R404A and to a lesser extent R134a 90% R22, 10% R404A, R134a, 0% AO 96% R404A, R134a, 4% AO 89% R404A, R134a, 11% AO
Average unit data:		
Refrigerant charge	Average 8 kg, ranging from 1 to 5 kg (UNEP2010) or ranging from 10 to 20 kg (Rhiemeier et al 2008).	Average 4 kg, ranging from 1 to 5 kg (UNEP2010)
Lifetime	15 years (UNEP2010)	Av. 20 (15 to 25) years (UNEP2010)
Leakage rate	10% p.a. (7 – 12% p.a.) (UNEP2010)	20% p.a. (5 – 35% p.a.) (UNEP2010)
Rated capacity	Average 15 kW, ranging from 5 kW to 20 kW /UNEP2010/ or even up to 50 kW /Rhiemeier et al 2008/	Average 5 kW, ranging from 5 kW to 20 kW /UNEP2010/. A5 systems are smaller therefore average 5 kW
Annual energy use	22,000 kWh (cop = 3. 50% run time)	9,000 kWh (cop 2.5; 50% runtime)
Cost of unit	*Cost condensing unit alone: € 8,000*	*Cost condensing unit alone: € 1,200*

Abatement Options

Abate-ment option	Year	Max. technical penetration rate in new units		Capital investment costs per unit	Unit investment costs per unit	Additional operating costs[59]
		A2	A5			
R290/ R1270 [60]	2015 2020 2030	20% 30%[61] 40%	20% 40% 60%	1% additional cost; possibly explosion proof charging equipment	20% additional costs for explosion proof electric components close to refrigeration circuit; pipe sizes can be reduced which will counterweigh the additional cost for ex-proof); training of personal etc. Assumed investment costs reduction to 10% additional costs in 2020 and 5% additional costs in 2030. Charge reduction 50%.	3% lower energy consumption.
R744[62]	2015 2020 2030	10% 20% 30%	2% 5% 10%	Tooling is estimated €250,000 for a company building 1,000 supermarkets a year, so one could say that it will be €250 per supermarket with a threshold value, i.e. a company cannot buy tooling for only building 4 supermarkets for 1,000 €. This is accounted for in 1% cap. Invest cost.	35% additional costs including additional measures to achieve same efficiency as HFC-unit (Assumed investment costs reduction to 20% additional costs 2020 and 0% in 2030)	Same energy efficiency achieved through higher investment cost; in moderate climate -3% energy use. 25% more in warmer climates. Additional Service cost: +2 working hours per year compared to those for HFC systems.

59 Climate: A2 50% moderate climate, 50% warm climate, A5: 100% warm climate

60 Maximum potential for is based on a change in legislation concerning the liability when using flammable gases and the maximum charge. It is now 150 g would have to be raised to a few kg.

61 Typical condensing units in A2 are too big for HCs, i.e. refrigerant charge is too high.

62 R744 is so far only installed in moderate climates due to lower energy efficiency at high ambient temperatures when compared to HFC systems. This is reflected in low penetration rates, only taking moderate climates as possible locations.

HC+ liquid secondary refr.	2015 2020 2030	5% 30% 60%	5% 20% 40%		35% additional costs due to explosion proof components and training; (Assumed investment costs reduction to 10% additional costs in 2020 and 0% in 2030). In addition 30% for improving energy efficiency to the level of the HFC system. Charge reduction 80%.	Same energy efficiency achieved through higher investment cost; otherwise should use 5% more energy than comparable HFC systems in all climates. This difference is expected to remain also in 2020 and 2030
Unsat. HFC + liquid secondary refr. [63]	2015 2020 2030	1% 20% 60%	0% 10% 20%		35% additional costs; (assumed invest costs reduction to 10% additional cost in 2020 and 0% in 2030). In addition 40% for improving energy efficiency to the level of the HFC system. Charge reduction 70%	Same energy efficiency achieved through higher investment cost; otherwise should use 10% more energy than comparable HFC systems in all climates. This difference is expected to remain also in 2020 and 2030

R134a is marketed by several companies as a lower GWP option. According to our AOs, this is not an AO and therefore is not included in this DIS.
Development of CO_2 components for centralized systems goes into the direction of 75 bar pressure proof components such that those systems will not suffer from excessive system pressure and subsequent CO_2 venting.
R717 is not seen as a commercially viable alternative for condensing units due to the fact that no small ammonia compressors are produced and those systems would have to be indirect and hence add a considerable amount of complexity as well as cost and energetic penalty.
It is to be seen if currently discussed low GWP alternatives will be used due to their flammability; if flammable refrigerants are to be used in indirect supermarket systems, HCs will probably be more cost efficient and probably also energy efficient due to better thermodynamic properties than low GWP HFCs.

An abatement option could be using several plug-in units.

[63] It is more likely that HCs would be used in indirect systems. Low GWP HFCs are only interesting in DX systems.

Data Input Sheet – Commercial refrigeration – stand alone refrigerators and freezers

Business as Usual

Region	A2	A5
New units per year	10 to 14% of total stock in A2 annually ca. 3 m units/yr (EU Ecodesign, Lot12). Lifetime 7 - 10 years	5 to 14% of total stock in A5 annually: about 3m units/yr. Lifetime in A5 between 7 and 20 years
Total stock	52.5 m units (20.5m vending and 32m other). (UNEP 2010) Assumption: A2/A5: 50/50 %. A2: 26.25m (2006)	A5: 26.25m (2006) (UNEP 2010)
Consumption	1,552 t (refill: 352 t, new units: 1,200 t)	1,552 t (refill: 352 t, new units: 1,200 t)
Bank	19,000 t (Worldwide 38,000 t in 2006; UNEP 2010) Assumption: 50% in A2, 50 % in A5 (CFCs, HCFCs and HFCs)	19,000 t (CFCs+HCFCs+HFCs).
Annual growth	Annually +2.0 to +3.9 % 2010-2020 (EU Ecodesign Lot12) 2% annual growth until 2030	Worldwide annual growth in commercial refrigeration expected to be 5.3 % in 2005 – 2008 (EU Ecodesign Lot12). A5 countries expected to range at av. 8,5% (7% – 10%) p.a. in 2010 – 2030.
Refrigerant type (BAU) 2010 2015 2020 2030	49% R404A, 49% R134a, 2% all AOs (R290+R600a) 47% R404A, 47% R134a, 6% AO 40% R404A, 40% R134a, 20% AO 30% R407C, 30% R134a, 40% AO	50% R404A, 50% R134a, 0% AO 49% R404A, 49% R134a, 2% AO 47% R404A, 47% R134a, 6% AO 40% R404A, 40% R134a, 20% AO
Average unit data:		
Refrigerant charge	Average 0.4 kg, ranging from 0.1 to 1 kg	Average 0.4 kg, ranging from 0.1 to 1 kg
Lifetime	Av.10 (7 – 10) years	Av. 14 (7 – 20) years
Leakage rate	1 % p.a. (UBA 2009)	3 % p.a.
Rated capacity	Average 500 W, ranging from 100W to more than 4500 W (Rhiemeier et al, 2008)	Average 500 W, ranging from 100W to more than 4500 W (Rhiemeier et al, 2008)
Annual energy use	1,800 kWh (400 l bottle cooler)	1,800 kWh (400 l bottle cooler)
Cost of unit	800 Euro (400 l bottle cooler)	600 Euro (400 l bottle cooler)

Abatement Options

Abate-ment option	Year	Max. technical penetration rate in new units		Capital investment costs per unit	Unit investment costs per unit	Additional operating costs
		A2	A5			
R 600a and R 290	2015 2020 2030	50% 85% 85%	20% 85% 85%		A2+ A5 : 10% Charge reduction: 50%	The technology is commercially available and no significant extra cost for the units occur except for bigger plug-in ice machines and vending machines. Hydrocarbon machines are more energy efficient (-5% energy consumption.
R 744	2015 2020 2030	20% 40% 60%	5% 10% 20%		+20 - +40 % additional costs in 2010. Assumed investment cost reduction -25% in 2020 and -50% in 2030	In average -5% energy consumption compared to HFC units in 2015 (moderate or indoor climate)

Unsaturated HFCs might also be seen as a viable alternative. However there is no data available yet. Total number of units seems rater low in UNEP2010 compared to figures in EU Ecodesign reports.

Data Input Sheet – Small Industrial refrigeration systems

Business as Usual

Region	A2	A5
New units per year	394 units	1,414 units
Bank	36,850 t	21,200 t
Total stock	11,383 units	6,703 units
Annual growth	+4% to 2015 (IPCC/TEAP 2005) +4% to 2020 +3% to 2030	+7% to 2015 (IPCC/TEAP 2005) +7% to 2020 +5% to 2030
Refrigerant type (BAU) 2010 2015 2020 2030	 45% R404A, 55% AOs (mostly NH3) 45% R404A, 55% AO 45% R404A, 55% AO 45% R404A, 55% AO	 82 % R-22, (2)% R404A, 16% AO 62 % R-22, 22% R404A, 16% AO 76% R404A, 24% AO 84 % R404A, 16% AO
Consumption	4,845 t	6,592 t
Average unit data:		
Refrigerant charge	650 kg	650 kg
Lifetime	30 years	30 years
Leakage rate	Av. 8% (7.2% – 8.2%) p.a. (UNEP2010)	HCFC: 21.5% (UNEP 2010) HFC: 8.2% (UNEP2010) Av. 12%
Rated capacity	270 kW	270 kW
Annual energy use	500,000 kWh	500,000 kWh
Cost of unit	425,000 Euro	425,000 Euro

Abatement Option

Abate-ment option	Year	Max potential New systems		Capital investment costs per unit	Unit investment costs per unit	Additional operating costs
		A2	A5			
NH_3	2015 2020 2030	60% 70% 95%	30% 40% 80%		A2+A5: Installations are built on site with commercially available components Small base case: + 50%	This technology is more energy efficient compared to HFC. Small base case: - 15 % el. consumption

Data Input Sheet – Large Industrial refrigeration systems

Business as Usual

Region	A2	A5
New units per year	1,181 units (2006)	4,242 units (2006)
Bank	110,550 t (2006)	63,600 t (2006)
Total stock	34,150 units (2006)	20,110 units (2006)
Annual growth	+4% to 2015 (IPCC/TEAP 2005) +4% to 2020 +3% to 2030	+7% to 2015 (IPCC/TEAP 2005) +7% to 2020 +5% to 2030
Refrigerant type (BAU) 2010 2015 2020 2030	 45% R404A, 55% AOs (mostly NH3) 45% R404A, 55% AO 45% R404A, 55% AO 45% R404A, 55% AO	 82 % R-22, (2)% R404A, 16% AO 62 % R-22, 22% R404A, 16% AO 76% R404A, 24% AO 84 % R404A, 16% AO
Consumption	14,535 t (2006)	19,777 t (2006)
Average unit data:		
Refrigerant charge	4,000 kg	4,000 kg
Lifetime	30 years	30 years
Leakage rate	Av. 8% (7.2% – 8.2%) p.a. (UNEP 2010)	HCFC: 21.5%; HFC: 8.2% (UNEP 2010) Average: 12%
Rated capacity	5 MW, various temp.	5 MW, various temp.
Annual energy use	9,000,000 kWh/yr	9,000,000 kWh/yr
Cost of unit	6 million Euro	6 million Euro

Abatement Option

Abatement option	Year	Max potential New systems		Capital investment costs per unit	Unit investment costs per unit	Additional operating costs
		A2	A5			
NH_3	2015 2020 2030	60% 70% 95%	30% 40% 80%		A2+A5: Installations are built on site from commercially available components 50 % additional investment costs	This technology is more energy efficient compared to HFC -15 % energy consumption

Data Input Sheet – Transport refrigeration – trucks and trailers (including vans)

Business as Usual

Region	A2	A5
New units per year	0.32m	0.08m
Total stock	3.2m[64] A2+A5: 4 million in total; 30% are trailers (volume up to and over 100 m^3), 30% are large trucks (volume between 20 and 59 m^3) and 40% are small trucks and vans (below 19 m^3) (UNEP 2010) The region of North America has the major share, ca. 60%, followed by Europe with a market share of 20%. The remaining 20% is shared among rest of the countries (Infinity Research Limited Inc. 2009)	0.8m
Consumption	New units : 1,616 t = 320,000 *(0.3*7.5+0.7*4)/1,000 t Leakage recharge: 2,424 t	New units : 404 t =80,000*(0.3*7.5+0.7*4)/1,000 t Leakage recharge: 1,010 t
Bank	4 m*80%*(0.3*7.5+0.7*4)/1,000 t = 16,160 t[65]	4 m*20%*(0.3*7.5+0.7*4)/1,000 t = 4,040 t
Annual growth	Global Road Freight Transport is expected to grow at a rate of 2.5 percent by 2030 /Technavio/ 1% to 2015 1% to 2020 1% to 2030	+10% to 2015 +10% to 2020 +10% to 2030
Refrigerant type (BAU) new units 2010 2015 2020 2030	Refrigerants typically used are R-404A and HFC-134a but also R-410A or R-407C /UNEP2010/ 100 % HFC, 0%AO 98% HFC, 2% AO 89% HFC, 11% AO 77% HFC, 23% AO	 100% HFC, 0% AO 100% HFC, 0% AO 96.5% HFC, 3.5% AO 92.5% R134a, 7.5% AO
Average unit data:		
Refrigerant charge	Trucks: Average charge 4 kg ranging from 0.5 kg to 10 kg Trailers: Average 7.5 kg /UNEP2010/ Average over both 6.5 kg	Trucks: Average charge 4 kg ranging from 0.5 kg to 10 kg Trailers: Average 7.5 kg /UNEP2010/ Average over both 6.5 kg
Lifetime	Av. 12 (10 to 15) years	Av. 15 (10 to 20) years
Leakage rate	20% p.a. (5 – 25% p.a.)	25% p.a. (10 – 50% p.a.)
Rated capacity	LT: 0.5 to 10 kW; MT: 0.8 to 20 kW /UNEP2010/	LT: 0.5 to 10 kW; MT: 0.8 to 20 kW /UNEP2010/

[65] UNEP2010: 19,400 t total for A2+A5

Annual energy use	32,000 kWh	32,000 kWh
Cost of unit	Average 20,000 (Trucks and vans (direct drive from vehicle engine) € 4-10,000; Trucks (diesel engine) € 10-20,000; Trailers € 20,000. One can find multi temperature units priced at € 30,000, but this is rather extreme)	€ 18,000

Abatement Options

Abate-ment option	Year	Max. technical penetration rate in new units		Capital investment costs per unit	Unit investment costs per unit	Additional operating costs
		A2	A5			
R290/ R1270	2015 2020 2030	20% 40% 80%	20% 40% 80%		Unit investment slightly higher (+10%) due to more safety requirements, other charging equipment and training; Refrigerant cost is negligible Refrigerant charge reduction: 50%	4% lower energy consumption
R744[66]	2015 2020 2030	12.5 % 25% 45%	1.25% 5% 12.5%		2015: 15% 2020: 10% and 2030: 5%. Refrigerant cost negligible	-2% energy consumption – except for high ambient temperatures
Unsaturated HFCs *)	2015 2020 2030	0% 5% 20%	0% 0% 10%		Unit investment slightly higher (+5%) due to more safety requirements; refrigerant is much more expensive than R134a.	Same energy consumption as HFC reference system; refrigerant cost at service is much more expensive.

*) Unsaturated HFCs (R1234yf) will not be suitable for multi-temperature use trucks and/or trailers, i.e. HT, MT and LT with the same unit.

[66] R744 will only be an energy efficient alternative in moderate and cold climates. In hot climates, energy consumption is expected to be higher than the HFC-reference system no matter what improvements are made to the R744 system.

Data Input Sheet – Transport refrigeration – containers

Business as Usual

Region	A2	A5
New units per year	Worldwide: 100,000 (UNEP 2010)	Refrigerated containers are a worldwide business – there is no difference between A2 and A5
Total stock	Worldwide: 150,000 units of 20ft containers and 800,000 units of 40ft (UNEP 2010)	
Consumption	664 t =(100,000 new units*4.5 kg +950,000 stock units*4.5 kg *5%)/1,000 kg/t	included in A2 figure
Bank	4250 t (3,600 t of HFC- 134a and 650 t of R404A)	Included in A2 figure
Annual growth	+3% to 2015 +3% to 2020 +3% to 2030	
Refrigerant type (BAU) new units 2010 2015 2020 2030	approx. 10 – 15% R404A, all others R134a, 0% AO 99% HFC, 1% AO 95% HFC, 5% AO 90% HFC, 10% AO	
Average unit data:		
Refrigerant charge	Average charge 4.5 kg; ranging from 3.8 kg to 5.3 kg	
Lifetime	Av. 14 (12 to 15) years	
Leakage rate	5% p.a.	
Rated capacity	maximum refrigeration capacity is around 4 kW at box temperature of –29 ℃, around 6 kW at box temperature of –18 ℃, and it is around 12 kW at box temperature of 2 ℃ (UNEP 2010)	
Annual energy use	8,000 kWh (4 kW; 2000 h run time)	
Cost of unit	€ 6,000 for refrigeration unit alone; US$ 18,000 (40'' reefer container including refrigeration unit, refrigeration unit is USD 8,000)	
Operation Cost per unit (maintenance +refill, excl electricity cost)	~US$ 500 – 1,000 (excl. electricity, excl. re-positioning)	

Abatement Options

Abate-ment option	Year	Max. technical penetration rate in new units		Capital investment costs per unit	Unit investment costs per unit	Additional operating costs
		A2	A5			
CO_2	2015 2020 2030	10% 70% 100%	10% 70% 100%		2010: 20% additional costs 2015: 15% 2020: 10% and 2030: 5%.	Energy consumption about equal – except for high ambient temperatures and high box temperatures

R1234yf will not be suitable due to multi-temperature use of reefer containers, i.e. HT, MT and LT with the same unit.
Reefer containers are used globally, i.e. no difference between A2 and A5.

Data Input Sheet – Stationary air conditioning – moveables (factory sealed)

Business as Usual

Region	A2	A5
New units per year (Total 16.0m; 1.0m portables, 15,0m window)	9.4m (59% of total) 0.6 m portable, 8.8m window (BSRIA 2009)	6.6m (41% of total) (0.4m portable, 6.2m window) (BSRIA 2009)
Total stock	105m (estimated)	115m (estimated)
Consumption (new + serv)	11 kt (8.5 kt HFC, 2.5 kt HCFC) (estimated)	13.5 kt (HCFC) (estimated)
Bank	80 kt (25 kt HFC, 55 kt HCFC) (estimated)	85 kt (HCFC) (estimated)
Annual growth	-1.8% to 2015 -1.8% to 2020 -1.8% to 2030 (BSRIA 2009)	-1.8% to 2015 -1.8% to 2020 -1.8% to 2030 (BSRIA 2009)
Refrigerant type 2010 2015 2020 2030	 99% HFC R407C, R410A, 1% HC R290 (UNEP 2006) 98% R407C, R410A, 2% AO 97% R407C, R410A, 3% AO 95% R407C, R410A, 5% AO	 100% HCFC R22 (RTOC 2006) 90% R22, 10% R407C, R410A 98% R407C, R410A, 2% AO 96% R407C, R410A, 4% AO
Average unit data:		
Refrigerant charge	0.75 kg per unit	0.75 kg per unit
Lifetime	10 years	15 years
Leakage rate	5% p.a.	10% p.a.
Rated capacity	3 kW	3 kW
Annual energy use	1,000 kWh	1,000 kWh
Cost of unit	€ 300	€ 200

Abatement Options

Abatement option	Year	Max. technical penetration rate in new units		Capital investment costs per unit †	Unit investment costs per unit	Additional operating costs
		A2	A5			
R290 / R1270	2015 2020 2030	20% 50% 60%	20% 50% 60%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +0.5% onto product cost (10 year reference period). (Equates to €3m per 250,000 units annual production)	A2 and A5 the same. For same efficiency rating, product costs marginally less because material (condenser, refrigerant) costs one-third less than R22 and HFC systems; -1% per unit. Charge reduction 50%	Same energy consumption (due to target energy label)
R744 ‡	2015 2020 2030	10% 15% 20%	10% 15% 20%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, approx +0.5% onto product cost for first year. (Equates to €4 m per 250,000 units annual production)	A2 and A5 the same. For same efficiency rating, product costs more because of more material weight costs and to compensate for poor performance for high ambient; approx 3/4 more than R22 or HFC systems; +20% per unit	Same energy consumption (due to target energy label)
Unsat. HFCs (R1234yf) ‡	2015 2020 2030	1% 35% 70%	0% 35% 70%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +0.5% onto product cost (10 year reference period). (Equates to €3m per 250,000 units annual production)	A2 and A5 the same. For same efficiency rating, product costs more because of more material weight and much greater refrigerant costs; double R22 and HFC systems; +6% per system	Same energy consumption (due to target energy label)

† Assumes costs to be identical in A2 and A5 countries since, 80% of manufacturing is centralised in very few manufacturing sites within a small number of A5 countries.

‡ Approximations because (a) no manufacturer currently using this AO and (b) no feedback information on R1234yf.

Please note: Energy assumptions for the abatement technologies are in line with the draft COMMISSION REGULATION implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans.

Data Input Sheet – Stationary air conditioning – single split type

Business as Usual

Region	A2	A5
New units per year (Total 65.9m; 59m non-ducted, 6.9m ducted)	26.3m (39.9% of total) 19.8m non-ducted, 6.5m ducted (BSRIA 2009, UNEP 2006)	39.6m (60.1% of total) (39.2m non-ducted, 0.4m ducted) (BSRIA 2009, UNEP 2006)
Total stock	180 m (estimated)	340 m (estimated)
Consumption	45 kt (35 kt HFC, 10 kt HCFC) (estimated)	95 kt (HCFC) (estimated)
Bank	230 kt (60 kt HFC, 170 kt HCFC) (estimated)	440 kt (HCFC) (estimated)
Annual growth	+7% to 2015 +4% to 2020 0% to 2030 (BSRIA 2009, Daikin, 2010)	+4.7% to 2015 +4.7% to 2020 +4.7% to 2030 (BSRIA 2009, BSRIA, 2008)
Refrigerant type 2010 2015 2020 2030	 100% HFC R407C, R410A (UNEP 2006) 98% R407C, R410A, 2% AO 97% R407C, R410A, 3% AO 95% R407C, R410A, 5% AO	 100% HCFC R22 (UNEP 2006) 90% R22, 10% R407C, R410A 33% R407C, R410A, 2% AO 96% R407C, R410A, 4% AO
Average unit data:		
Refrigerant charge	1.5 kg per unit	1.5 kg per unit
Lifetime	10 years	15 years
Leakage rate	5% p.a.	10% p.a.
Rated capacity	4.5 kW	4.5 kW
Annual energy use	1,500 kWh	1,500 kWh
Cost of unit	€750	€500

Abatement Options

Abate-ment option	Year	Max. technical penetration rate in new units		Capital investment costs per unit †	Unit investment costs per unit	Additional operating costs
		A2	A5			
R290 / R1270	2015 2020 2030	20% 45% 50%	20% 50% 70%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +0.5% onto product cost (10 year reference period). (Equates to €4m per 250,000 units annual production)	A2 and A5 the same. For same efficiency rating, product costs marginally less because material (condenser, refrigerant) costs one-third less than R22 and HFC systems; -2% per unit. Charge red. 50%	Same energy consumption (due to target energy label)
R744 ‡	2015 2020 2030	10% 15% 30%	5% 10% 20%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, approx +0.5% onto product cost for first year. (Equates to €6 m per 250,000 units annual production)	A2 and A5 the same. For same efficiency rating, product costs more because of more material weight costs and to compensate for poor performance for high ambient; approx 3/4 more than R22 or HFC systems; +25% per unit	Same energy consumption
Unsat. HFCs (R1234 yf) ‡	2015 2020 2030	1% 40% 60%	0% 30% 40%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +0.5% onto product cost (10 year reference period). (Equates to €4m per 250,000 units annual production)	A2 and A5 the same. For same efficiency rating, product costs more because of more material weight and much greater refrigerant costs; double R22 and HFC systems; +8% per system	Same energy consumption (due to target energy label)

† Assumes costs to be identical in A2 and A5 countries since, 80% of manufacturing is centralised in very few manufacturing sites within a small number of A5 countries.

‡ Approximations because (a) no manufacturer currently using this AO and (b) no feedback information on R1234yf.

Please note: Energy assumptions for the abatement technologies are in line with the draft COMMISSION REGULATION implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans.

Remark on the replacement potential of hydrocarbon refrigerants in split room air conditioners

The purpose of this remark is to estimate the proportion of HCFC/HFC use in split air conditioners that could be displaced by Class A3 flammable refrigerants within the constraints applied by current standards.

The table below provides the distribution of split air conditioners according to rated cooling capacity for the world. This base sales data is taken from BSRIA studies.

Windows and portables are not considered here.

The following table is explained as:

- Column 1 – the capacity range.
- Column 2 – the estimated number of sales for the particular capacity range.
- Column 3 – total cooling capacity of sold products, i.e., sales × average capacity.
- Column 4 – the average HCFC or HFC specific charge size in kg/kW; note that the specific charge is greater for smaller capacity units and less for larger capacity units. The average for the entire population is 0.25 kg/kW according to RTOC, 2010.
- Column 5 – the average HCFC/HFC charge size for the particular capacity range, i.e., specific charge × capacity.
- Column 6 – the total HCFC/HFC required for the sold population of units within the capacity range, i.e., charge size × sales.
- Column 7 – the distribution of the HCFC/HFC use or (first) charge according to the unit capacity.

1	2	3	4	5	6	7
Capacity range (kW)	Sales (2010) (000's units)	Total cooling capacity (kW)	HFC specific charge (kg/kW)	HFC charge size (kg)	Total HFC charged (tonnes)	Mass HFC proportion (%)
<2.5	16,726	41,816	0.30	0.7	12,356	20%
2.5-4	16,239	52,776	0.27	0.9	14,414	23%
4-5	14,002	63,007	0.25	1.1	15,607	25%
5-7	7,563	45,380	0.23	1.4	10,311	17%
7-10	3,160	26,860	0.20	1.7	5,498	9%
10-17	886	11,957	0.18	2.4	2,130	3%
>17	443	7,528	0.17	2.8	1,252	2%
Total	59,019	249,324	–	–	61,567	–

As with HCFCs/HFCs, the required refrigerant charge is similarly linked to the rated cooling capacity.

The table below compares the R290 charge size expected with a particular capacity against the room-size limited charge size determined according to safety standards.

The following table is explained as:

- Column 1 – the capacity range.
- Column 2 – HC charge size (R290) based on specific charge of current high efficiency AC models (averaging 100 g/kW for a 5 kW rated unit).
- Column 3 – the room size that would normally be satisfied by a unit of the given capacity. This is estimated based on a nominal heat load of 100 W per m^2 of room floor. This would vary by ±50% depending upon application, local climate, and so on. This value is considered to represent the majority of situation.
- Column 4 – the R290 charge limit according to the formula used in certain standards, based on floor unit. The formula referred to is: $M = 2.5 \times LFL^{1.25} h_{unit} \sqrt{A}$, where LFL is lower flammability limit, h_{unit} is install height of unit and A is room floor area. Note that if R1270 (propylene) to be used instead of R290 (propane) the charge limit in columns 4 and 5 would be 10% higher.
- Column 5 – the R290 charge limit according to the formula used in certain standards, based on wall unit.
- Column 6 – the R290 charge limit according to the formula used in certain standards, based on ceiling unit.
- Column 7 – the upper limit for R290 specified by certain standards. If R1270 were used this would be 1.05 kg.

1	2	3	4	5	6	7
Capacity range (kW)	HC charge size (kg)	Room area (m2)	Charge limit – floor (kg)	Charge limit – wall (kg)	Charge limit – ceiling (kg)	Upper limit (kg)
<2.5	0.30	25	0.13	0.38	0.46	0.99
2.5-4	0.36	33	0.14	0.43	0.53	0.99
4-5	0.45	45	0.17	0.51	0.62	0.99
5-7	0.55	60	0.19	0.58	0.71	0.99
7-10	0.70	85	0.23	0.70	0.85	0.99
10-17	0.96	135	0.29	0.88	1.07	0.99
>17	1.13	170	0.33	0.98	1.20	0.99

By comparing the HC charge size for the units against the standard limits applied based on room size and the upper limit, it can be estimated the proportion of HCFC/HFC that can be displaced. This is indicated on the next table.

It can be seen that for units with cooling capacity up to about 7 kW R290 or R1270 can be widely used for wall and ceiling units, whilst HCs could not be used in some larger systems.

Accordingly, HC can be used in about 80% of the cases where HCFC/HFC mass charged in these systems. In none of the cases can HCs be used in floor units; these represent about 15% of sales, implying that HCs would instead be limited to about 65% of the HCFC/HFC refrigerant mass.

Capacity range (kW)	Remark on HC use	Percentile (mass HFC displaced)	Percentile (number HFC units displaced)	Percentile (cooling capacity displaced)
<2.5	HC can be used for wall and ceiling	20%	28%	17%
2.5-4	HC can be used for wall and ceiling	43%	56%	38%
4-5	HC can be used for wall and ceiling	69%	80%	63%
5-7	HC can be used for wall and ceiling	86%	92%	81%
7-10	Borderline for wall units	95%	98%	92%
10-17	Borderline for ceiling units	98%	99%	97%
>17	HC Cannot be used due to charge > 1 kg	100%	100%	100%

Additional remarks

- Specific charge sizes vary widely, however, with improved technical development it is seen that these will reduce over time.
- The averaged specific charge of 100 g/kW of HC is for cooling only models. Typically reversible models require around 10% more refrigerant. However, many models have been found that are both reversible and inverter-driven that still do not exceed this specific charge whilst also meeting A-rated efficiency.
- Typically systems are pre-charged for 7.5 m pipe length; additional refrigerant can be added for piping of up to 15 m – this would result in additional 50 g (approximately) of HC refrigerant charge which could reduce the percentage of HFC displaced by some 10%.
- Cooling loads (in relation to room size) vary widely.
- The standard referred to is IEC 60335-2-40 and EN 60335-2-40. European standard EN 378: 2008 does not impose the 1 kg upper charge size limit.
- The use of R161 (GWP = 12) has not been considered, but the charge limits would be approximately double those estimated above for HCs.

Data Input Sheet – Stationary air conditioning – multi-split systems

Business as Usual

Region	A2	A5
New units per year (Total 3.3m) (includes conventional multi-split, VRV, VRF), etc)	1.95m (59% of total) (BSRIA 2009, UNEP 2006)	1.35m (41% of total) (BSRIA 2009, UNEP 2006)
Total stock	15m (estimated)	10m (estimated)
Consumption	40 kt (30 kt HFC, 10 kt HCFC) (estimated)	35 kt (HCFC) (estimated)
Bank	220 kt (50 kt HFC, 170 kt HCFC) (estimated)	130 kt (HCFC) (estimated)
Annual growth	+5% to 2015 +3% to 2020 0% to 2030 (BSRIA 2009, UNEP 2006, Daikin 2010)	+9.5% to 2015 +9.5% to 2020 +9.5% to 2030 (BSRIA 2009, UNEP 2006, BSRIA 2007)
Refrigerant type 2010 2015 2020 2030	100% HFC R407C, R410A (UNEP 2006) 100% HFC, 0% AO 100% HFC, 0% AO 100% HFC, 0% AO	70% HCFC R22, 30% HFC R407C, R410A (UNEP 2006) 65% R22, 35% HFC 100% HFC 100% HFC
Average unit data:		
Refrigerant charge	13.5 kg per unit	13.5 kg per unit
Lifetime	10 years	15 years
Leakage rate	8% p.a.	10% p.a.
Rated capacity	27 kW	27 kW
Annual energy use	25,000 kWh	25,000 kWh
Cost of unit	€10,000	€10,000

NOTE: All numbers (number of units, refrigerant charge, capacity, etc) refers to individual outdoor modules, not the total installation (which may comprise 1 or more outdoor modules).

Abatement Options

Abatement option	Year	Max. technical penetration rate in new units		Capital investment costs per unit †	Unit investment costs per unit	Additional operating costs
		A2	A5			
R744	2015 2020 2030	10% 20% 30%	5% 10% 20%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, negligible, +1% onto product cost (10 year reference period). (Equates to €10m per 10,000 units annual production, respectively)	A2 and A5 the same. Product costs notably more because materials and components (condenser, compressor, piping, etc) required is more, in addition to extra components; overall cost increase approx +20%	Efficiency typically the same in moderate climates but -10% in warm climates compared to R22 or R407C
Unsat. HFCs (R1234 yf) ‡	2015 2020 2030	1% 30% 70%	0% 30% 70%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, negligible, +1% onto product cost (10 year reference period). (Equates to €10m per 10,000 units annual production, respectively)	A2 and A5 the same. Product costs notably more because general material required (condenser, compressor, piping, etc) is more and refrigerant has much higher cost, in addition to other safety features; overall cost increase ca. +12%	Same efficiency is assumed.
R290 / R1270 + second ary	2015 2020 2030	20% 30% 70%	20% 30% 70%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, negligible, +1% onto product cost (10 year reference period). (Equates to €10m per 10,000 units annual production, respectively)	A2 and A5 the same. Chilled water system costs less than DX system, but product costs notably more because of need to improve efficiency relative to DX, and general material required (extra heat exchanger, pump, etc), in addition to other safety features, whilst cost	Same energy efficiency achieved through higher investment cost; otherwise the efficiency is about 10% lower due to poorer part-load operating efficiency (multi-split vs. chiller has 10 to 30% better efficiency)

					of (water) piping is lower; overall cost increase approx +25%; Charge reduction 85%	
R290 / R1270 + evapora t-ing second-ary) ‡	2015 2020 2030	5% 10% 20%	1% 5% 10%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, negligible, +1% onto product cost (10 year reference period). (Equates to €10 m per 10,000 units annual production, respectively)	A2 and A5 the same. Chilled water system costs less than DX system, but product costs notably more because of need to improve efficiency relative to DX, and general material (extra heat exchanger, pump, steel piping, etc) required, in addition to safety features; overall cost increase approx +35%; Charge reduction 85%	Same energy efficiency achieved through higher investment cost; otherwise the efficiency is about 5% lower due to poorer part-load operating efficiency (multi-split vs. chiller has 10 to 30% better efficiency)

† Costs are assumed to be identical in A2 and A5 countries since the costs within the manufacturing centres will become closer over projection period.

‡ Approximations because no manufacturer currently using these AOs.

NOTE 1: 'Negative' difference between AOs and R22 and R410A are generally less than 'negative' difference between AOs and R407C, since R407C is generally less efficient and requires more materials.

Data Input Sheet – Stationary air conditioning – ducted systems

Business as Usual

Region	A2	A5
New units per year (Total 2.07m) (0.75m rooftop ducted; 0.62m close-control; 0.70m central ducted AHU)	1.73m (84% of total) (BSRIA 2009, UNEP 2006)	0.34m (16% of total) (BSRIA 2009, UNEP 2006)
Total stock	17m (estimated)	4m (estimated)
Consumption	40 kt (30 kt HFC, 10 kt HCFC) (estimated)	10 kt (2 kt HFC, 8 kt HCFC) (estimated)
Bank	250 kt (190 kt HFC, 60 kt HCFC) (estimated)	60 kt (5 kt HFC, 55 kt HCFC) (estimated)
Annual growth	-0.1% to 2015 -0.1% to 2020 -0.1% to 2030 (BSRIA 2009, UNEP 2006, Daikin 2010)	+3% to 2015 +3% to 2020 +3% to 2030 (BSRIA 2008, UNEP 2006)
Refrigerant type 2010 2015 2020 2030	100% HFC R407C, R410A (UNEP 2006) 100% HFC, 0% AO 100% HFC, 1% AO 100% HFC, 2% AO	70% HCFC R22, 30% HFC R407C, R410A (UNEP 2006) 65% R22, 35% HFC 100% HFC 100% HFC
Average unit data:		
Refrigerant charge	10,5 kg per unit	10,5 kg per unit
Lifetime	10 years	10 years
Leakage rate	5% p.a.	10% p.a.
Rated capacity	30 kW	30 kW
Annual energy use	60,000 kWh	60,000 kWh
Cost of unit	€10,000	€8,000

Abatement Options

Abate-ment option	Year	Max. technical penetration rate in new units		Capital investment costs per unit †	Unit investment costs per unit	Additional operating costs
		A2	A5			
R744 ‡	2015 2020 2030	5% 15% 35%	2% 5% 10%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, negligible, +1% onto product cost (10 year reference period). (Equates to €10m per 10,000 units annual production)	A2 and A5 the same. Product costs notably more because materials and components (condenser, compressor, etc) required is more, in addition to extra components; overall cost increase approx +15%	Efficiency typically the same in moderate climates but -10% in warm climates compared to R22 or R407C
Unsat. HFCs (R1234 yf) ‡	2015 2020 2030	1% 30% 70%	0% 30% 70%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, negligible, +1% onto product cost (10 year reference period). (Equates to €10m per 10,000 units annual production, respectively)	A2 and A5 the same. Product costs notably more because general material (condenser, compressor, etc) required is more and refrigerant has much higher cost, in addition to other safety features; overall cost increase ca. +12%	Assuming same efficiency means no difference in energy consumption
R290 / R1270 + second ary	2015 2020 2030	20% 40% 80%	20% 40% 80%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, negligible, +1% onto product cost (10 year reference period). (Equates to €10m per 10,000 units annual production)	A2 and A5 the same. Product costs notably more because general material (extra heat exchanger, pump, etc) required, in addition to other safety features; overall cost increase approx +15%	Assuming same efficiency (due to design including larger exchanger surfaces to compensate for additional DT) means no difference in energy consumption

R290 / R1270 + evapor-ating second-ary ‡	2015 2020 2030	10% 15% 30%	5% 10% 20%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training etc, negligible, +1% onto product cost (10 yr reference period). (Equates to €10m per 10,000 units annual production)	A2 and A5 the same. Product costs notably more because general material (extra heat exchanger, pump, steel piping, etc) required, in addition to other safety features; overall cost increase approx +20%	Assuming same efficiency (due to design including larger exchanger surfaces to compensate for additional DT) means no difference in energy consumption

† Assumes costs to be identical in A2 and A5 countries since the costs within the manufacturing centres will become closer over projection period

‡ Approximations because no manufacturer currently using these AOs

NOTE 1: ‘Negative’ difference between AOs and R22 and R410A are generally less than ‘negative’ difference between AOs and R407C, since R407C is generally less efficient and requires more materials

<u>Data Input Sheet – Stationary air conditioning – small chillers (<350 kW)</u>

Business as Usual

Region	A2	A5
New units per year (Total 0.14m)	0.11m (78% of total) (BSRIA 2009, RTOC 2006)	0.03m (22% of total) (BSRIA 2009, RTOC 2006)
Total stock	1.5m (est)	0.3m (est)
Consumption	6.5 kt (4.5 kt HFC, 2.0 kt HCFC) (est)	2.5 kt (0.5 kt HFC, 2.0 kt HCFC) (est)
Bank	55 kt (15 kt HFC, 40 kt HCFC) (est)	11 kt (1 kt HFC, 10 kt HCFC) (est)
Annual growth	+1% to 2015 +1% to 2020 +1% to 2030 (BSRIA 2009, Daikin 2010)	+6% to 2015 +6% to 2020 +6% to 2030 (BSRIA 2009, BSRIA 2008)
Refrigerant type 2010 2015 2020 2030	100% HFC R134a, R407C, R410A (RTOC 2006) 98% HFC, 2% AO 97% HFC, 3% AO 94% HFC, 6% AO	70% HCFC R22, 30% HFC R134a, R407C, R410A (RTOC 2006) 65% R22, 35% HFC 100% HFC 98% HFC, 2% AO
Average unit data:		
Refrigerant charge	35 kg per unit	35 kg per unit
Lifetime	15 years	20 years
Leakage rate	5%p.a.	10% p.a.
Rated capacity	100 kW	100 kW
Annual energy use	70,000 kWh	70,000 kWh
Cost of unit	€20,000	€15,000

Abatement Options

Abate-ment option	Year	Max. technical penetration rate in new units		Capital investment costs per unit †	Unit investment costs per unit	Additional operating costs
		A2	A5			
R290 / R1270	2015 2020 2030	20% 40% 80%	15% 30% 70%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, av. 3%(+5% (small-scale) to +1% (large-scale)) onto product cost (10 year reference period). (Equates to €0.1 – 0.2m per 10 – 100 units ann production, respectively)	A2 and A5 the same. Product costs marginally less because material (condenser, refrigerant) costs one-quarter less, but other safety features increase overall cost to +5%	A2 and A5 the same. Efficiency typically +10% better than R22 or R407C
R717 ‡	2015 2020 2030	10% 20% 30%	10% 20% 30%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +50% (small-scale) to +10% (large-scale) onto product cost (10 year reference period). (= €1 – 1.5m per 10 – 100 units annual production, respectively)	A2 and A5 the same. Product costs considerably more because materials and components (condenser, compressor, etc) required is more, in addition to other safety features; overall cost increase approx +40%	A2 and A5 the same. Efficiency typically +20% better than R22 or R407C
R744 ‡	2015 2020 2030	5% 10% 30%	2% 10% 25%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +20% (small-scale) to +5% (large-scale) onto product cost (10 year reference period). (Equates to €0.3 – 0.7m per 10 – 100 units ann production, respectively)	A2 and A5 the same. Product costs considerably more because materials and components (condenser, compressor, etc) required is more, in addition to extra components; overall cost increase approx +25%	Efficiency typically the same in moderate climates but -10% in warm climates compared to R22 or R407C

Unsat. HFCs (R1234 yf) ‡	2015 2020 2030	1% 40% 80%	0% 30% 70%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +5% (small-scale) to 1% (large-scale) onto product cost (10 year reference period). (Equates to €0.1 – 0.2 m per 10 – 100 units annual production, respectively)	A2 and A5 the same. Product costs considerably more because general material (condenser, compressor, etc) required is more and refrigerant has much higher cost, in addition to other safety features; overall cost increase approx +15%	Energy efficiency slightly lower

† Assumes costs to be identical in A2 and A5 countries since the costs within the manufacturing centres will become closer over projection period

‡ Approximations because (a) no manufacturer currently using this AO and (b) no feedback information on R1234yf

NOTE 1: “small scale” production approx 10 – 20 units per year; “large scale” production over 100 units per year

NOTE 2: ‘Negative’ difference between AOs and R22 and R410A are generally less than ‘negative’ difference between AOs and R407C, since R407C is generally less efficient and requires more materials

NOTE 3: Sorption chillers only cost effective when waste heat or other heat sources are available, and due to cost savings under these conditions, it is assumed that this choice is BAU and therefore not included as an AO

Data Input Sheet – Stationary air conditioning – large chillers (>350 kW)

Business as Usual

Region	A2	A5
New units per year (Total 0.12m, 5% centrifugal type)	0.09 m (78% of total) (BSRIA 2009, UNEP 2006)	0.03m (22% of total) (BSRIA 2009, UNEP 2006)
Total stock	1.3m (est)	0.3m (est)
Consumption	30 kt (20 kt HFC, 10 kt HCFC) (estimated)	12 kt (2 kt HFC, 10.0 kt HCFC) (estimated)
Bank	250 kt (60 kt HFC, 190 kt HCFC) (estimated)	65 kt (5 kt HFC, 60 kt HCFC) (estimated)
Annual growth	+1% to 2015 +1% to 2020 +1% to 2030 (BSRIA 2009, Daikin 2010)	+6% to 2015 +6% to 2020 +6% to 2030 (BSRIA 2009, BSRIA 2008)
Refrigerant type 2010 2015 2020 2030	100% HFC R134a, R407C, R410A (RTOC 2006) 98% HFC, 1% AO 97% HFC, 2% AO 94% HFC, 4% AO	70% HCFC R22, 30% HFC R134a, R407C, R410A (RTOC 2006) 65% R22, 35% HFC 100% HFC 97% HFC, 2% AO
Average unit data:		
Refrigerant charge	200 kg per unit	200 kg per unit
Lifetime	15 years	20 years
Leakage rate	5% p.a.	10%p.a.
Rated capacity	1,000 kW	1,000 kW
Annual energy use	700,000 kWh	700,000 kWh
Cost of unit	€200,000	€150,000

Abatement Options

Abate-ment option	Year	Max. technical penetration rate in new units A2	A5	Capital investment costs per unit †	Unit investment costs per unit	Additional operating costs
R290 / R1270	2015 2020 2030	20% 30% 40%	10% 20% 30%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, <+1% (small-scale and large-scale) onto product cost (10 year reference period). (Equates to €0.2 – 1.0m per 10 – 100 units annual production, respectively)	A2 and A5 the same. Product costs marginally less because material (condenser, refrigerant) costs one-quarter less, which off-sets other safety features increase overall cost to -0%.	A2 and A5 the same efficiency typically +10% better than R22 or R407C
R717 ‡	2015 2020 2030	20% 40% 60%	20% 40% 60%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +7% (small-scale) to +3% (large-scale) onto product cost (10 year reference period). (Equates to €1.5 – 5m per 10 – 100 units annual production, respectively)	A2 and A5 the same. Product costs considerably more because materials and components (condenser, compressor, etc) required is more, in addition to other safety features; overall cost increase ca. +20%	A2 and A5 the same efficiency typically +15% better than R22 or R407C
R744‡	2015 2020 2030	5% 10% 20%	2% 10% 20%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +5% (both small-scale and large-scale) onto product cost (10 year reference period). (Equates to €1 – 4 m per 10 – 100 units annual production, respectively)	A2 and A5 the same. Product costs somewhat more because materials and components (condenser, compressor, etc) required is more, in addition to extra components; overall cost increase ca. +20%	Efficiency typically the same in moderate climates but -10% in warm climates compared to R22 or R407C
R718	2015 2020 2030	5% 20% 25%	5% 20% 25%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +5% (small-scale	A2 and A5 the same. Product costs somewhat more because materials and	A2 and A5 the same. Efficiency typically +5% better than R22

				and large-scale) onto product cost (10 year reference period). (Estimated based on indicated unit cost decrease over period)	components associated with different system architecture and parts, increase ca. +15% (average of +25% and 0%)	
Unsat. HFCs (R1234 yf) ‡	2015 2020 2030	1% 20% 60%	0% 20% 40%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, <+1% (small-scale and large-scale) onto product cost (10 year reference period). (Equates to €0.2 – 1.0m per 10 – 100 units annual production, respectively)	A2 and A5 the same. Product costs considerably more because general material (condenser, compressor, etc) required is more and refrigerant has much higher cost, in addition to other safety features; overall cost increase approx +8%	Energy efficiency slightly lower

† Assumes costs to be identical in A2 and A5 countries since the costs within the manufacturing centres will become closer over projection period

‡ Approximations because (a) no manufacturer currently using this AO and (b) no feedback information on R1234yf

NOTE 1: "small scale" production approx 10 – 20 units per year; "large scale" production over 100 units per year

NOTE 2: 'Negative' difference between AOs and R22 and R410A are generally less than 'negative' difference between AOs and R407C, since R407C is generally less efficient and requires more materials

NOTE 3: Sorption chillers only cost effective when waste heat or other heat sources are available, and due to cost savings under these conditions, it is assumed that this choice is BAU and therefore not included as an AO

NOTE 4: Values not valid for comparisons with centrifugal chillers

Data Input Sheet – Stationary air conditioning – centrifugal chillers

Business as Usual

Region	A2	A5
New units per year (Total 0.014 m)	0.008 m (78% of total) (BSRIA 2009, UNEP 2006)	0.006m (22% of total) (BSRIA 2009, UNEP 2006)
Total stock	0.20 m (estimated)	0.15 m (estimated)
Consumption	10 kt (5 kt HFC, 3 kt HCFC, 2 kt CFC) (estimated)	10 kt (1 kt HFC, 6 kt HCFC, 3 kt CFC) (est)
Bank	120 kt (60 kt HFC, 35 kt HCFC, 25 kt CFC) (estimated)	90 kt (30 kt HFC, 35 kt HCFC, 25 kt CFC) (estimated)
Annual growth	-1% to 2015 -1% to 2020 -1% to 2030 (BSRIA 2009)	+1% to 2015 +1% to 2020 +1% to 2030 (BSRIA 2009, BSRIA 2008)
Refrigerant type 2010 2015 2020 2030	100% HFC R134a, R245fa (UNEP 2006) 99% HFC, 1% AO 98% HFC, 2% AO 95% HFC, 5% AO	70% HCFC R123, 30% HFC R134a (UNEP 2006) 40% HCFC, 60% HFC 0% HCFC, 100% HFC 98% HFC, 2% AO
Average unit data:		
Refrigerant charge	630 kg per unit	630 kg per unit
Lifetime	25 years	35 years
Leakage rate	5% p.a.	5% p.a.
Rated capacity	1,500 kW	1,500 kW
Annual energy use	1,000,000 kWh	1,000,000 kWh
Cost of unit	€140,000	€120,000

Abatement Options

Abate-ment option	Year	Max. technical penetration rate in new units		Capital investment costs per unit †	Unit investment costs per unit	Additional operating costs
		A2	A5			
R290 / R1270, also R601 and R601a	2015 2020 2030	0% 5% 20%	0% 5% 20%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +1% onto product cost (10 year reference period).	A2 and A5 the same. Product costs marginally higher because of safety features, increase overall cost to +5%.	A2 and A5 the same Efficiency equal for all options
R718	2015 2020 2030	5% 10% 30%	5% 10% 30%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +5% onto product cost (10 year reference period).	A2 and A5 the same. Product costs somewhat more because materials and components associated with different system architecture and parts, increase approx +20% (average of +30% and 10%)	A2 and A5 the same. Efficiency equal for all options
Unsat. HFCs (R1234yf, also R1234ze) ‡	2015 2020 2030	1% 30% 80%	0% 20% 40%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +1% onto product cost (10 year reference period).	A2 and A5 the same. Product costs marginally higher because of safety features, increase overall cost to +5%.	A2 and A5 the same. Efficiency equal for all options

† Assumes costs to be identical in A2 and A5 countries since the costs within the manufacturing centres will become closer over projection period

‡ Approximations because (a) no manufacturer currently using this AO and (b) no feedback information on R1234yf

<u>Data Input Sheet – Heating only heat pumps (domestic and small commercial)</u>

Business as Usual

Region	A2	A5
New units per year (Total 1.45m for 2008) (includes hot water, space heating and combined; does not include R744 bathing hot water heaters)	1.13m (80% of total) (UNEP 2010, IEA Heat Pump Centre, 2010 draft report)	0.33m (20% of total) (UNEP 2010, IEA Heat Pump Centre, 2010 draft report)
Total stock	2,403,000	422,000
Consumption	2,160 t HFC (10% 134a, 60% 410A, 15% 407C, 15% 404A)	600 t (95% R22, 5% HFC 410A)
Bank	4,086 (40% R22, 10% HFC 134a, 35% 410A, 5% 407C, 5% 404A)	717 (98% R22, 2% HFC)
Annual growth	+6% to 2015 +5% to 2020 +20% to 2030 (RTOC 2010, EHPA 2009, Daikin 2010)	+13% to 2015 +11% to 2020 +4,5% to 2030 (RTOC 2010, EHPA, 2009)
Refrigerant type (BAU) 2010 2015 2020 2030	98% HFC R407C, R410A, R134a, 2% HC 290 (UNEP 2010) 95% HFC R407C, R410A, R134a, 5% AO 90% HFC R407C, R410A, R134a, 10% AO 85% HFC R407C, R410A, R134a, 15% AO	95% HCFC R22, 5% HFC R407C, R410A, R134a (UNEP 2010) 43% HCFC R22, 57% HFC R410A, R134a 100% HFC R410A, R134a 0% HCFC R22, 100% HFC R410A, R134a
Average unit data:		
Refrigerant charge	Average 2.6 kg	Average 2.6 kg
Lifetime	15 years	15 years
Leakage rate	5% p.a. (UNEP 2010)	10% p.a. (UNEP 2010)
Rated capacity	Average 11 kW	Average 11 kW
Annual energy use	13,000 kWh	13,000 kWh
Cost of unit	7,000 Euro	7,000 Euro
Operation Cost per unit (maintenance +refill, excl electricity cost)		

Abatement Options

Abate-ment option	Year	Max. technical penetration rate in new units		Capital investment costs per unit [†]	Unit investment costs per unit	Additional operating costs
		A2	A5			
R600a + R290/ R1270	2015 2020 2030	20% 30% 60%	20% 30% 60%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +1% onto product cost (10 year reference period). (Equates to €5m per 10,000 units annual production)	A2 and A5 the same. For same efficiency rating, product costs marginally more because material (compressor, heat exchangers) costs more than for R22 and additional cost for ventilated enclosure and safe electrics; +5% per unit; Charge reduction 50%	A2 and A5 the same. Same energy consumption due to efficiency rating schemes
	2020 2030	30% 60%	30% 60%			
R744 [‡]	2015 2020 2030	10% 20% 50%	5% 10% 30%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +2% onto product cost (10 year reference period). (Equates to €9m per 10,000 units annual production)	A2 and A5 the same. For same efficiency rating, product costs more because of more material weight costs; approx half as much again compared to R22 systems; +10% per unit	A2 and A5 the same. Same energy consumption due to efficiency rating schemes
Unsat. HFCs (R1234yf) [‡]	2015 2020 2030	1% 30% 90%	0% 20% 70%	A2 and A5 the same. Initial investment costs for R&D, infrastructure, production line, training, etc, +1% onto product cost (10 year reference period). (Equates to €2.5m per 10,000 units annual production)	A2 and A5 the same. For same efficiency rating, product costs marginally more because material (compressor, heat exchangers, refrigerant) costs more than for R22 and additional cost for safety features; +5% per unit	A2 and A5 the same. Same energy consumption due to efficiency rating schemes

[†] Assumes costs to be identical in A2 and A5 countries since, 80% of manufacturing is centralised in very few manufacturing sites within a small number of A5 countries.
[‡] Approximations because (a) no manufacturer currently using this AO and (b) no feedback information on R1234yf
CO_2 for hot water heating

Data Input Sheet – Mobile Air Conditioning – cars

Business as Usual

Region	A2	A5
New units per year	33.3m in 2008 and 25.1m in 2009 (OICA 2010); estimated 80% with AC A2+A5: 2008: 53m and 2009: 47m (OICA2010) :other sources 66m worldwide in 2010 /www.polk.com/	19.7m in 2008 and 21.9m in 2009 (OICA 2010) - estimated 70% with AC
Total stock	450m in 2002 /Worldmapper/ A2 + A5: 600m (www.worldometers.info/cars) in 2010 – estimated 70% with AC; other sources 590m in 2002 (Worldmapper) or 1,000m (including light trucks) in 2010 (www.polk.com)	140m in 2002 – estimated 50% with AC
Consumption	48,500 t = 30m *0.55kg*80%+450m *70%*0.8kg*14%. Annual market 53,400 t , RTOC 2006 (complete MAC (UNEP 2006))	16,100 t = 20m *0.55kg*70%+140m *50%*0.6kg*20%. Annual market 16,700 t (UNEP 2006)
Bank	252,000 t = 450 m*0.8 kg*70%	56,000 t =140 m*0.8 kg*50%
Annual growth *Increase per year compared to previous year*	+2% to 2015 (www.polk.com) +1.5% to 2020 +1.5% to 2030 (all based on 2010)	+6% to 2015 (www.polk.com) +6% to 2020 +6% to 2030 (all based on 2010)
Refrigerant type (BAU) 2010 2015 2020 2030	Bank 265,000 t R134a in 2003, annual market 53,400 t (UNEP 2006) 98 to 100% R134a, 0 to 2% AO 90 to 99% R134a, 1 to 10% AO 70 to 97% R134a, 3 to 30% AO	Bank 40,500 t R134a in 2003, annual market 16,700 t (UNEP 2006) 100% R134a, 0% AO 98 to 100 R134a, 0 to 2% AO 95 to 100% R134a, 0 to 5% AO
Average unit data:		
Refrigerant charge	Average charge new systems 0.6 kg[67]	Average charge new systems 0.6 kg
Lifetime	10 to 15 years – average 12	10 to 20 years - average 15 years
Leakage rate	14% p.a. (5 – 25 % p.a.)	20% p.a. (10 – 50 % p.a.)
Rated capacity	Average 5 kW, ranging from 3 kW to 8 kW	Average 5 kW, ranging from 3 kW to 8 kW
Annual energy use	1,500 kWh (cop = 1; 300 h run time)	1,500 kWh (cop 1; 300 h runtime)
Cost of unit	160 to 170 €	160 to 170 €

[67] Existing fleet has higher charges, Average 0.8

Abatement Options

Abate-ment option	Year	Max. technical penetration rate in new units		Capital investment costs per unit	Unit investment costs per unit	Additional operating costs
		A2	A5			
CO_2	2015 2020 2030	20% 50% 100%	1% 30% 60%	4,000 to 4,500 € per service station (350,000 needed in A2, 150,000 needed in A5). Production line equipment for R744 is expected to cost 50 to 75% more than for R134a, i.e. 300,000 to 440,000 €. This type of equipment can handle (charge) one car every 85 seconds. This is accounted for in 0.3-0.6% cap. investment cost	2010 (small scale production): €100 to €120 additional cost, i.e. 62 to 75% more; 2015 (large scale production): 20 to 30 €, i.e. 12 to 19%additional costs 2020: 5% and 2030: +0%. Refrigerant cost negligible.	Energy consumption about equal
Unsatu-rated HFCs (R1234yf)	2015 2020 2030	40% 80% 100%	20% 70% 100%	4,800 € per service station (350,000 needed in A2, 150,000 needed in A5). Production line equipment for R1234yf expected to cost 30% more than for R134a, i.e. 260,000 to 325,000 € instead of 200,000 to 250,000 €. This type of equipment can handle (charge) one car every 85 seconds. This is accounted for in 0.2-0.3% cap. investment cost	Refrigerant is much more expensive than R134a.	Same energy consumption as R134a; refrigerant cost at service is significantly more expensive.
HC + liquid secondary	2015 2020 2030	5% 30% 80%	0% 15% 40%	Should be similar to AO6 This is accounted for in 0.2-0.3% cap. investment cost	50% in total; 30% additional costs at any time due to secondary loop, safety measures and training, in	Same energy efficiency achieved through higher investment cost; otherwise expected to use 5

					addition 20% more for improving energy efficiency to achieve same efficiency as HFC-unit	to 10% more energy than equivalent HFC system

A global solution is assumed, i.e. the AOs will not be accumulative. New challenges will arise from electric cars. They need a heat pump system for the passenger compartment and possibly for the battery. Ixetic (LuK) has developed a hermetic R744 compressor. They have also shown that R744 performs better than R134a or R1234yf in heat pump mode.

<u>Data Input Sheet – MAC – buses</u>

Business as Usual

Region	A2	A5
New units per year	129,000 in 2008 and 81,400 in 2009 (OICA 2010); 80% with AC (Ökorecherche study) A2+A5: 2008: 370,000 and 2009: 313,000 (OICA2010) and 352,000 (World Buses, Industry study #2084. Cleveland: The Freedonia Group, 2006)	241,000 in 2008 and 231,600 in 2009 (OICA 2010); estimated 70% with AC
Total stock	A2+A5: 3.1m in 2005. The estimate for 2010 is 3.6m (Lance A. Ealey, Andrew C. Gross: The global market for buses, 2000-2010. April, 2008) A2: 1.1m (total 3.6m x 30%)	A5: 2.5m.
Consumption	2,360 t = 80%*(1.1m*10kg*15%+130,000*10kg)	5,490 t = 70%*(2.5m*8kg*30%+230,000*8kg)
Bank	8,800 t = Total stock x IC: 80%* 1.1m*10kg	14,000 t =Total stock x IC: 70%*2.5m * 8kg
Annual growth	+0.4% to 2015 /Ealey et al/ +0.4% to 2020 +0.3% to 2030	+1.2% to 2015 /Ealey et al/ +1.2% to 2020 +1.5% to 2030
Refrigerant type (BAU) 2010 2015 2020 2030	100% R134a 98% R134a, 2% AO 91.5% R134a, 8.5% AO 82% R134a, 18% AO	100% R134a 100% R134a, 0% AO 98% R134a, 2% AO 93% R134a, 7% AO
Average unit data:		
Refrigerant charge	10 kg used as average; Charges from 6 to 10 kg (UNEP 2002); in EU average 12 kg due to many double deck and articulated buses with 2 AC units (Ökorecherche study)	Average charge 8kg (6 to 10 kg) (UNEP 2002)
Lifetime	10 to 15 years – average 12	10 to 20 years - average 15 years
Leakage rate	15% p.a. (5 – 25% p.a.)	30% p.a. (10 – 50% p.a.)
Rated capacity	Average 20 to 30 kW /UNEP2002/	Average 20 to 30 kW (UNEP 2002)
Annual energy use	33,300 kWh (cop = 1.5; 2,000 h run time); Berlin 400 h/y, Singapore 6 to 8,000 h/y	33,300 kWh (cop = 1.5; 2,000 h run time); Berlin 400 h/y, Singapore 6 to 8,000 h/y
Cost of unit	6.5% of bus price, i.e. € 13,000 for large travel bus	€ 10,000

Abatement Options

Abate-ment option	Year	Max. technical penetration rate in new units		Capital investment costs per unit	Unit investment costs per unit	Additional operating costs
		A2	A5			
CO_2	2015 2020 2030	2.5% 30% 50%	0% 5% 15%	4000 to 4500 € per service station (350,000 needed in A2, 150,000 needed in A5). Production line equipment for R744 is expected to cost 50 to 75% more than for R134a, i.e. 300,000 to 440,000 €. This is accounted for in 1% cap. investment cost.	2010: 20% additional costs 2015: 15% 2020: 10% 2030: 5%. Refrigerant cost negligible.	Energy consumption about equal – except for high ambient temperatures
Unsaturated HFCs (R1234yf)	2015 2020 2030	10% 60% 100%	0% 25% 60%	4800 € per service station (350,000 needed in A2, 150,000 needed in A5). Production line equipment for R1234yf expected to cost 30% more than for R134a, i.e. 260,000 to 325,000 € instead of 200,000 to 250,000 €. This is accounted for in 0.5% cap. investment cost	Unit investment 2% higher due to more safety requirements; Refrigerant is much more expensive than R134a.	Same energy consumption as reference HFC system; refrigerant cost at service is much more expensive.
HC + liqu. Sec.	2015 2020 2030	2.5% 40% 90%	0% 20% 50%	4800 € per service station (350,000 needed in A2, 150,000 needed in A5). Production line equipment for R1234yf expected to cost 30% more than for R134a, i.e. 260,000 to 325,000 € instead of 200,000 to 250,000 €. This is accounted for in 0.5% cap. investment cost	40% additional costs at any time, 20% due to HC (safety, training, charging equipment) and 20% for improving energy efficiency of secondary loop to achieve same energy efficiency as reference HFC system	Same energy efficiency achieved through higher investment cost; otherwise expected to use 5 to 10% more energy as equivalent HFC system

References

References cited in the DIS on refrigeration and air conditioning sectors include:

- BSRIA 2008: BSRIA. World Air Conditioning Overview 2008 for 2007 and 2008 including forecast until 2012 for 14 EU countries.
- BSRIA 2009: BSRIA report. Worldwide Air Conditioning. Europe. Report 50570/A, Bracknell (UK). This report presents annual sales data for 2007 and 2008 with forecast for 2009-2012 for all types of stationary air conditioning for the nine most important EU markets: Austria, Czech Republic, France, Germany, Greece, Italy, Poland, Spain, United Kingdom.
- Daikin 2010: Meeting of W. Schwarz, B. Gschrey (Öko-Recherche) and Daniel Colbourne (Re-phridge) with Daikin Europe NV, Oostende (Hilde Dhont, Environment Readiness Section; Martin Dieryckk, Assistant Director Environment Readiness Center), Oostende 19 May, 2010.
- Ealey, L.A. & Gross, A.C.: The global market for buses, 2000-2010. April 2008.
- European Commission DG TREN (ed.) 2007: Lot 12 Commercial refrigerators and freezers. Final Report. Preparatory Studies for Eco-design Requirements of EuPs [TREN/D1/40-2005/LOT12/S07.56644].
- http://www.ecofreezercom.org/doc_unprotected/BIO_EuP_Lot_12_Final_Report.pdf
- European Heat Pump Association: Ebmeyer & Ebmeyer GmbH (2010): EHPA Outlook Cover 2010. European Heat Pump Statistics. On behalf of the European Heat Pump Association EEIG.
- http://www.ehpa.org/fileadmin/red/Heat_Pump_Statistics/2010_EHPA_Outlook_executive_summary.pdf (last checked on 13.04.2011)
- IEA Heat Pump Centre 2010: NEWSLETTER NEWSLETTER VOL. 28 NO. 4/2010. Supermarket refrigeration. IEA Heat Pump Centre (Volume 28 - No. 4/2010, No. 4). http://www-v2.sp.se/hpc/publ/HPCOrder/viewdocument.aspx?RapportId=722.
- Infinity Research Limited 2009: The 2010-2015 World Outlook for Refrigerated Transportation. Hg. v. Inc Icon Group International. http://www.marketresearch.com/browse.asp?categoryid=913&page=8.
- IPCC/ UNEP TEAP 2005: Special Report on Safeguarding the Ozone Layer and the Global Climate System.
- OICA 2010: OICA (ed.) 2010: 1 st MIDDLE EAST AUTOMOTIVE SUMMIT. Our Global Road Transport Priority: Reducing CO2 Emissions Through an Integrated Approach. Through an Integrated Approach. By Eugenio Razelli.
- http://www.qatarmotorshow.gov.qa/app/webroot/files/TECH%201_5%20EUGENIO%20Razelli%20OICA%20pres.pdf (last checked on 06.04.2011)
- Rhiemeier et al 2009: Comparative Assessment of the Climatic Relevance of Supermarket Refrigeration Systems and Equipment. Study on behalf of the German EPA.

- Schwarz, W. 2007: Establishing the leakage rates of mobile air conditioners in heavy duty vehicles (070501/2005/422963/MAR/C1). Study on behalf of the European Commission (DG Environment). Part I: Trucks. Part II: Buses.
- The Freedonia Group: World Buses, Industry study No. 2084. Cleveland, 2006.
- UNEP 2002: 2002 Assessment Report of the Refrigeration, Air conditioning and Heat Pumps Technical Options Committee (RTOC)
- UNEP 2006: 2006 Assessment Report of the Refrigeration, Air conditioning and Heat Pumps Technical Options Committee (RTOC)
- UNEP 2010: 2010 Assessment Report of the Refrigeration, Air conditioning and Heat Pumps Technical Options Committee (RTOC)

IV.2 Foam Blowing

Introduction

1) Pricing of blowing agents

Raw Material Costs						
	Type	***Cost*** €/kg			***Type***	***Cost*** €/kg
HFC	*HC*	*0.8*		***HCFC***	*141b*	*1.5*
	water				*22*	*1.3*
	245fa	*5*		*Foam*	*PU*	*2.5*
	365/227ea	*5*			*XPS*	*1.5*
	134a	*5*				
	152a	*2*				
	unsat HFC	*12*				

For reference, note that unsaturated HFC includes several options. Trade-names are not relevant at the moment as all the options were under development when this study was made. There are continuous developments but no production company uses them commercially yet. As it is a viable option, it has been included in the study as Abatement Option (AO), even though technical details are not yet available on a commercial scale.

2) Production data

The production data has been converted to equal units in order to have a consistent method.

Foam sector	kg /piece	Density kg/m^3	Surface m^2	Thickness mm	Prod. quantity/ year m^2
PU					
Insulation foams for the construction sectors					
Sandwich panels with metal facings, continuous (CME[68])	4.00	40	2	50	960,000
Sandwich panels with metal facings, discontinuous (DIP)	45.00	50	9	100	11,520
Sandwich panels with flexible facings, boardstock (CFF)	4.00	40	2	50	960,000
Spray foam (SPR)	4.80	60	1	80	48,000
Insulation for refrigeration applications					
Domestic refrigeration (DOR)	4.00	35	3.81	30	138,240
Commercial refrigeration (COR)	4.00	40	2	50	34,560
Refrigerated trucks, reefer containers (RTRU)	150.00	50	30	100	11,520
Integral foam for automotive, furniture sectors					
Integral foams (INT)	0.60	400	0.03	50	134,400
XPS					
Insulation foam boards (XPS)	1.26	35.00	0.72	50.00	2,073,600

The production quantity is then used for determining the amount of blowing agent used and the calculation of marginal abatement costs for each abatement option on the basis of 1 metric tonne of Business as usual (BAU) consumption

3) Raw materials used in BAU and abatement options

The focus is on the use of blowing agents. For proper comparison the basic raw materials are kept the same in the BAU and the AO. The property changes are results of the alternative blowing agents.
The other important consideration is that co-blowing of several kinds of blowing agents has not been considered. This has a major impact on the use of expensive blowing agents as to achieve an equal blowing effect the equivalent molecular weight approach provides a good indicator. In the case of unsaturated HFC and there are several types under development where the molecular weight is considerably higher than for HC's. Therefore the impact on the incremental costs of the blowing agent is the largest.

[68] The abbreviations within the brackets are used for the abatement options descriptions later on.

		COR, DIP, DOR, CME, RTRU	CFF	SPRAY	INT	COR, DIP, DOR, CME, RTRU	CFF
	AO Code	2.1	2.1	2.2	2.2	3.1	3.1
Blowing agent	BAU	HFC245fa	HFC245fa	HFC 245fa	HFC 245fa	HFC 365mfc/ 227ea	HFC 365mfc/ 227ea
	AO	HC	HC	H_2O	H_2O	HC	HC
Delta BAU-AO BLA PBW		3	3	14	8	5	5
Delta (λ Bau-λ AO)		-1	0	-5	0	-1	0

		INT	SPRAY	COR, DIP, DOR, CME, RTRU	CFF	SPRAY	INT
	AO Code	3.1	3.2	3.3	3.3	3.3	3.3
Blowing agent	BAU	HFC 365mfc/ 227ea	HFC 365mfc/ 227ea	HFC 365mfc/ 227ea	HFC 365mfc/ 227ea	HFC 365mfc/ 227ea	HFC 365mfc/ 227ea
	AO	HC	H_2O	HFO	HFO	HFO	HFO
Delta BAU-AO BLA PBW		6	15	-2	-2	0	0
Delta (λ Bau-λ AO)		0	-5	0	0	0	0

		COR, DIP,DOR, RTRU	CME	CFF	SPRAY	INT
	AO Code	4.1	4.1	4.1	4.2	4.2
Blowing agent	BAU	HCFC 141b	HCFC 141b	HCFC 141b	HCFC 141b	HCFC 141b
	AO	HC	HC	HC	H_2O	H_2O
Delta BAU-AO BLA PBW		9	5	5	18	10
Delta (λ Bau-λ AO)		-1	-1	0	-6	0

		XPS	XPS	XPS	XPS	XPS
	AO Code	5.1	5.3	6.1	7.1	8.1
Blowing agent	BAU	HFC 134a	HFC 134a	HFC 152a	HCFC 142b	HCFC 22
	AO	HC	HFO	HC	HC	HC
Delta BAU-AO BLA PBW		2	-1	4	6	8
Delta (λ Bau-λ AO)		-2	0	0	-2	0

The values with negative deltas in blowing agent BAU-AO PBW mean that for the abatement scenario additional blowing agent is required. For the thermal conductivity change, a negative prefix indicates an increase in insulation effect.

For all the building applications a lifetime of 50 years has been considered. This is especially of relevance to CFF and XPS. All other applications are calculated with a production line lifetime of 10 years except for refrigeration applications where the lifetimes considered in the refrigeration section of this study are applied.

Concerning the thermal insulation for XPS, it is taken into account that HFC 134a and HCFC 142b provide a better long term insulation benefit compared to HCs and CO_2+organic solvent.
With respect to unsaturated HFCs, it is assumed that there won't be losses in thermal conductivity but due to the higher molecular weight an increase in blowing agent quantity/unit has to be expected as well as extensive raw material development.
In case of HCFC users, the main market is China, were the majority of XPS producers is using up to 100% recycled EPS grades. A conservative approach has been taken when calculating changes in thermal conductivity and blowing agent quantities.

Any conversion should take into account the existing standards in the country of application; these regard especially fire retardant properties.

With regard to HFC 152a for XPS it can be considered also the abatement option to HFO's. In order not to create market shifts in the EU with respect to 134a users. Additionally, the conversion of 152a to HCs is available.

With regard to the terminology, HCs for XPS application represent not only the conversion to e.g Isobutane but also CO_2+organic solvent. Insulation properties remain the same.

For PU the conversion to HCs means Pentane blowing agents and when H_2O is indicated it is water blown foam.

Data Input Sheet - Sandwich panels with metal facings, continuous (CME)

Business as Usual

Region	A2			A5		
Consumption BA FTOC 2006	A2	CFC	0	A5	CFC	297
		HCFC	872		HCFC	1,430
		HFC	4,034		HFC	0
		HC	11,136		HC	381
		Other	519		Other	0
Annual growth	3% to 2030			6% to 2030		

Blowing agent distribution (BAU)

A2	2010	2015	2020	2030
HFC-245fa	37%	37%	37%	37%
HFC-365mfc	34%	34%	34%	34%
HFC-227ea	3%	3%	3%	3%
HC	26%	26%	26%	26%
Other	0%	0%	0%	0%

A5	2010	2015	2020	2030
HCFC-141b	74%	52%	29%	0%
HFC-245fa	0%	23%	46%	74%
HC	7%	7%	7%	7%
Other	18%	18%	18%	18%

Abatement Options

AO	Year	Maximum technical potential		Research cost (per t replaced BA)	Capital investment costs (per t replaced BA)	Incremental operating costs (per t replaced BA)
		A2	A5			
2.1 From HFC-245fa to HCs	2015 2020 2030	90% 90% 90%	90% 90% 90%	50€	250€	Blowing agent: -4,433€ Raw materials: 0€ Thickness increase to balance insulation: 2,857€
3.1 From HFC-365mfc/227 to HCs	2015 2020 2030	90% 90% 90%	90% 90% 90%	42€	210€	Blowing agent: -4,523€ Raw materials: 0€ Thickness increase to balance insulation: 2,401€
3.3 From HFC-365mfc/227 to unsat HFCs	2015 2020 2030	30% 70% 100%	30% 70% 100%	42€	210€	Blowing agent: 8,885€ Raw materials: 4,792€ Thickness increase to balance insulation: 0€
4.1 From HCFC-141b to HCs	2015 2020 2030	N/A	90% 90% 90%	42€	210€	Blowing agent: -1,500€ Raw materials: 0€ Thickness increase to balance insulation: 2401€

Data Input Sheet - Sandwich Panels with flexible facings, Boardstock (CFF)

Business as Usual

Region	A2			A5		
Consumption BA FTOC 2006	*A2*	*CFC*	*0*	*A5*	*CFC*	*0*
		HCFC	*66*		*HCFC*	*0*
		HFC	*1,343*		*HFC*	*0*
		HC	*53,531*		*HC*	*110*
		Other	*0*		*Other*	*0*
Annual growth	3% to 2030			6% to 2030		

Blowing agent distribution (BAU)

A2	*2010*	*2015*	*2020*	*2030*
HFC-245fa	*1%*	*1%*	*1%*	*1%*
HFC-365mfc	*1%*	*1%*	*1%*	*1%*
HFC-227ea	*0%*	*0%*	*0%*	*0%*
HC	*97%*	*97%*	*97%*	*97%*

A5	*2010*	*2015*	*2020*	*2030*
HC	*100%*	*100%*	*100%*	*100%*

Abatement Options

AO	Year	Maximum technical potential		Research cost (per t replaced BA)	Capital investment costs (per t replaced BA)	Incremental operating costs (per t replaced BA)
		A2	A5			
2.1 From HFC-245fa to HCs	2015 2020 2030	90% 90% 90%	90% 90% 90%	50€	250€	Blowing agent: -4,433€ Raw materials: 0€ Thickness increase to balance insulation: 0€
3.1 From HFC-365mfc/227to HCs	2015 2020 2030	90% 90% 90%	90% 90% 90%	42€	210€	Blowing agent: -4,523€ Raw materials: 0€ Thickness increase to balance insulation: 0€
3.2 From HFC-365mfc/227 to unsat HFCs	2015 2020 2030	30% 70% 100%	30% 70% 100%	42€	210€	Blowing agent: 8,885€ Raw materials: 4,792€ Thickness increase to balance insulation: 0€
4.1 From HCFC-141b to HCs	2015 2020 2030	N/A	90% 90% 90%	42€	210€	Blowing agent: -1,500€ Raw materials: 0€ Thickness increase to balance insulation: 0€

Data Input Sheet - Commercial refrigeration (COR)

Business as Usual

Region	A2			A5		
Consumption BA FTOC 2006	*A2*	*CFC*	*0*	*A5*	*CFC*	*4*
		HCFC	*514*		*HCFC*	*2,229*
		HFC	*3,715*		*HFC*	*21*
		HC	*2,252*		*HC*	*119*
		Other	*518*		*Other*	*0*
Annual growth	3% to 2030			6% to 2030		

Blowing agent distribution (BAU)

A2	*2010*	*2015*	*2020*	*2030*
HFC-245fa	*30%*	*30%*	*30%*	*30%*
HFC-365mfc	*28%*	*28%*	*28%*	*28%*
HFC-227ea	*2%*	*2%*	*2%*	*2%*
HC	*32%*	*32%*	*32%*	*32%*
Other	*7%*	*7%*	*7%*	*7%*

A5	*2010*	*2015*	*2020*	*2030*
HCFC-141b	*94%*	*65%*	*36%*	*0%*
HFC-245fa	*1%*	*30%*	*59%*	*95%*
HC	*5%*	*5%*	*5%*	*5%*
Other	*0%*	*0%*	*0%*	*0%*

Abatement Options

AO	Year	Maximum technical potential		Research cost (per t replaced BA)	Capital investment costs (per t replaced BA)	Incremental operating costs (per t replaced BA)
		A2	A5			
2.1 From HFC-245fa to HCs	2015 2020 2030	100% 100% 100%	100% 100% 100%	1,389€	6,944€	Blowing agent: -4,433€ Raw materials: 2,875€ Thickness increase to balance insulation: 2,857€
3.1 From HFC-365mfc/227 to HCs	2015 2020 2030	100% 100% 100%	100% 100% 100%	1,167€	5,835€	Blowing agent: -4,523€ Raw materials: 2,396€ Thickness increase to balance insulation: 2401€
3.3 From HFC-365mfc/227 to unsat HFCs	2015 2020 2030	30% 70% 100%	30% 70% 100%	1,167€	5,835€	Blowing agent: 8,885€ Raw materials: 2396€ Thickness increase to balance insulation: 0€
4.1 From HCFC-141b to HCs	2015 2020 2030	N/A	100% 100% 100%	890€	4,449€	Blowing agent: -1,137€ Raw materials: 1,797€ Thickness increase to balance insulation: 1,830€

Data Input Sheet - Sandwich panels with metal facings, discontinuous (DIP)

Business as Usual

Region	A2			A5		
Consumption BA FTOC 2006	A2	CFC	0	A5	CFC	560
		HCFC	1,440		HCFC	4,831
		HFC	6,685		HFC	0
		HC	2,897		HC	516
		Other	0		Other	1,333
Annual growth	3% to 2030			6% to 2030		

Blowing agent distribution (BAU)

A2	2010	2015	2020	2030
HFC-245fa	37%	37%	37%	37%
HFC-365mfc	34%	34%	34%	34%
HFC-227ea	3%	3%	3%	3%
HC	26%	26%	26%	26%
Other	0%	0%	0%	0%

A5	2010	2015	2020	2030
HCFC-141b	74%	52%	29%	0%
HFC-245fa	0%	23%	46%	74%
HC	7%	7%	7%	7%
Other	18%	18%	18%	18%

Abatement Options

AO	Year	Maximum technical potential		Research cost (per t replaced BA)	Capital investment costs (per t replaced BA)	Incremental operating costs (per t replaced BA)
		A2	A5			
2.1 From HFC-245fa to HCs	2015 2020 2030	90% 90% 90%	90% 90% 90%	370€	1,852€	Blowing agent: -4,433€ Raw materials: 0€ Thickness increase to balance insulation: 2,857€
3.1 From HFC-365mfc/227 to HCs	2015 2020 2030	90% 90% 90%	90% 90% 90%	311€	1,556€	Blowing agent: -4,523€ Raw materials: 0€ Thickness increase to balance insulation: 2401€
3.3 From HFC-365mfc/227 to unsat HFCs	2015 2020 2030	30% 70% 100%	30% 70% 100%	311€	1,556€	Blowing agent: 8,885€ Raw materials: 2,396€ Thickness increase to balance insulation: 0€
4.1 From HCFC-141b to HCs	2015 2020 2030	N/A	90% 90% 90%	237€	1,186€	Blowing agent: -1,137€ Raw materials: 0€ Thickness increase to balance insulation: 1,830€

Data Input Sheet - Refrigerated trucks, Reefer containers (RTRU)

Business as Usual

Region	A2			A5		
Consumption BA FTOC 2006	*A2*	*CFC*	*0*	*A5*	*CFC*	*0*
		HCFC	*170*		*HCFC*	*2,556*
		HFC	*1,219*		*HFC*	*98*
		HC	*882*		*HC*	*0*
		Other	*0*		*Other*	*0*
Annual growth	3% to 2030			6% to 2030		

Blowing agent distribution (BAU)

A2	*2010*	*2015*	*2020*	*2030*
HFC-245fa	*31%*	*31%*	*31%*	*31%*
HFC-365mfc	*28%*	*28%*	*28%*	*28%*
HFC-227ea	*2%*	*2%*	*2%*	*2%*
HC	*39%*	*39%*	*39%*	*39%*

A5	*2010*	*2015*	*2020*	*2030*
HCFC-141b	*96%*	*67%*	*37%*	*0%*
HFC-245fa	*2%*	*17%*	*31%*	*50%*
HFC-365mfc	*2%*	*15%*	*29%*	*47%*
HFC-227ea	*0%*	*1%*	*2%*	*4%*

Abatement Options

AO	Year	Maximum technical potential		Research cost (per t replaced BA)	Capital investment costs (per t replaced BA)	Incremental operating costs (per t replaced BA)
		A2	A5			
2.1 From HFC-245fa to HCs	2015 2020 2030	90% 90% 90%	90% 90% 90%	111€	556€	Blowing agent: -4,433€ Raw materials: 0€ Thickness increase to balance insulation: 2,857€
3.1 From HFC-365mfc /227 to HCs	2015 2020 2030	90% 90% 90%	90% 90% 90%	93€	467€	Blowing agent: -4,523€ Raw materials: 0€ Thickness increase to balance insulation: 2,401€
3.3 From HFC-365mfc /227 to unsat HFCs	2015 2020 2030	30% 70% 100%	30% 70% 100%	93€	356€	Blowing agent: 8885€ Raw materials: 4,792€ Thickness increase to balance insulation: 0€
4.1 From HCFC-141b to HCs	2015 2020 2030	N/A	90% 90% 90%	71€	356€	Blowing agent: -1,137€ Raw materials: 0€ Thickness increase to balance insulation: 1,830€

Data Input Sheet - Domestic refrigeration (DOR)

Business as Usual

Region	A2			A5		
Consumption BA FTOC 2006	*A2*	*CFC*	*0*	*A5*	*CFC*	*572*
		HCFC	*320*		*HCFC*	*10,301*
		HFC	*9,250*		*HFC*	*277*
		HC	*19,305*		*HC*	*21,347*
		Other	*31*		*Other*	*98*
Annual growth	3% to 2030			6% to 2030		

Blowing agent distribution (BAU)

A2	*2010*	*2015*	*2020*	*2030*
HFC-245fa	*17%*	*17%*	*17%*	*17%*
HFC-365mfc	*15%*	*15%*	*15%*	*15%*
HFC-227ea	*1%*	*1%*	*1%*	*1%*
HC	*67%*	*67%*	*67%*	*67%*

A5	*2010*	*2015*	*2020*	*2030*
HCFC-141b	*33%*	*23%*	*13%*	*0%*
HFC-245fa	*1%*	*11%*	*21%*	*34%*
HC	*65%*	*65%*	*65%*	*65%*

Abatement Options

AO	Year	Maximum technical potential		Research cost (per t replaced BA)	Capital investment costs (per t replaced BA)	Incremental operating costs (per t replaced BA)
		A2	A5			
2.1 From HFC-245fa to HCs	2015 2020 2030	100% 100% 100%	100% 100% 100%	347€	1,736€	Blowing agent: -4,433€ Raw materials: 0€ Thickness increase to balance insulation: 2,857€
3.1 From HFC-365mfc /227 to HCs	2015 2020 2030	100% 100% 100%	100% 100% 100%	292€	1,459€	Blowing agent: -4,523€ Raw materials: 0€ Thickness increase to balance insulation: 2,401€
3.3 From HFC-365mfc /227 to unsat HFCs	2015 2020 2030	30% 70% 100%	30% 70% 100%	292€	1,459€	Blowing agent: 8,885€ Raw materials: 4,792€ Thickness increase to balance insulation: 0€
4.1 From HCFC-141b to HCs	2015 2020 2030	N/A	100% 100% 100%	222€	1,112€	Blowing agent: -1,137€ Raw materials: 0€ Thickness increase to balance insulation: 1,830€

Data Input Sheet - Integral foams (INT)

Business as Usual

Region	A2			A5		
Consumption BA FTOC 2006	*A2*	*CFC*	*11*	*A5*	*CFC*	*387*
		HCFC	*983*		*HCFC*	*5,927*
		HFC	*9,300*		*HFC*	*0*
		HC	*520*		*HC*	*0*
		Other	*553*		*Other*	*129*
Annual growth	3% to 2030			6% to 2030		

Blowing agent distribution (BAU)

A2	*2010*	*2015*	*2020*	*2030*
HFC-245fa	*16%*	*16%*	*16%*	*16%*
HFC-365mfc	*15%*	*15%*	*15%*	*15%*
HFC-227ea	*1%*	*1%*	*1%*	*1%*
HC	*19%*	*19%*	*19%*	*19%*
Other	*49%*	*49%*	*49%*	*49%*

A5	*2010*	*2015*	*2020*	*2030*
HCFC-141b	*96%*	*67%*	*38%*	*0%*
HFC-245fa	*0%*	*15%*	*30%*	*49%*
HFC-365mfc	*0%*	*14%*	*28%*	*46%*
HFC-227ea	*0%*	*1%*	*2%*	*3%*

Abatement Options

AO	Year	Maximum technical potential		Researchcost (per t replaced BA)	Capital investment costs (per t replaced BA)	Incremental operating costs (per t replaced BA)
		A2	A5			
2.2 From HFC-245fa to H_20	2015 2020 2030	100% 100% 100%	100% 100% 100%	2,951€	277€	Blowing agent: -5,000€ Raw materials: 3594€ Thickness increase to balance insulation: 0€
3.1 From HFC-365mfc/227to HCs	2015 2020 2030	100% 100% 100%	100% 100% 100%	2381€	5,208€	Blowing agent: -4,672€ Raw materials: 0€ Thickness increase to balance insulation: 0€
3.3 From HFC-365mfc/227 to unsat HFC	2015 2020 2030	30% 70% 100%	30% 70% 100%	2,381€	5,208€	Blowing agent: 7,000€ Raw materials: 5,750€ Thickness increase to balance insulation: 0€
4.4 From HCFC-141b to H_2O	2015 2020 2030	N/A	100% 100% 100%	2,381€	223€	Blowing agent: -1,500€ Raw materials: 2,875€ Thickness increase to balance insulation: 0€

Data Input Sheet - Spray foam (SPR)

Business as Usual

Region	A2			A5		
Consumption BA FTOC 2006	A2	CFC	11	A5	CFC	387
		HCFC	983		HCFC	5,927
		HFC	9,300		HFC	0
		HC	520		HC	0
		Other	553		Other	129
Annual growth	3% to 2030			6% to 2030		

Blowing agent distribution (BAU)

A2	2010	2015	2020	2030
HFC-245fa	46%	46%	46%	46%
HFC-365mfc	42%	42%	42%	42%
HFC-227ea	3%	3%	3%	3%
HC	4%	4%	4%	4%
Other	5%	5%	5%	5%

A5	2010	2015	2020	2030
HCFC-141b	98%	68%	38%	0%
HFC-245fa	0%	30%	60%	98%
Other	2%	2%	2%	2%

Abatement Options

AO	Year	Maximum technical potential		Researchcost (per t replaced BA)	Capital investment costs (per t replaced BA)	Incremental operating costs (per t replaced BA)
		A2	A5			
2.2 From HFC-245fa to H_2O	2015 2020 2030	50 50% 50%	50 50% 50%	57€	57€	Blowing agent: -5,000€ Raw materials: 6,161€ Thickness increase to balance insulation: 7,512€
3.2 From HFC-365mfc/227ea to H_2O	2015 2020 2030	50 50% 50%	50 50% 50%	53€	53€	Blowing agent: -5,000€ Raw materials: 5,750€ Thickness increase to balance insulation: 7,040€
3.3 From HFC-365mfc/227ea to unsat HFC	2015 2020 2030	30% 70% 100%	30% 70% 100%	53€	53€	Blowing agent: 7,000€ Raw materials: 3,833€ Thickness increase to balance insulation: 0€
4.2 From HCFC-141b to H_2O	2015 2020 2030	N/A	50 50% 50%	45€	45€	Blowing agent: -1,500€ Raw materials: 1,597€ Thickness increase to balance insulation: 7,381€

Data Input Sheet - XPS

Business as Usual

Region	A2			A5		
Consumption BA FTOC 2006	*A2*	*CFC*	*0*	*A5*	*CFC*	*22*
		HCFC	*19,172*		*HCFC*	*22,900*
		HFC	*6,599*		*HFC*	*0*
		HC	*5,575*		*HC*	*7*
		Other	*6,285*		*Oth□r*	*0*
Annual growth	3% to 2030			6% to 2030		

Blowing agent distribution (BAU)

A2	*2010*	*2015*	*2020*	*2030*
HFC-134a	*22%*	*22%*	*22%*	*22%*
HFC-152a	*46%*	*46%*	*46%*	*46%*
HC	*14%*	*14%*	*14%*	*14%*
Other	*17%*	*17%*	*17%*	*17%*

A5	*2010*	*2015*	*2020*	*2030*
HCFC-22	*64%*	*44%*	*25%*	*0%*
HCFC-142b	*36%*	*25%*	*14%*	*0%*
HFC-152a	*0%*	*31%*	*62%*	*100%*

Abatement Options

AO	Year	Maximum technical potential		Researchcost (per t replaced BA)	Capital investment costs (per t replaced BA)	Incremental operating costs (per t replaced BA)
		A2	A5			
5.1 From HFC-134a to HCs	2015 2020 2030	85% 85% 85%	85% 85% 85%	35€	660€	Blowing agent: -4,413€ Raw materials: 788€ Thickness increase to balance insulation: 1078€
6.1 From HFC-152a to HCs	2015 2020 2030	85% 85% 85%	85% 85% 85%	28€	517€	Blowing agent: -1,540€ Raw materials: 600€ Thickness increase to balance insulation: 0€
5.3 From HFC-134a to unsat HFC	2015 2020 2030	30% 70% 100%	30% 70% 100%	35€	660€	Blowing agent: 8,648€ Raw materials: 1,575€ Thickness increase to balance insulation: 0€
7.1 From HCFC-142b to HCs	2015 2020 2030	N/A	85% 85% 85%	22€	421€	Blowing agent: -1,126€ Raw materials: 475€ Thickness increase to balance insulation: 688€
8.1 From HCFC-142b /22 to HCs	2015 2020 2030	N/A	85% 85% 85%	19€	353€	Blowing agent: -986€ Raw materials: 386€ Thickness increase to balance insulation:0 €

IV.3 Fire Protection and Aerosols

Data Input Sheet - Fire protection

Business as Usual

Region	A2	A5
New units per year	12,500 (2005)	1,325 (2005)
Total stock of HFC systems	125,000 (2005)	10,000 (2005)
Consumption of HFC	2,500 t new (+ 2.5% of bank for refill) (2010) = half annual reduction in halon bank until 2020; continuation at same amount until 2030	600 t new (+ 3% of bank for refill) (2010) = annual reduction in halon bank until 2020; continuation at same amount until 2030
Bank of HFC*	25,000 t (2005) halon bank: 27,000 t	2,000 t (2005) halon bank: 6,000 t
Growth of new HFC units	7% to 2015 0% to 2020 0% to 2030	8.5% to 2015 6.5% to 2020 4.5% to 2030
HFC types (BAU) 2010 2015 2020 2030	 90% HFC- 227ea/10% HFC-23 90% HFC- 227ea/10% HFC-23 90% HFC- 227ea/10% HFC-23 90% HFC- 227ea/10% HFC-23	 90% HFC- 227ea/10% HFC-23 90% HFC- 227ea/10% HFC-23 90% HFC- 227ea/10% HFC-23 90% HFC- 227ea/10% HFC-23
Average unit data:		
Initial charge	200 kg	200 kg
Lifetime	20 years	20 years
Leakage rate	2.5 % p.a.	3 %
Cost of unit	€ 10,000 (227ea); €11,500 (23) Average: € 10,150	€ 9,000 (227ea); €10,500 (23) Average: € 9,150

Abatement Option

Abate-ment option	Year	Max. Technical replacement rate in new units**		Capital investment costs per unit †	Unit investment costs per unit	Additional operating costs
		A2	A5			
FK-5-1-12	2015	85%	75%		A2 and A5 the same: Hardware +14% for average size. Gas charge increase: +23%	Additional costs due to higher gas cost for refill
	2020	90%	80%			
	2030	95%	90%			

* It is assumed that halons are completely substituted in 2015 (A2 and A5). Retired halons are assumed to be replaced by HFCs by 25 only which is half of the new HFC consumption. The other half results from growth in new equipment which formerly did not exist.

**Penetration rates for the alternative option fluoro-ketone (FK-5-1-12) refer only to the fraction of new equipment for which HFCs come into question, but not also to the additional number of new units for which not-in-kind agents or carbon dioxide or inert gases are used.

Data Input Sheet - Aerosols

Business as Usual

Region	A2	A5
New units per year	43,000,000 (2010)	19,000,000 (2010)
Consumption of HFC	12,000 t (2010)	5,400 t (2010)
Growth of new HFC units	0% to 2015 0% to 2020 0% to 2030	1% to 2015 1% to 2020 1% to 2030
HFC types (BAU) 2010	90% HFC-134a/10% HFC-152a	90% HFC-134a/10% HFC-152a
2015	90% HFC-134a/10% HFC-152a	90% HFC-134a/10% HFC-152a
2020	90% HFC-134a/10% HFC-152a	90% HFC-134a/10% HFC-152a
2030	90% HFC-134a/10% HFC-152a	90% HFC-134a/10% HFC-152a
Average unit data:		
Charge per can	0.280 kg	0.280 kg
Lifetime		
Leakage rate		
Cost of unit	€ 8.00	€ 8.00

Abatement Option

Abate-ment option	Year	Max. Technical replacement rate in new units**		Capital investment costs per unit †	Unit investment costs per unit	Additional operating costs
		A2	A5			
Unsat. HFC (HFC-1234ze)	2015	40%	30%	negligible	negligible	In A2 and A5 the same. Additional costs due to higher gas price. Price of 1 can with-1234ze: + €4.00 = + €14.30 per kg.
	2020	75%	65%			
	2030	95%	85%			

Annex V. EU sector sheets

1. Domestic refrigeration
2. Commercial stand-alone systems
3. Commercial condensing units
4. Commercial centralised systems
5. Industrial refrigeration small
6. Industrial refrigeration large
7. Refrigerated vans
8. Refrigerated trucks & trailers
9. Refrigerated fishing vessels
10. Factory sealed moveable air conditioners
11. Single split air conditioners
12. Multisplit air conditioners (VRF)
13. Packaged (rooftop) air conditioners
14. Chillers (displacement)
15. Centrifugal chillers
16. Heat pumps (ground source, heating only)
17. Rail vehicle air conditioning
18. Cargo ship air conditioning
19. Passenger ship air conditioning
20. Fire protection HFC-227ea
21. Fire protection HFC-23
22. Technical aerosols
23. XPS with 134a
24. XPS with 152a
25. PU spray foam
26. Other PU foam
27. Medium voltage secondary switchgear
28. Bus mobile air conditioning
29. Truck mobile air conditioning

Sheet	1	Domestic Refrigerators		
		WOM (WEEE) R-134a	WM (WEEE+Art4) R-134a	WAM R-600a
refrigerating capacity	*kW*	0.2	0.2	0.2
el power	kW	0.035	0.035	0.03446975
running time	h/y	7,200	7,200	7,200
invest cost hardware	€	400	400	408
refrigerant charge	kg	0.12	0.12	0.06
cost first fill	€	1	1.2	0.3
GWP of refrigerant		1,430	1,430	4
lifetime	*years*	15	15	15
cost Art 4	€/y	0	0.10	0
leakage rate	kg/kg	0.3%	0.3%	0.3%
use emissions	kg/y	0.00036	0.00036	0.00018
disp emiss factor	kg/kg	0.4	0.3	0.4
disp emissions	kg/y	0.0032	0.0024	0.0016
consumption	kg/y	0.01	0.01	0.00
global warming emiss	tCO2 eq	0.005091	0.003947	0.000007
emiss difference to WM	tCO2 eq	0.00114	0	0.0039
consumption	tCO2 eq	0.01144	0.01144	0.000016
cons difference to WM	tCO2 eq	0.0	0.0	0.01
energy consumption	kWh	252	252	248
cost per kWh	*€*	*0.14*	*0.14*	*0.14*
energy cost	€/y	35	35.3	34.7
cost refrigerant refill	€/y			
discount rate	%	4%	4%	4%
annuity factor discount		0.0899	0.0899	0.0899
annual running cost	€	35.28	35.38	34.75
annual invest cost	€	36	36	37
annual total cost	€	71.4	71.5	71.5
add ann cost vs WM	€	-0.1	0.0	0.004
abatem cost emiss	€/tCO2eq			**1.04**
abatem cost consumption	€/tCO2eq			**0.36**
Penetration 2015	%			100
Penetration 2020	%			100
Penetration 2030	%			100
Penetration mix 2015	%			100
Penetration mix 2020	%			100
Penetration mix 2030	%			100
first fill 2030	ktCO2eq		0.0	
use em 2030	ktCO2eq		1.4	
disp em 2030	ktCO2eq		10.5	
2030 av abat cost emiss	€/tCO2eq			**1.04**
2030 av abat cost cons	€/tCO2eq			**0.36**
red 2030 emissions	ktCO2eq			12
red 2030 consumption	ktCO2eq			0

Sheet	**2**	**Hermetic Units Commercial Refrigeration (stand alone)**			
		WOM R134a direct	**WM R-134a direct**	**WAM R-600a/290 direct**	**WAM R-744**
refrigerating capacity	*kW*	*0.6*	*0.6*	*0.6*	*0.6*
el power	kW	0.3	0.3	0.2865	0.2865
running time	h/y	6,000	6,000	6,000	6,000
invest cost hardware	€	1,000	1,000	1,100	1,200
refrigerant charge	kg	0.4	0.4	0.2	0.4
cost first fill	€	4.0	4.0	1.0	1.6
GWP of refrigerant		1,430	1,430	3	1
lifetime	*years*	10	10	10	10
cost Art 4	€/y	0	2.50	0	0
leakage rate	kg/kg	1.0%	1.0%	1.0%	1.0%
use emissions	kg/y	0.004	0.004	0.002	0.004
disp emiss factor	kg/kg	0.7	0.35	0.7	0.7
disp emissions	kg/y	0.028	0.014	0.014	0.028
consumption	kg/y	0.04	0.04	0.02	0.04
global warming emiss	tCO2 eq	0.05	0.03	0.000048	0.000032
emiss difference to WM	tCO2 eq	0.02	0.00	0.0257	0.0257
consumption	tCO2 eq	0.06292	0.06292	0.000066	0.0000220
cons difference to WM	tCO2 eq	0.00	0.000	0.063	0.06
energy consumption	kWh	1,800	1,800	1,719	1,719
cost per kWh	*€*	*0.14*	*0.14*	*0.14*	*0.14*
energy cost	€/y	252	252	241	241
cost refrigerant refill	€/y				
discount rate	%	4%	4%	4%	4%
annuity factor discount		0.1233	0.1233	0.1233	0.1233
annual running cost	€	252.00	254.50	240.66	240.66
annual invest cost	€	124	124	136	148
annual total cost	€	376	378	376	389
add ann cost vs WM	€	-2.50	0	-1.88	10.52
abatem cost emiss	€/tCO2eq			**-73**	**409**
abatem cost consumption	€/tCO2eq			**-30**	**167**
Penetration 2015	%			50	20
Penetration 2020	%			85	40
Penetration 2030	%			85	60
Penetration mix 2015	%			50	20
Penetration mix 2020	%			85	15
Penetration mix 2030	%			85	15
first fill 2030	ktCO2eq		219		
use em 2030	ktCO2eq		33		
disp em 2030	ktCO2eq		116		
2030 av abat cost emiss	€/tCO2eq			**-0.79**	
2030 av abat cost cons	€/tCO2eq			**-0.32**	
red 2030 emissions	ktCO2eq			149	
red 2030 consumption	ktCO2eq			219	

Sheet	3	Condensing Units Commercial Refrigeration					
System		WOM R-404A direct	WM R-404A direct	WAM R-290 direct	WAM R-744	WAM R-290 +secondary liquid	WAM R-1234yf + secondary liquid
refrigerating capacity	*kW*	*15*	*15*	*15*	*15*	*15*	*15*
el power	kW	5	5	4.85	4.85	5	5
running time	h/y	4,380	4,380	4,380	4,380	4,380	4,380
invest cost hardware	€	8,000	*8,000*	9,600	10,260	12,000	12,400
add cost hardware				20%	35%	50%	55%
refrigerant charge	kg	8	8	4	8	1.6	2.4
cost first fill	€	120	120	20	32	8	144
GWP of refrigerant		3,922	3,922	3	1	3	4
lifetime	*years*	15	15	15	15	15	15
cost Ar t3+4	€/y	0	160	0		0	0
add maintenance	€/y				50		
leakage rate	kg/kg	0.10	0.06	0.10	0.10	0.10	0.10
use emissions	kg/y	0.8	0.48	0.4	0.8	0.16	0.24
disp emiss factor	kg/kg	0.5	0.25	0.5	0.5	0.5	0.5
disp emissions	kg/y	0.27	0.13	0.13	0.27	0.05	0.08
consumption	kg/y	1.33	1.01	0.67	1.33	0.27	0.40
global warming emiss	tCO2 eq	4.18	2.41	0.0016	0.0011	0.0006	0.0013
emiss difference to WM	tCO2 eq	1.78	0.00	2.4039	2.4044	2.4049	2.4042
consumption	tCO2 eq	5.23	3.97	0.002	0.00	0.00	0.00
cons difference to WM	tCO2 eq	1.26	0.000	3.97	3.97	3.97	3.97
energy consumption	kWh	21,900	21,900	21,243	21,243	21,900	21,900
cost per kWh	*€*	*0.14*	*0.14*	*0.14*	*0.14*	*0.14*	*0.14*
energy cost	€/y	3,066	3,066	2,974	2,974	3,066	3,066
cost refrigerant refill	€/y	12.00	7.20	2.00	3.20	0.8	14.4
discount rate	%	4%	4%	4%	4%	4%	4%
annuity factor discount		0.0899	0.0899	0.0899	0.0899	0.0899	0.0899
annual running cost	€	3,078.00	3,233.20	2,976.02	3,027.22	3,066.80	3,080.40
annual invest cost	€	730	730	865	926	1,080	1,128
annual total cost	€	3,808	3,964	3,841	3,953	4,147	4,209
add ann cost vs WM	€	-155.20	0	-122	-11	183	245
abatem cost emiss	€/tCO2eq			**-51**	**-4**	**76**	**102**
abatem cost consumptior	€/tCO2eq			**-31**	**-3**	**46**	**62**
Penetration 2015	%			20	10	5	1
Penetration 2020				30	20	30	20
Penetration 2030				40	30	60	60
Penetration mix 2015				20	10	5	1
Penetration mix 2020				30	20	30	20
Penetration mix 2030				40	30	30	0
first fill 2030	ktCO2eq		5,396				
use em 2030	ktCO2eq		3,885				
disp em 2030	ktCO2eq		1,039				
2030 av abat cost emiss	€/tCO2eq			**1.20**			
2030 av abat cost cons	€/tCO2eq			**0.73**			
red 2030 emissions	ktCO2eq			3,927			
red 2030 consumption	ktCO2eq			8,949			

Sheet	**4**	**Centralised Systems Commercial Refrigeration**					
		WOM R-404A direct	**WM R-404A direct**	**WAM HC + sec liquid + CO2**	**WAM HC+CO2 + CO2 cascade**	**WAM R-744 transcritical**	**WAM R-1234yf + CO2 + CO2 cascade**
refrigerating capacity	*kW*	*100*	*100*	*100*	*100*	*100*	*100*
el power	kW	40	40	40	37	37	38.8
running time	h/y	4,380	4,380	4,380	4,380	4,380	4,380
invest cost hardware	€	320,000	320,000	371,200	368,000	384,000	368,000
refrigerant charge	kg	230	230	23	57.5	230	77
cost first fill	€	3,450	3,450	115	288	920	4,600
GWP of refrigerant		3,922	3,922	3	3	1	1
lifetime	*years*	12	12	12	12	12	12
cost Ar t3+4	€/y	0	602	0	0		0
add maintenance	€/y					500	
leakage rate	kg/kg	0.15	0.090	0.15	0.15	0.15	0.15
use emissions	kg/y	34.5	20.7	3.45	8.625	34.5	11.5
disp emiss factor	kg/kg	0.3	0.20	0.3	0.3	0.3	0.3
disp emissions	kg/y	5.75	3.83	0.58	1.44	5.75	1.92
consumption	kg/y	53.67	39.87	5.37	13.42	53.67	17.89
global warming emiss	tCO2 eq	157.86	96.22	0.01	0.03	0.04	0.01
emiss difference to WM	tCO2 eq	61.64	0.00	96.21	96.19	96.18	96.21
consumption	tCO2 eq	210.4806667	156.3570667	0.0161	0.04	0.05	0.02
cons difference to WM	tCO2 eq	54.12	0.000	156.34	156.32	156.30	156.34
energy consumption	kWh	175,200	175,200	175,200	162,060	162,060	169,944
cost per kWh	*€*	*0.14*	*0.14*	*0.14*	*0.14*	*0.14*	*0.14*
energy cost	€/y	24,528	24,528	24,528	22,688	22,688	23,792
cost refrigerant refill	€/y	517.50	310.50	17.25	43.13	138.00	690.00
discount rate	%	4%	4%	4%	4%	4%	4%
annuity factor discount		0.1066	0.1066	0.1066	0.1066	0.1066	0.1066
annual running cost	€	25,045.50	25,440.17	24,545.25	22,731.53	23,326.40	24,482.16
annual invest cost	€	34,464	34,464	39,564	39,242	41,014	39,701
annual total cost	€	59,510	59,904	64,110	61,973	64,340	64,183
add ann cost vs WM	€	-394.67	0	4,205	2,069	4,436	4,279
abatem cost emiss	€/tCO2eq			**43.7**	**21.5**	**46.1**	**44.5**
abatem cost consumptior	€/tCO2eq			**26.9**	**13.2**	**28.4**	**27.4**
Penetration 2015	%			20	20	5	1
Penetration 2020	%			40	40	15	30
Penetration 2030	%			90	90	30	90
Penetration mix 2015	%			20	20	5	1
Penetration mix 2020	%			40	40	15	5
Penetration mix 2030	%			10	90	0	0
first fill 2030	ktCO2eq		12,181				
use em 2030	ktCO2eq		13,151				
disp em 2030	ktCO2eq		2,179				
2030 av abat cost emiss	€/tCO2eq			**23.73**			
2030 av abat cost cons	€/tCO2eq			**14.60**			
red 2030 emissions	ktCO2eq			14,741			
red 2030 consumption	ktCO2eq			25,214			

Sheet	5	Industrial Refrigeration - small base case		
		WOM **R-404A direct**	**WM** **R-404A direct**	**WAM** **R-717**
refrigerating capacity	*kW*	*270*	*270*	*270*
el power	kW	110	110	93.5
running time	h/y	4,500	4,500	4,500
invest cost hardware	€	425,000	425,000	620,118
refrigerant charge	kg	650	650	650
cost first fill	€	9,750	9,750	1,300
GWP of refrigerant		3,922	3,922	0
lifetime	*years*	30	30	30
cost Art 3+4	€/y	0	1,098	
add maintenance	€/y			1,000
leakage rate	kg/kg	0.10	0.06	0.10
use emissions	kg/y	65	39	65
disp emiss factor	kg/kg	0.3	0.2	0.3
disp emissions	kg/y	6.5	4.3	6.5
consumption	kg/y	86.7	60.7	86.7
global warming emiss	tCO2 eq	280.4	170.0	0.0
emiss difference to WM	tCO2 eq	110.47	0.00	169.95
consumption	tCO2 eq	339.9	237.9	0
cons difference to WM	tCO2 eq	101.97	0.000	237.93
energy consumption	kWh	495,000	495,000	420,750
cost per kWh	*€*	*0.14*	*0.14*	*0.14*
energy cost	€/y	69,300	69,300	58,905
cost refrigerant refill	€/y	975.00	585.00	130.00
discount rate	%	4%	4%	4%
annuity factor discount		0.0578	0.0578	0.0578
annual running cost	€	70,275.00	70,983.33	60,035.00
annual invest cost	€	25,142	25,142	35,937
annual total cost	€	95,417	96,125	95,972
add ann cost vs WM	€	-708.33	0	-153
abatem cost emiss	€/tCO2eq			**-0.90**
abatem cost consumption	€/tCO2eq			**-0.64**
Penetration 2015	%			60
Penetration 2020	%			70
Penetration 2030	%			95
first fill 2030	ktCO2eq		1,384	
use em 2030	ktCO2eq		2,128	
disp em 2030	ktCO2eq		415	
2030 av abat cost emiss	€/tCO2eq			**-0.90**
2030 av abat cost cons	€/tCO2eq			**-0.64**
red 2030 emissions	ktCO2eq			871
red 2030 consumption	ktCO2eq			2,186

Sheet	6	Industrial Refrigeration - large base case		
		WOM **R-404A direct**	**WM** **R-404A direct**	**WAM** **R-717**
refrigerating capacity	*kW*	*5,000*	*5,000*	*5,000*
el power	kW	2,000	2,000	1,700
running time	h/y	4,500	4,500	4,500
invest cost hardware	€	6,000,000	6,000,000	8,964,000
refrigerant charge	kg	4,000	4,000	4,000
cost first fill	€	60,000	60,000	8,000
GWP of refrigerant		3,922	3,922	0
lifetime	*years*	30	30	30
cost Art 3+4	€/y	0	1,243	
add maintenance	€/y			2,000
leakage rate	kg/kg	0.10	0.06	0.10
use emissions	kg/y	400	240	400
disp emiss factor	kg/kg	0.3	0.2	0.3
disp emissions	kg/y	40.0	26.7	40.0
consumption	kg/y	533.3	373.3	533.3
global warming emiss	tCO2 eq	1725.7	1045.9	0.000
emiss difference to WM	tCO2 eq	679.81	0.00	1,046
consumption	tCO2 eq	2092	1464	0
cons difference to WM	tCO2 eq	627.52	0.000	1,464
energy consumption	kWh	9,000,000	9,000,000	7,650,000
cost per kWh	*€*	*0.14*	*0.14*	*0.14*
energy cost	€/y	1,260,000	1,260,000	1,071,000
cost refrigerant refill	€/y	6,000.00	3,600.00	800.00
discount rate	%	4%	4%	4%
annuity factor discount		0.0578	0.0578	0.0578
annual running cost	€	1,266,000.00	1,264,843.33	1,073,800.00
annual invest cost	€	350,450	350,450	518,852
annual total cost	€	1,616,450	1,615,294	1,592,652
add ann cost vs WM	€	1156.67	0	-22,642
abatem cost emiss	€/tCO2eq			**-21.65**
abatem cost consumption	€/tCO2eq			**-15.46**
Penetration 2015	%			60
Penetration 2020	%			70
Penetration 2030	%			95
first fill 2030	ktCO2eq		4,153	
use em 2030	ktCO2eq		6,383	
disp em 2030	ktCO2eq		1,246	
2030 av abat cost emiss	€/tCO2eq			**-21.6**
2030 av abat cost cons	€/tCO2eq			**-15.5**
red 2030 emissions vs. WM	ktCO2eq			2,612
red 2030 consumption vs. W	ktCO2eq			6,557

Sheet	7	Road Transport Refrigeration Vans			
		WOM=WM R-134a	WAM1 R-134a Art4(1)	WAM 2 R-744	WAM 2 R-1234yf
refrigerating capacity	*kW*	*3*	*3*	*3*	*3*
el power	kW	1.5	1.5	1.3875	1.5
running time	h/y	1,500	1,500	1,500	1,500
invest cost hardware	€	3,000	3,000	3,369	3,150
refrigerant charge	kg	1.5	1.5	1.5	1.5
cost first fill	€	15	15	6	90
GWP of refrigerant		1,430	1,430	1	4
lifetime	*years*	10	10	10	10
cost Art 3+4	€/y	0	6.25		
add maintenance	€/y			10	
leakage rate	kg/kg	0.30	0.30	0.30	0.30
use emissions	kg/y	0.45	0.45	0.45	0.45
disp emiss factor	kg/kg	0.3	0.2	0.3	0.3
disp emissions	kg/y	0.05	0.03	0.05	0.05
consumption	kg/y	0.60	0.60	0.60	0.60
global warming emiss	tCO2 eq	0.71	0.6864	0.0005	0.0020
emiss differ to reference	tCO2 eq	0	0.021	0.707	0.706
consumption	tCO2 eq	0.858	0.858	0.0006	0.0024
cons difference to referer	tCO2 eq	0	0.000	0.857	0.856
energy consumption	kWh	2,250	2,250	2,081	2,250
cost per kWh	*€*	*0.2*	*0.2*	*0.2*	*0.2*
energy cost	€/y	450	450	416	450
cost refrigerant refill	€/y	6.75	6.75	1.80	27
discount rate	%	4%	4%	4%	4%
annuity factor discount		0.1233	0.1233	0.1233	0.1233
annual running cost	€	457	463	428	477
annual invest cost	€	372	372	416	399
annual total cost	€	828	835	844	876
add ann cost vs referenc	€	0	6	16	48
abatem cost emiss	€/tCO2eq		**291**	**22.2**	**68**
abatem cost consumptio	€/tCO2eq			**18.3**	**56**
Penetration 2015	%			3	3
Penetration 2020	%			30	70
Penetration 2030	%			65	100
Penetration mix 2015	%			3	3
Penetration mix 2020	%			30	70
Penetration mix 2030	%			50	50
first fill 2030	ktCO2eq	129	129		
use em 2030	ktCO2eq	387	387		
disp em 2030	ktCO2eq	34	23		
2030 av abat cost emiss	€/tCO2eq			**45.06**	
2030 av abat cost cons	€/tCO2eq			**37.17**	
red 2030 emissions	ktCO2eq		11	421	
red 2030 consumption	ktCO2eq		0	516	

Sheet	8	Road Transport Refrigeration Trucks&Trailers			
		WOM=WM R-404A	WAM1 R-404A Art3+4	WAM R-290 direct	WAM R-744
refrigerating capacity	*kW*	*9*	*9*	*9*	*9*
el power	kW	8	8	7.68	7.84
running time	h/y	4,000	4,000	4,000	4,000
invest cost hardware	€	20,000	20,000	22,000	22,600
refrigerant charge	kg	6.5	6.5	3.25	6.5
cost first fill	€	98	98	16	26
GWP of refrigerant		3,922	3,922	3	1
lifetime	*years*	10	10	10	10
cost Art 3+4	€/y	0	112.9	0	
add maintenance	€/y				50
leakage rate	kg/kg	0.20	0.12	0.20	0.20
use emissions	kg/y	1.3	0.78	0.65	1.3
disp emiss factor	kg/kg	0.3	0.2	0.3	0.3
disp emissions	kg/y	0.20	0.13	0.10	0.20
consumption	kg/y	1.95	1.43	0.98	1.95
global warming emiss	tCO2 ec	5.86	3.57	0.002	0.001
emiss differ to reference	tCO2 ec	0	2.294	5.861	5.862
consumption	tCO2 ec	7.6479	5.60846	0.002925	0.00195
cons difference to referer	tCO2 ec	0	2.039	7.645	7.646
energy consumption	kWh	32,000	32,000	30,720	31,360
cost per kWh	*€*	*0.2*	*0.2*	*0.2*	*0.2*
energy cost	€/y	6,400	6,400	6,144	6,272
cost refrigerant refill	€/y	19.50	11.70	3.25	5.20
discount rate	%	4%	4%	4%	4%
annuity factor discount		0.1233	0.1233	0.1233	0.1233
annual running cost	€	6,419.50	6,524.62	6,147.25	6,326.80
annual invest cost	€	2,478	2,478	2,714	2,790
annual total cost	€	8,897	9,002	8,862	9,116
add ann cost vs reference	€	0	105	-36	219
abatem cost emiss	€/tCO2eq		**45.8**	**-6.1**	**37.4**
abatem cost consumption	€/tCO2eq		**52**	**-4.7**	**28.6**
Penetration 2015	%			20	12.5
Penetration 2020	%			40	25
Penetration 2030	%			80	45
Penetration mix 2015	%			20	12.5
Penetration mix 2020	%			40	25
Penetration mix 2030	%			80	20
first fill 2030	ktCO2e	1,611	1,611		
use em 2030	ktCO2e	3,222	1,933		
disp em 2030	ktCO2e	424	283		
2030 av abat cost emiss	€/tCO2eq			**2.60**	
2030 av abat cost cons	€/tCO2eq			**2.00**	
red 2030 emissions	ktCO2eq		*1,430*	2,990	
red 2030 consumption	ktCO2eq		*1,289*	4,325	

Sheet	9	Fishing vessels (freezer trawlers)		
		WOM=WM 404A/CO2	**WAM1 404A/CO2 Art3+4**	**WAM 2 NH3 / CO2**
refrigerating capacity	*kW*	*990*	*990*	*990*
power installed	kW	468	468	*440*
Installed pump el power	kW	6	6	6
running time	h/y	5,000	5,000	5,000
invest cost hardware	€	2,000,000	2,000,000	2,300,000
refrigerant charge	kg	1,000	1,000	750
cost first fill	€	15,000	15,000	1,500
GWP of refrigerant		3922	3922	0
lifetime	*years*	*30*	30	*30*
maintenance cost	€/y	20,000	20,000	20,000
cost Art 3+4	€/y		1,930	
add maintenance	€/y			2,000
leakage rate	kg/kg	0.4	0.24	0.4
use emissions	kg/y	400	240	300.00
disp emiss factor	kg/kg	0.3	0.2	0.3
disp emissions	kg/y	10	6.67	7.5
consumption	kg/y	433.33	273.33	325
global warming emiss	tCO2 eq	1608.02	967.43	8
emiss differ to reference	tCO2 eq	0	640.6	1,600
consumption	tCO2 eq	1699.53	1072.01	0
cons difference to referer	tCO2 eq	0	627.5	1,700
energy consumption	kWh	2,370,000	2,370,000	2,230,000
cost per kWh	*€*	*0.07*	0.07	*0.07*
energy cost	€/y	165,900	165,900	156,100
cost refrigerant refill	€/y	4,000	2,400	600.00
discount rate	%	4%	4%	4%
annuity factor discount		0.0578	0.0578	0.0578
annual running cost	€	189,900	190,230	178,700
annual invest cost	€	116,528	116,528	133,096
annual total cost	€	306,428	306,758	311,796
add ann cost vs referenc	€	0	330	5,368
abatem cost emiss	€/tCO2eq		**0.52**	**3.36**
abatem cost consumptior	€/tCO2eq		**0.53**	**3.16**
Penetration 2015	%			70
Penetration 2020	%			90
Penetration 2030	%			95
first fill 2030	ktCO2eq	141	141	
use em 2030	ktCO2eq	864	518	
disp em 2030	ktCO2eq	42	*28*	
2030 av abat cost emiss	€/tCO2eq			**3.36**
2030 av abat cost cons	€/tCO2eq			**3.16**
red 2030 emissions	ktCO2eq		*360*	405
red 2030 consumption	ktCO2eq		*345*	539

Sheet	**10**	**Moveable Room Air Conditioners (factory sealed)**					
		WOM R-410A direct	**WM R-410A direct**	**WAM HC-290**	**WAM R-744**	**WAM R-1234yf**	***WAM R-32***
refrigerating capacity	*kW*	*3*	*3*	*3*	*3*	*3*	*3*
el power	kW	0.665	0.665	0.665	0.665	0.665	*0.665*
running time	h/y	1,500	1,500	1,500	1,500	1,500	*1,500*
invest cost hardware	€	300	300	299	362	320	308
refrigerant charge	kg	0.75	0.75	0.375	0.75	0.75	*0.6225*
cost first fill	€	11	11	2	3	45	*8*
GWP of refrigerant		2,088	2,088	3	1	4	*675*
lifetime	*years*	10	10	10	10	10	*10*
cost Art 4	€/y	0	2.50	0	0	0	*2.50*
leakage rate	kg/kg	0.03	0.03	0.03	0.03	0.03	0.03
use emissions	kg/y	0.0225	0.0225	0.01125	0.0225	0.0225	*0.018675*
disp emiss factor	kg/kg	0.7	0.35	0.7	0.7	0.7	0.7
disp emissions	kg/y	0.0525	0.02625	0.02625	0.0525	0.0525	*0.043575*
consumption	kg/y	0.0975	0.0975	0.04875	0.0975	0.0975	0.080925
global warming emiss	tCO2 eq	0.1566	0.10179	0.0001125	0.000075	0.0003	*0.042019*
emiss difference to WM	tCO2 eq	0.055		0.10168	0.10172	0.10	0.06
consumption	tCO2 eq	0.204	0.204	0.00015	0.00010	0.00039	0.05462
cons difference to WM	tCO2 eq	0.0		0.20	0.20	0.20	0.15
energy consumption	kWh	998	998	998	998	998	*998*
cost per kWh	*€*	*0.14*	*0.14*	*0.14*	*0.14*	*0.14*	*0.14*
energy cost	€/y	140	140	140	140	140	*140*
cost refrigerant refill	€/y						
discount rate	%	4%	4%	4%	4%	4%	*4%*
annuity factor discount		0.1233	0.1233	0.1233	0.1233	0.1233	*0.1233*
annual running cost	€	139.7	142.2	139.7	139.7	139.7	*142.2*
annual invest cost	€	38.4	38.4	37.0	44.9	44.9	*38.9*
annual total cost	€	178.0	180.5	176.7	184.6	184.6	*181.1*
add ann cost vs WM	€	-2.5		-3.8	4.1	4.1	0.5
abatem cost emiss	€/tCO2eq			**-37.8**	**40.0**	**40.1**	***9.0***
abatem cost consumption	€/tCO2eq			**-18.9**	**20.0**	**20.0**	***3.6***
Penetration 2015	%			20	10	1	*15*
Penetration 2020	%			50	15	35	*30*
Penetration 2030	%			60	20	70	*40*
Penetration mix 2015	%			20	10	1	*15*
Penetration mix 2020	%			50	15	35	*0*
Penetration mix 2030	%			40	20	40	*0*
first fill 2030	ktCO2eq		5,369				
use em 2030	ktCO2eq		1,611				
disp em 2030	ktCO2eq		1,170				
2030 av abat cost emiss	€/tCO2eq			**8.89**			
2030 av abat cost cons	€/tCO2eq			**4.44**			
red 2030 emissions	ktCO2eq			2,781			
red 2030 consumption	ktCO2eq			5,369			

The energy assumptions are in line with the draft COMMISSION REGULATION implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans

Sheet	11	Single Split Room Air Conditioners					
		WOM R-410A direct	**WM R-410A direct**	**WAM R-290 direct**	**WAM R-744**	**WAM HFC-1234yf**	***WAM HFC-32***
refrigerating capacity	*kW*	*4.5*	*4.5*	*4.5*	*4.5*	*4.5*	*4.5*
el power	kW	1	1	1	1	1	*1*
running time	h/y	1,500	1,500	1,500	1,500	1,500	*1,500*
invest cost hardware	€	750	750	739	941	814	769
refrigerant charge	kg	1.5	1.5	0.75	1.5	1.5	*0.9*
cost first fill	€	23	23	4	6	90	*12*
GWP of refrigerant		2,088	2,088	3	1	4	*675*
lifetime	*years*	10	10	10	10	10	*10*
cost Art 4	€/y	0	5.00	0	0	0	*5.00*
leakage rate	kg/kg	0.05	0.05	0.05	0.05	0.05	*0.05*
use emissions	kg/y	0.075	0.075	0.0375	0.075	0.075	*0.045*
disp emiss factor	kg/kg	0.7	0.35	0.7	0.7	0.7	*0.35*
disp emissions	kg/y	0.105	0.0525	0.0525	0.105	0.105	*0.0315*
consumption	kg/y	0.225	0.225	0.1125	0.225	0.225	*0.135*
global warming emiss	tCO2 eq	0.37584	0.26622	0.00027	0.00018	0.00072	0.0516375
emiss difference to WM	tCO2 eq	0.110		0.27	0.27	0.2655	0.21458
consumption	tCO2 eq	0.4698	0.4698	0.0003375	0.00	0.00	0.09
cons difference to WM	tCO2 eq	0		0.47	0.47	0.47	0.38
energy consumption	kWh	1,500	1,500	1,500	1,500	1,500	*1,500*
cost per kWh	*€*	*0.14*	*0.14*	*0.14*	*0.14*	*0.14*	*0.14*
energy cost	€/y	210	210	210	210	210	*210*
cost refrigerant refill	€/y	1.13	1.1	0.1875	0.30	4.5	*0.585*
discount rate	%	4%	4%	4%	4%	4%	*4%*
annuity factor discount		0.1233	0.1233	0.1233	0.1233	0.1233	*0.1233*
annual running cost	€	211.1	216.1	210.2	210.3	214.5	*215.6*
annual invest cost	€	95.2	95.2	91.5	116.8	111.4	*96.2*
annual total cost	€	306.4	311.4	301.7	327.1	325.9	*311.8*
add ann cost vs WM	€	-5		-10	16	15	0.4
abatem cost emiss	€/tCO2eq			**-36.23**	**59.09**	**54.83**	***2.05***
abatem cost consumption	€/tCO2eq			**-20.5**	**33.5**	**31.0**	***1.16***
Penetration 2015	%			20	10	1	*15*
Penetration 2020	%			45	15	45	*30*
Penetration 2030	%			50	30	45	*40*
Penetration mix 2015	%			20	10	1	*15*
Penetration mix 2020	%			40	15	45	
Penetration mix 2030	%			40	15	45	
first fill 2030	ktCO2eq		30,286				
use em 2030	ktCO2eq		15,143				
disp em 2030	ktCO2eq		7,828				
2030 av abat cost emiss	€/tCO2eq			**19.02**			
2030 av abat cost cons	€/tCO2eq			**10.77**			
red 2030 emissions	ktCO2eq			22,970			
red 2030 consumption	ktCO2eq			45,428			

The energy assumptions are in line with the draft COMMISSION REGULATION implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans.

Sheet	12	Multi-Split Room Air Conditioners (VRF)					
System		WOM R-410A direct	WM R-410A direct	WAM R-290 + secondary	WAM R-744	WAM R-1234yf	WAM R-290 + evap secondary
refrigerating capacity	*kW*	*27*	*27*	*27*	*27*	*27*	*27*
el power	kW	8	8	8	8	8	8
running time	h/y	3.000	3.000	3.000	3.000	3.000	3.000
invest cost hardware	€	9.500	9.500	11.970	10.830	10.735	12.920
refrigerant charge	kg	13,5	13,5	2	13,5	13,5	2
cost first fill	€	203	203	10	54	810	10
GWP of refrigerant		2.088	2.088	3	1	4	3
lifetime	*years*	13	13	13	13	13	13
cost Art 3+4	€/y	0	185	0		0	0
add maintenance	€/y				67		
leakage rate	kg/kg	0,08	0,056	0,08	0,08	0,08	0,08
use emissions	kg/y	1,08	0,756	0,16	1,08	1,08	0,16
disp emiss factor	kg/kg	0,3	0,2	0,3	0,3	0,3	0,3
disp emissions	kg/y	0,312	0,208	0,046	0,312	0,312	0,046
consumption	kg/y	2,118	1,794	0,314	2,118	2,118	0,314
global warming emiss	tCO2 eq	2,906	2,012	0,001	0,001	0,006	0,001
emiss difference to WM	tCO2 eq	-0,89	0,00	2,01	2,01	2,01	2,01
consumption	tCO2 eq	4,42335	3,74684	0,00094	0,0021	0,0085	0,0009
cons difference to WM	tCO2 eq	-0,68	0,000	3,75	3,74	3,74	3,75
energy consumption	kWh	24.000	24.000	24.000	24.000	24.000	24.000
cost per kWh	*€*	*0,14*	*0,14*	*0,14*	*0,14*	*0,14*	*0,14*
energy cost	€/y	3.360	3.360	3.360	3.360	3.360	3.360
cost refrigerant refill	€/y	16,20	11,34	0,8	4,32	64,8	0,8
discount rate	%	4%	4%	4%	4%	4%	4%
annuity factor discount		0,1001	0,1001	0,1001	0,1001	0,1001	0,1001
annual running cost	€	3.376,20	3.556,60	3.360,80	3.430,92	3.424,80	3.360,80
annual invest cost	€	972	972	1.200	1.090	1.156	1.295
annual total cost	€	4.348	4.528	4.561	4.521	4.581	4.656
add ann cost vs WM	€	-180,40	0	32	-7	53	127
abatem cost emiss	€/tCO2eq			**16**	**-4**	**26**	**63**
abatem cost consumption	€/tCO2eq			**9**	**-2**	**14**	**34**
Penetration 2015	%			20	10	1	5
Penetration 2020	%			30	20	30	10
Penetration 2030	%			70	30	70	20
Penetration mix 2015	%			20	10	1	5
Penetration mix 2020	%			30	20	30	10
Penetration mix 2030	%			70	20	10	0
first fill 2030	ktCO2eq		3.946				
use em 2030	ktCO2eq		2.702				
disp em 2030	ktCO2eq		603				
2030 av abat cost emiss	€/tCO2eq			**13,12**			
2030 av abat cost cons	€/tCO2eq			**7,05**			
red 2030 emissions	ktCO2eq			2.827			
red 2030 consumption	ktCO2eq			6.426			

Sheet	13	Packaged (Rooftop) AC					
		WOM R-410A direct	WM R-410A direct	WAM R-290 + secondary	WAM R-744	WAM R-1234yf	WAM R-290 + evap secondary
refrigerating capacity	*kW*	*30*	*30*	*30*	*30*	*30*	*30*
el power	kW	15	15	15	15	15	15
running time	h/y	3.000	3.000	3.000	3.000	3.000	3.000
invest cost hardware	€	10.000	10.000	11.600	11.300	11.300	12.100
refrigerant charge	kg	10,5	10,5	1,5	10,5	10,5	1,5
cost first fill	€	158	158	8	42	630	8
GWP of refrigerant		2.088	2.088	3	1	4	3
lifetime	*years*	10	10	10	10	10	10
cost Art 3+4	€/y	0	167	0		0	0
add maintenance	€/y				37		
leakage rate	kg/kg	0,05	0,030	0,05	0,05	0,05	0,05
use emissions	kg/y	0,525	0,315	0,075	0,525	0,525	0,075
disp emiss factor	kg/kg	0,3	0,2	0,3	0,3	0,3	0,3
disp emissions	kg/y	0,315	0,21	0,045	0,315	0,315	0,045
consumption	kg/y	1,575	1,365	0,225	1,575	1,575	0,225
global warming emiss	tCO2 eq	1,75392	1,0962	0,00036	0,00084	0,00336	0,00036
emiss difference to WM	tCO2 eq	0,66	0,00	1,10	1,10	1,09	1,10
consumption	tCO2 eq	3,2886	2,85012	0,000675	0,00	0,01	0,00
cons difference to WM	tCO2 eq	0,44	0,000	2,85	2,85	2,84	2,85
energy consumption	kWh	45.000	45.000	45.000	45.000	45.000	45.000
cost per kWh	*€*	*0,14*	*0,14*	*0,14*	*0,14*	*0,14*	*0,14*
energy cost	€/y	6.300	6.300	6.300	6.300	6.300	6.300
cost refrigerant refill	€/y	7,88	4,73	0,375	2,10	31,5	0,375
discount rate	%	4%	4%	4%	4%	4%	4%
annuity factor discount		0,1233	0,1233	0,1233	0,1233	0,1233	0,1233
annual running cost	€	6.307,88	6.471,39	6.300,38	6.339,10	6.331,50	6.300,38
annual invest cost	€	1.252	1.252	1.431	1.398	1.471	1.493
annual total cost	€	7.560	7.724	7.731	7.737	7.802	7.793
add ann cost vs WM	€	-163,52	0	8	14	79	69
abatem cost emiss	€/tCO2eq			**7**	**13**	**72**	**63**
abatem cost consumption	€/tCO2eq			**3**	**5**	**28**	**24**
Penetration 2015	%			20	5	1	10
Penetration 2020	%			40	15	30	15
Penetration 2030	%			80	35	70	30
Penetration mix 2015	%			20	5	1	10
Penetration mix 2020	%			40	15	30	15
Penetration mix 2030	%			80	20	0	0
first fill 2030	ktCO2eq		1.146				
use em 2030	ktCO2eq		344				
disp em 2030	ktCO2eq		229				
2030 av abat cost emiss	€/tCO2eq			**8,17**			
2030 av abat cost cons	€/tCO2eq			**3,14**			
red 2030 emissions	ktCO2eq			573			
red 2030 consumption	ktCO2eq			1.489			

Sheet	14	Chillers (displacement compressors)					
		WOM R-407C direct	WM R-407C direct	WAM R-290 direct	WAM R-717	WAM R-744	WAM R-1234yf
refrigerating capacity	*kW*	*100*	100	100	100	100	100
el power	kW	20	20	20	18.5	20	20
running time	h/y	3,500	3,500	3,500	3,500	3,500	3,500
invest cost hardware	€	22,000	22,000	23,100	30,382	28,380	23,100
refrigerant charge	kg	50	50	25	50	50	50
cost first fill	€	750	750	125	100	200	3,000
GWP of refrigerant		2,107	2,107	3	0	1	4
lifetime	*years*	12	12	12	12	12	12
cost Art 3+4	€/y	0	206	0			0
add maintenance	€/y				50	50	
leakage rate	kg/kg	0.04	0.024	0.04	0.04	0.04	0.04
use emissions	kg/y	2.0	1.2	1.0	2.0	2.0	2.0
disp emiss factor	kg/kg	0.3	0.2	0.3	0.3	0.3	0.3
disp emissions	kg/y	1.3	0.8	0.6	1.3	1.3	1.3
consumption	kg/y	6.2	5.4	3.1	6.2	6.2	6.2
global warming emiss	tCO2 eq	6.8	4.3	0.005	0.000	0.003	0.013
emiss difference to WM	tCO2 eq	2.56	0.00	4.28	4.28	4.28	4.27
consumption	tCO2 eq	12.99316667	11.30756667	0.00925	0.00	0.01	0.02
cons difference to WM	tCO2 eq	1.69	0.000	11.30	11.31	11.30	11.28
energy consumption	kWh	70,000	70,000	70,000	64,750	70,000	70,000
cost per kWh	*€*	*0.14*	*0.14*	*0.14*	*0.14*	*0.14*	*0.14*
energy cost	€/y	9,800	9,800	9,800	9,065	9,800	9,800
cost refrigerant refill	€/y	30.00	18.00	5.00	4.00	8.00	120
discount rate	%	4%	4%	4%	4%	4%	4%
annuity factor discount		0.1066	0.1066	0.1066	0.1066	0.1066	0.1066
annual running cost	€	9,830.00	10,023.50	9,805.00	9,119.15	9,858.00	9,920.00
annual invest cost	€	2,424	2,424	2,475	3,248	3,045	2,781
annual total cost	€	12,254	12,448	12,280	12,367	12,903	12,701
add ann cost vs WM	€	-193.50	0	-168	-80	456	253
abatem cost emiss	€/tCO2eq			**-39**	**-19**	**106**	**59**
abatem cost consumption	€/tCO2eq			**-15**	**-7**	**40**	**22**
Penetration 2015	%			20	15	5	1
Penetration 2020	%			30	30	10	30
Penetration 2030	%			40	50	20	70
Penetration mix 2015	%			20	15	5	1
Penetration mix 2020	%			30	30	20	20
Penetration mix 2030	%			40	30	20	10
first fill 2030	ktCO2eq		5,095				
use em 2030	ktCO2eq		1,773				
disp em 2030	ktCO2eq		990				
2030 av abat cost emiss	€/tCO2eq			**5.88**			
2030 av abat cost cons	€/tCO2eq			**2.23**			
red 2030 emissions	ktCO2eq			2,512			
red 2030 consumption	ktCO2eq			6,851			

Sheet	15	Centrifugal chillers				
		WOM R-134a	**WM R-134a**	**WAM R-290**	**WAM R-718**	**WAM R-1234ze**
refrigerating capacity	*kW*	*1500*	*1500*	*1500*	*1500*	*1500*
el power	kW	300	300	300	300	300
running time	h/y	3,350	3,350	3,350	3,350	3,350
invest cost hardware	€	140,000	140,000	147,000	166,600	147,000
refrigerant charge	kg	630	630	315	630	630
cost first fill	€	6,300	6,300	1,575	2	25,200
GWP of refrigerant		1,430	1,430	3	0	6
lifetime	*years*	25	25	25	25	25
cost Art 3+4	€/y	0	808	0	0	0
add maintenance	€/y				90	
leakage rate	kg/kg	0.04	0.024	0.04	0.04	0.04
use emissions	kg/y	25.2	15.12	12.6	25.2	25.2
disp emiss factor	kg/kg	0.3	0.2	0.3	0.3	0.3
disp emissions	kg/y	7.6	5.0	3.8	7.6	7.6
consumption	kg/y	50.4	40.3	25.2	50.4	50.4
global warming emiss	tCO2 eq	46.8	28.8	0.049	0.000	0.197
emiss difference to WM	tCO2 eq	18.02	0.00	28.78	28.83	28.63
consumption	tCO2 eq	72.07	57.66	0.076	0.00	0.30
cons difference to WM	tCO2 eq	14.41	0.000	57.58	57.66	57.36
energy consumption	kWh	1,005,000	1,005,000	1,005,000	1,005,000	1,005,000
cost per kWh	*€*	*0.14*	*0.14*	*0.14*	*0.14*	*0.14*
energy cost	€/y	140,700	140,700	140,700	140,700	140,700
cost refrigerant refill	€/y	378.00	226.80	63.00	50.40	100.80
discount rate	%	4%	4%	4%	4%	4%
annuity factor discount		0.0640	0.0640	0.0640	0.0640	0.0640
annual running cost	€	141,078.00	141,735.13	140,763.00	140,840.40	140,800.80
annual invest cost	€	9,365	9,365	9,511	10,665	11,023
annual total cost	€	150,443	151,100	150,274	151,505	151,824
add ann cost vs WM	€	-657.13	0	-827	405	724
abatem cost emiss	€/tCO2eq			**-28.7**	**14.0**	**25.3**
abatem cost consumption	€/tCO2eq			**-14.4**	**7.0**	**12.6**
Penetration 2015	%			0	5	1
Penetration 2020	%			5	10	30
Penetration 2030	%			20	30	80
Penetration mix 2015	%			0	5	1
Penetration mix 2020	%			5	10	30
Penetration mix 2030	%			20	30	50
reduct first fill						
first fill 2030	ktCO2eq		378			
use em 2030	ktCO2eq		227			
disp em 2030	ktCO2eq		74			
2030 av abat cost emiss	€/tCO2eq				**11.07**	
2030 av abat cost cons	€/tCO2eq				**5.53**	
red 2030 emissions	ktCO2eq				82	
red 2030 consumption	ktCO2eq				460	

Sheet	16	Heat Pumps (heating only)						
System		WOM R-410A	WM R-410A	WAM R-290	WAM R-744	WAM R-600a	WAM R-1234yf	*WAM* *R-32*
refrigerating capacity	*kW*	*11*	*11*	*11*	*11*	*11*	*11*	*11*
el power	kW	3	3	3	3	3	3	*3*
running time	h/y	4,380	4,380	4,380	4,380	4,380	4,380	*4,380*
invest cost hardware	€	7,000	7,000	7,350	7,840	7,490	7,420	*7,420*
refrigerant charge	kg	2.4	2.4	1.2	2.4	1.2	2.4	*1.92*
cost first fill	€	36	36	6	10	6	144	*25*
GWP of refrigerant		2,088	2,088	3	1	4	4	*675*
lifetime	*years*	15	15	15	15	15	15	*15*
cost Art 4	€/y	0	3.33	0	0	0	0	*3.33*
leakage rate	kg/kg	0.035	0.035	0.035	0.035	0.035	0.035	0.035
use emissions	kg/y	0.084	0.084	0.042	0.084	0.042	0.084	*0.0672*
disp emiss factor	kg/kg	0.7	0.35	0.7	0.7	0.7	0.7	*0.7*
disp emissions	kg/y	0.11	0.06	0.06	0.11	0.06	0.11	0.09
consumption	kg/y	0.24	0.24	0.12	0.24	0.12	0.24	*0.20*
global warming emiss	tCO2 eq	0.41	0.29232	0.00029	0.00020	0.00039	0.00078	*0.10584*
emiss difference to WM	tCO2 eq	0.12		0.29	0.29	0.29	0.29	0.19
consumption	tCO2 eq	0.509472	0.509472	0.000366	0.00	0.00	0.00	0.13
cons difference to WM	tCO2 eq	0.00		0.51	0.51	0.51	0.51	0.38
energy consumption	kWh	13,140	13,140	13,140	13,140	13,140	13,140	*13,140*
cost per kWh	*€*	*0.14*	*0.14*	*0.14*	*0.14*	*0.14*	*0.14*	*0.14*
energy cost	€/y	1,840	1,840	1,840	1,840	1,840	1,840	*1,840*
cost refrigerant refill	€/y	1.26	1.26	0.21	0.34	0.21	5.04	*0.8736*
discount rate	%	4%	4%	4%	4%	4%	4%	*4%*
annuity factor discount		0.0899	0.0899	0.0899	0.0899	0.0899	0.0899	*0.0899*
annual running cost	€	1,840.86	1,844.19	1,839.81	1,839.94	1,839.81	1,844.64	*1,843.81*
annual invest cost	€	633	633	662	706	674	680	*670*
annual total cost	€	2,474	2,477	2,501	2,546	2,514	2,525	*2,513*
add ann cost vs WM	€	-3.33		24	69	37	48	36
abatem cost emiss	€/tCO2eq			**84**	**236**	**127**	**164**	***195***
abatem cost consumptior	€/tCO2eq			**48**	**135**	**73**	**94**	***96***
Penetration 2015	%			20	10	20	1	*15*
Penetration 2020	%			30	20	30	30	*30*
Penetration 2030	%			60	50	60	90	*40*
Penetration mix 2015	%			20	10	20	1	*15*
Penetration mix 2020	%			30	20	25	25	*0*
Penetration mix 2030	%			60	20	0	20	*0*
first fill 2030	ktCO2eq		4,394					
use em 2030	ktCO2eq		1,849					
disp em 2030	ktCO2eq		865					
2030 av abat cost emiss	€/tCO2eq			**130.19**				
2030 av abat cost cons	€/tCO2eq			**74.67**				
red 2030 emissions	ktCO2eq			2,282				
red 2030 consumption	ktCO2eq			6,147				

Sheet	17	Air conditioning cargo ship			
		WOM=WM R-134a direct	**WAM1 R-134a Art3+4**	**WAM 2 NH3/brine**	**WAM 2 XP10 (DR-11)**
refrigerating capacity	*kW*	*300*	*300*	*300*	300
el power	kW	55.3	55.3	46.86	55.3
Installed pump el power	kW	0	0	8	0
running time	h/y	3,000	3,000	3,000	3,000
invest cost hardware	€	38,000	38,000	60,000	39,900
refrigerant charge	kg	160	160	53	160
cost first fill	€	1,600	1,600	107	4,800
GWP of refrigerant		1,430	1,430	0	600
lifetime	*years*	*30*	*30*	*30*	30
cost Art 3+4	€/y	0	650		0
add maintenance	€/y			1,000	
leakage rate	kg/kg	0.4	0.24	0.4	0.4
use emissions	kg/y	64	38.4	21.33	64
disp emiss factor	kg/kg	0.3	0.2	0.3	0.3
disp emissions	kg/y	1.6	1.1	0.5	1.6
consumption	kg/y	69.33	43.73	23	69.33
global warming emiss	tCO2 eq	93.81	56.44	0	39.36
emiss differ to reference	tCO2 eq	0	37.4	93.8	54.4
consumption	tCO2 eq	99.15	62.54	0	41.60
cons difference to refere	tCO2 eq	0	36.608	99.147	57.547
energy consumption	kWh	165,900	165,900	164,580	165,900
cost per kWh	*€*	*0.07*	*0.07*	*0.07*	0.07
energy cost	€/y	11,613	11,613	11,521	11,613
cost refrigerant refill	€/y	640	384	42.67	1920
discount rate	%	4%	4%	4%	4%
annuity factor discount		0.0578	0.0578	0.0578	0.0578
annual running cost	€	12,253	12,647	12,563	13,533
annual invest cost	€	2,290	2,290	3,476	2,585
annual total cost	€	14,543	14,937	16,039	16,118
add ann cost vs referenc	€	0	394	1,496	1,575
abatem cost emiss	€/tCO2eq		**10.5**	**15.9**	**28.9**
abatem cost consumptio	€/tCO2eq		**10.8**	**15.1**	**27.4**
Penetration 2015	%			70	1
Penetration 2020	%			80	20
Penetration 2030	%			90	90
Penetration mix 2015	%			70	1
Penetration mix 2020	%			80	20
Penetration mix 2030	%			90	10
first fill 2030	ktCO2eq	34	34		
use em 2030	ktCO2eq	674	405		
disp em 2030	ktCO2eq	10	7		
2030 av abat cost emiss	€/tCO2eq			**16.74**	
2030 av abat cost cons	€/tCO2eq			**15.83**	
red 2030 emissions	ktCO2eq		273	320	
red 2030 consumption	ktCO2eq		270	353	

Sheet	18	Air conditioning passenger ship		
		WOM=WM R-134a direct	**WAM1 R-134a Art3+4**	**WAM 2 XP10 (DR-11)**
refrigerating capacity	*kW*	*975*	*975*	*975*
power installed	kW	180	*180*	*180*
Installed pump el power	kW	0	0	0
running time	h/y	3,000	3,000	3,000
invest cost hardware	€	123,500	123,500	148,200
refrigerant charge	kg	520	*520*	520
cost first fill	€	5200	5200	15600
GWP of refrigerant		1430	1430	600
lifetime	*years*	*30*	*30*	*30*
cost Art 3+4	€/y	0	1,867	0
leakage rate	kg/kg	0.4	0.24	0.4
use emissions	kg/y	208	124.8	208
disp emiss factor	kg/kg	0.3	0.2	0.3
disp emissions	kg/y	5.2	3.5	5.2
consumption	kg/y	225.33	142.13	225.33
global warming emiss	tCO2 eq	304.876	183.42	127.92
emiss differ to reference	tCO2 eq	0	**121.5**	**177.0**
consumption	tCO2 eq	322.23	203.25	135.20
cons difference to referer	tCO2 eq	0	**118.976**	**187.027**
energy consumption	kWh	540,000	540,000	540,000
cost per kWh	*€*	*0.07*	*0.07*	*0.07*
energy cost	€/y	37,800	37,800	37,800
cost refrigerant refill	€/y	2,080	1,248	6,240
discount rate	%	4%	4%	4%
annuity factor discount		0.0578	0.0578	0.0578
annual running cost	€	39,880	40,915	44,040
annual invest cost	€	7,443	7,443	9,473
annual total cost	€	47,323	48,357	53,513
add ann cost vs referenc	€	0	**1,035**	**6,190**
abatem cost emiss	€/tCO2eq		**8.52**	**35.0**
abatem cost consumptior	€/tCO2eq		**8.70**	**33.1**
Penetration 2015	%			1
Penetration 2020	%			20
Penetration 2030	%			90
first fill 2030	ktCO2eq	67	67	
use em 2030	ktCO2eq	995	597	
disp em 2030	ktCO2eq	20	13	
2030 av abat cost emiss	€/tCO2eq			**35.0**
2030 av abat cost cons	€/tCO2eq			**33.1**
red 2030 emissions	ktCO2eq		405	125
red 2030 consumption	ktCO2eq		398	160

Sheet	19	Rail Vehicle Air Conditioning		
		WOM=WM R-134a	**WAM1 R-134a Art3+4**	**WAM R-744**
refrigerating capacity	*kW*	*35*	*35*	*35*
el power	kW	15	15	15
running time	h/y	2,000	2,000	2,000
invest cost hardware	€	25,000	25,000	32,500
refrigerant charge	kg	8	8	8
cost first fill	€	80	80	32
GWP of refrigerant		1,430	1,430	1
lifetime	*years*	25	25	25
cost Art 3+4	€/y	0	72	
add maintenance	€/y			50
leakage rate	kg/kg	0.07	0.056	0.07
use emissions	kg/y	0.56	0.448	0.56
disp emiss factor	kg/kg	0.3	0.2	0.3
disp emissions	kg/y	0.10	0.06	0.10
consumption	kg/y	0.88	0.77	0.88
global warming emiss	tCO2 eq	0.94	0.7322	0.0007
emiss differ to reference	tCO2 eq	0	**0.206**	**0.937**
consumption	tCO2 eq	1.2584	1.09824	0.00088
cons difference to referer	tCO2 eq	0	**0.160**	**1.258**
energy consumption	kWh	30,000	30,000	30,000
cost per kWh	*€*	*0.14*	*0.14*	*0.14*
energy cost	€/y	4,200	4,200	4,200
cost refrigerant refill	€/y	8.40	6.72	2.24
discount rate	%	4%	4%	4%
annuity factor discount		0.0640	0.0640	0.0640
annual running cost	€	4,208.40	4,278.39	4,252.24
annual invest cost	€	1,605	1,605	2,082
annual total cost	€	5,814	5,884	6,335
add ann cost vs referenc	€		**70**	**521**
abatem cost emiss	€/tCO2eq		**339.9**	**555.6**
abatem cost consumptior	€/tCO2eq		**437.0**	**414.2**
Penetration 2015	%			5
Penetration 2020	%			25
Penetration 2030	%			60
first fill 2030	ktCO2eq	64	64	
use em 2030	ktCO2eq	107	96	
disp em 2030	ktCO2eq	15	10	
2030 av abat cost emiss	€/tCO2eq			**555.6**
2030 av abat cost cons	€/tCO2eq			**414.2**
red 2030 emissions	ktCO2eq		*16*	26
red 2030 consumption	ktCO2eq		*11*	129

Sheet	20	Fire Protection HFC-227ea		
		WOM HFC-227ea	**WM HFC-227ea**	**WAM FK-5-1-12**
Technical data				
room size	m3	200	200	200
requried gas concentration	kg/m3	0.6773	0.6773	0.8253
installed gas quantity	kg	135.5	135.5	165.1
hardware invest cost	€	10,000	10,000	11,500
gas cost	€/kg	12	12	22
Total gas cost	€	1,626	1,626	3,631
Total invest cost	€	11,626	11,626	15,131
cost Art 3+4	€ /y		91	
lifetime	*years*	20	20	20
annual leakage		2.5%	2.0%	2.5%
loss/refill per year	kg/y	3.39	2.71	4.13
disp loss		10.0%	9.0%	10.0%
disposal emiss per y	kg/y	0.68	0.43	0.83
Total emissions per y	kg	4.06	3.14	4.95
Consumption per y	kg	10.16	9.48	12.38
GWP		3,220	3,220	1
global warming emissions	tCO2 eq	13.09	10.10	0.00
Difference emiss to WM	tCO2 eq	2.99		10.09
global warming consumption	tCO2 eq	32.71	30.53	0.01
Difference consum to WM	tCO2 eq	2.18		30.52
cost refill per year	€	40.6	32.5	90.8
discount rate	%	4%	4%	4%
annuity factor discount		0.0736	0.0736	0.0736
annual invest cost	€	855	855	1,113
annual running cost	€	40.64	123.34	90.78
annual total cost	€	896	979	1,204
add annual cost vs reference	€	-83		225
abatem cost emiss	€/tCO2eq			**22.33**
abatem cost consumption	€/tCO2eq			**7.39**
Penetration 2015	%			70
Penetration 2020	%			80
Penetration 2030	%			90
first fill 2030	ktCO2eq		2,375	
use em 2030	ktCO2eq		675	
disp em 2030	ktCO2eq		245	
2030 av abat cost emiss	€/tCO2eq			**22.33**
2030 av abat cost cons	€/tCO2eq			**7.39**
red 2030 emissions	ktCO2eq			440
red 2030 consumption	ktCO2eq			2,578

Sheet	21	Fire Protection HFC-23		
		WOM HFC-23	**WM HFC-23**	**WAM FK-5-1-12**
Technical data				
room size	m3	200	200	200
requried gas concentration	kg/m3	0.61	0.61	0.83
installed gas quantity	kg	122.0	122.0	165.1
hardware invest cost	€	11,500	11,500	11,500
gas cost	€/kg	12	12	22
Total gas cost	€	1,464	1,464	3,631
Total invest cost	€	12,964	12,964	15,131
cost Art 3+4	€ /y		91	
lifetime	*years*	20	20	20
annual leakage		2.5%	2.0%	2.5%
loss/refill per year	kg/y	3.05	2.44	4.13
Disp loss		10.0%	9.0%	10.0%
disposal emiss per y	kg/y	0.61	0.38	0.83
Total emissions per y	kg	3.66	2.82	4.95
Consumption per y	kg	9.15	8.54	12.38
GWP		14,800	14,800	1
global warming emissions	tCO2 eq	54.17	41.80	0.00
Difference emiss to WM	tCO2 eq	-12.37	0.00	41.79
global warming consumption	tCO2 eq	135.42	126.39	0.01
Difference consum to WM	tCO2 eq	-9.03	0.00	126.38
cost refill per year	€	36.6	29.3	90.8
discount rate	%	4%	4%	4%
annuity factor discount		0.0736	0.0736	0.0736
annual invest cost	€	954	954	1,113
annual running cost	€	36.60	120.11	90.78
annual total cost	€	991	1,074	1,204
add annual cost vs reference	€	-84	0	130
abatem cost emiss	€/tCO2eq			**3.11**
abatem cost consumption	€/tCO2eq			**1.03**
Penetration 2015	%			100
Penetration 2020	%			100
Penetration 2030	%			100
first fill 2030	tCO2eq		1,985	
use em 2030	tCO2eq		1,202	
disp em 2030	tCO2eq		179	
2030 av abat cost emiss	€/tCO2eq			**3.11**
2030 av abat cost cons	€/tCO2eq			**1.03**
red 2030 emissions	tCO2eq			961
red 2030 consumption	tCO2eq			2,946

Sheet	22	Aerosols	
		WOM=WM **HFC-134a**	**WAM** **unsat. HFC-1234ze**
Trade names		Micro Freeze Circuit Cooler	Micro•Freeze™ EU Circuit Chiller
		Big Blast Dry Circuit Cleaner	Big Blast EU Circuit Cleaner
		MicroCare DST	Big Blast™ EU Precision Duster
active ingredients		100% HFC-134a	100% unsat HFC-1234ze
chemical name		Tetrafluoroethane	Trans-1,3,3,3-tetrafluoropro-1-ene
can size	grams	280	280
F-gas content	grams	280	280
Flammability rating		nonflammable	nonflammable*
boiling point		-26.5 °C	-19°C
vapour density (air=1)		4,9 (25°C)	3,6 (25°C)
price end users 280g-can	€	8.00	12.00
price difference 1 can	€		4.00
price difference per kg	€		14.29
price diff whole salers 1 can	€		*3.50*
GWP		1,430	6
emissions per kg		1,430	6
emiss diff to reference	tCO2 eq	0.00	1.424
consumption per kg	tCO2 eq	1,430	6
cons diff reference	tCO2 eq	0.00	1.424
abatem cost emiss	€/tCO2eq		**10.03**
abatem cost consumption	€/tCO2eq		**10.03**
Penetration 2015	%		25
Penetration 2020	%		95
Penetration 2030	%		95
2030 av abat cost emiss	€/tCO2eq		**10.03**
2030 av abat cost cons	€/tCO2eq		**10.03**
use em 2030 WM	tCO2eq	3,828	3,637
red 2030 use emissions	tCO2eq		3,637

* at room temperature

Sheet	23	XPS-134a		
blowing agent (BLA)		WOM=WM HFC-134a	WAM HC/CO2	WAM HFC-1234ze
Product		Panel 1200 x 600 x 50 mm, density 35		
weight of 1 panel	kg	1.26		
square metres per year	m2	2,073,600		
weight of annual XPS output	tons	2,613		
BLA pbw (parts by weight)		8	6	9
total pbw		92	94	86
blowing agent in weight	%	9%	6%	10%
blowing agent consumption	t/year	227	167	273
thermal conductivity	mW	32	34	32
thermal conductivity loss	%	-	6.3%	0.0%
add. raw material (incr. thickness)	tons	-	163	
GWP of BLA		1,430	5	6
consumption BLA (GWP)	tCO2eq	324,888	834	1,641
difference to cons reference	tCO2eq	0	324,054	323,247
Manufacturing EF	%	30%	100%	30%
GWP of manufacturing emiss	tCO2eq	97,466	834	492
Use phase EF	%	0.75%	0%	0.75%
GWP use phase emiss	tCO2eq	1,706	0	9
GWP all emissions	tCO2eq	99,172	834	501
difference to emiss reference	tCO2eq	0	98,338	98,671
Operating cost				
Raw materials basic price w.o blowing	€/tonne	1,500	1,500	1,500
cost for BLA				
BLA costs kg	€	5.00	0.80	12.00
annual cost BLA	€/year	1,135,972	133,416	3,281,110
BLA cost difference to reference		0	-1,002,556	2,145,138
cost for thickness increase				
cost diff per tonne	€	0	94	0
cost diiference per year	€	0.00	244,944	0.00
cost increase change raw material		-	5%	10%
additional cost per year		0.00	195,955	391,910
difference operating cost	€/year	0.00	-561,657	2,537,049
Invest cost				
capital invest new production line	€	-	1,500,000	1,500,000
lifetime equipment	years	10	10	10
technology change cost			80,000	80,000
- design modification	€		*30,000*	*30,000*
- raw material tests min	€		*40,000*	*40,000*
- raw material tests max	€		*60,000*	*60,000*
Total invest cost	€		1,580,000	1,580,000
discount rate	%		4%	4%
annuity factor discount			0.1233	0.1233
annualised invest cost	€/y		194,800	194,800
Annual total cost difference	€/y		-366,857	2,731,848
Abatement cost				
abatem cost emiss	€/tCO2eq		**-3.73**	**27.69**
abatem cost consumption	€/tCO2eq		**-1.13**	**8.45**
Penetration 2015	%		90	30
Penetration 2020	%		90	100
Penetration 2030	%		90	100
Penetration mix 2015	%		85	15
Penetration mix 2020	%		85	15
Penetration mix 2030	%		85	15
reduction consumption			84.7%	14.94%
reduction manuf em 2030			84.7%	14.94%
red use phase em 2030/2015			40.2%	1.25%
consumption 2030	tCO2eq	4,092		
manuf emissions 2030	tCO2eq	1,228		
WOM-WM use em 2030	tCO2eq	582		
WAM use em 2030	*tCO2eq*	*257*		
2030 av abat cost emiss	€/tCO2eq		**1.00**	
2030 av abat cost cons	€/tCO2eq		**0.30**	
red 2030 emissions	tCO2eq		1,553	
red 2030 consumption	tCO2eq		4,092	

Sheet	24	XPS-152a		
blowing agent (BLA)		**WOM=WM HFC-152a**	**WAM HC**	**WAM HFC-1234ze**
Product		Panel 1200 x 600 x 50 mm, density 35		
weight of 1 panel	kg	1.26		
square metres per year	m2	2,073,600		
weight of annual XPS output	tons	2,613		
BLA pbw (parts by weight)		10	6	14
total pbw		90	94	86
blowing agent in weight	%	11%	6%	16%
blowing agent consumption	t/year	290	167	425
thermal conductivity	mW	34	34	32
thermal conductivity loss	%	-	0.0%	-5.9%
add. raw material (incr. thickness)	tons	-	0	-154
GWP of BLA		124	5	6
GWP of consumption BLA	tCO2eq	35,998	834	2,552
difference to cons reference	tCO2eq	0	35,164	33,446
Manufacturing EF	%	100%	100%	30%
manufacturing emiss	tCO2eq	35,998	834	766
Use phase EF	%	0%	0%	1%
use phase emiss	tCO2eq	0	0	18
all emissions	tCO2eq	35,998	834	783
difference to emiss reference	tCO2eq	0	35,164	35,214
Operating cost				
Raw materials basic price w.o blowing	€/tonne	1,500	1,500	1,500
cost for BLA				
BLA costs kg	€	2.00	0.80	12.00
annual cost BLA	€/year	580,608	133,416	5,103,949
cost difference to reference		0	-447,192	4,523,341
cost for thickness increase				
cost diff per tonne	€	0	0	-88
cost diiference per year	€	0.00	0	-230,536
cost increase change raw material		-	5%	10%
additional cost per year		0.00	195,955	391,910
difference operating cost	€/year	0.00	-251,236	4,684,716
Invest cost				
capital invest new production line	€	-	1,500,000	1,500,000
lifetime equipment	years	10	10	10
technology change cost			80,000	80,000
- design modification	€		*30,000*	*30,000*
- raw material tests min	€		*40,000*	*40,000*
- raw material tests max	€		*60,000*	*60,000*
Total invest cost	€		1,580,000	1,580,000
discount rate	%		4%	4%
annuity factor discount			0.1233	0.1233
annualised invest cost	€/y		194,800	194,800
Annual total cost difference	€/y		-56,437	4,879,516
Abatement cost	€/tCO2eq			
abatem cost emiss	€/tCO2eq		**-1.60**	**138.57**
abatem cost consumption	€/tCO2eq		**-1.60**	**145.89**
Penetration 2015	%		100	30
Penetration 2020	%		100	100
Penetration 2030	%		100	100
Penetration mix 2015	%		100	0
Penetration mix 2020	%		100	0
Penetration mix 2030	%		100	0
reduction EF			96%	
reduction consumption factor			96%	
manuf emissions 2030	tCO2eq	460		
consumption 2030	tCO2eq	460		
red 2030 emissions	tCO2eq		460	
red 2030 consumption	tCO2eq		460	
2030 av abat cost emiss	€/tCO2eq		**-1.60**	
2030 av abat cost cons	€/tCO2eq		**-1.60**	
red 2030 emissions	tCO2eq		460	
red 2030 consumption	tCO2eq		460	

Sheet	25	PU Spray foam		
blowing agent (BLA)		**WOM=WM HFC-365mfc/227ea**	**WAM H2O**	**WAM unsat HFC**
Product		sprayfoam 100 x100 x 8 cm, density 60		
weight of 1 square metre	kg	4.8		
square metres per year	m2	48,000		
weight of annual foam	tons	230		
BLA pbw (parts by weight)		15		15
total pbw		245	230	245
blowing agent in weight	%	6%	0%	6%
blowing agent consumption	t/year	14	0	14
thermal conductivity	mW	30	35	30
thermal conductivity loss	%	-	16.7%	0.0%
add. raw material (incr. thickness)	tons	-	38	0
GWP of BLA		964	0	6
consumption BLA	tCO2eq	13,596	0	85
difference to cons reference	tCO2eq	0	13,596	13,511
Manufacturing EF	%	15%	100%	15%
manufacturing emiss	tCO2eq	2,039	0	13
Use phase EF	%	1.5%	0%	1.5%
use phase emiss	tCO2eq	173.3	0	1.1
all emissions	tCO2eq	2,213	0	13.8
difference to emiss reference	tCO2eq	0	2,213	2,199
Operating cost				
Raw materials basic price w.o blov	€/tonne	2,500	2,500	2,500
cost for BLA				
BLA costs kg	€	5.00	0.00	12.00
annual cost BLA	€/year	70,531	0	169,273
cost difference to reference		0	-70,531	98,743
cost for thickness increase				
cost diff per tonne	€	0	417	0
cost diiference per year	€	0.00	96,000	0
cost increase change raw material*		-	15%	10%
additional cost per year		0.00	86,400	57,600
difference operating cost	€/year	0.00	111,869	156,343
Invest cost				
capital invest new production line	€	-	7,500	7,500
lifetime equipment	years	10	10	10
technology change cost			7,500	7,500
- design modification	€		*0*	*0*
- raw material tests min	€		*5,000*	*5,000*
- raw material tests max	€		*10,000*	*10,000*
Total invest cost	€		15,000	15,000
discount rate	%		4%	4%
annuity factor discount			0.1233	0.1233
annualised invest cost	€/y		1,849	1,849
Annual total cost difference	€/y		113,719	158,192
Abatement cost	€/tCO2eq			
abatem cost emiss	€/tCO2eq		**51.39**	**71.94**
abatem cost consumption	€/tCO2eq		**8.36**	**11.71**
Penetration 2015	%		100	50
Penetration 2020	%		100	100
Penetration 2030	%		100	100
Penetration mix 2015	%		50	50
Penetration mix 2020	%		50	50
Penetration mix 2030	%		50	50
reduction consumption			50%	50%
reduction manuf em 2030			50%	50%
red use phase em 2030/2015			30.7%	30.7%
consumption 2030	tCO2eq	4,801		
manuf emissions 2030	tCO2eq	604		
use em 2030	tCO2eq	1,245		
WAM use em 2030	*tCO2eq*	480		
2030 av abat cost emiss	€/tCO2eq		**61.63**	
2030 av abat cost cons	€/tCO2eq		**10.03**	
red 2030 emissions	tCO2eq		1,369	
red 2030 consumption	tCO2eq		4,801	

* linked to increase of material costs polyol and/or isocyanates

Sheet	26	Other PU foam (non-spray)		
blowing agent (BLA)		WOM=WM HFC-365mfc/227ea	WAM HC (Pentane)	WAM unsat HFC
Product				
weight of 1 panel	kg	4		
number of panels per year	m2	138,240		
weight of annual foam	tons	553		
BLA pbw (parts by weight)		12	7	14
total pbw		242	237	244
blowing agent in weight	%	5%	3%	6%
blowing agent consumption	t/year	27	16	32
thermal conductivity	mW	22	23	22
thermal conductivity loss	%	-	4.5%	0.0%
add. raw material (incr. thickness)	tons	-	25	0
GWP of BLA		964	5	6
GWP of consumption BLA	tCO2eq	26,427	82	190
difference to cons reference	tCO2eq	0	26,346	26,237
Manufacturing EF	%	4.5%	100%	4.5%
GWP of manufacturing emiss	tCO2eq	1,189	82	9
Use phase EF	%	0.25%	0%	0.25%
GWP use phase emiss	tCO2eq	63	0	0
GWP all emissions	tCO2eq	1,252	82	9
difference to emiss reference	tCO2eq	0	1,171	1,243
Operating cost				
Raw materials basic price w.o blov	€/tonne	2,500	2,500	2,500
cost for BLA				
BLA costs kg	€	5.00	0.80	12.00
annual cost BLA	€/year	137,098	13,066	380,727
cost difference to reference		0	-124,032	243,629
cost for thickness increase				
cost diff per tonne	€	0	114	0
cost difference per year	€	0.00	62,836	0
cost increase change raw material*		-	0%	10%
additional cost per year		0.00	0	138,240
difference operating cost	€/year	0.00	-61,195	381,869
Invest cost				
capital invest new production line	€	-	400,000	400,000
lifetime equipment	years	15	15	15
technology change cost			80,000	80,000
- design modification	€		*30,000*	*30,000*
- raw material tests min	€		*40,000*	*40,000*
- raw material tests max	€		*60,000*	*60,000*
Total invest cost	€		480,000	480,000
discount rate	%		4%	4%
annuity factor discount			0.0899	0.0899
annualised invest cost	€/y		43,172	43,172
Annual total cost difference	€/y		-18,024	425,041
Abatement cost	€/tCO2eq			
abatem cost emiss	€/tCO2eq		**-15.40**	**341.86**
abatem cost consumption	€/tCO2eq		**-0.68**	**16.20**
Penetration 2015	%		95	30
Penetration 2020	%		95	100
Penetration 2030	%		95	100
Penetration mix 2015	%		95	5
Penetration mix 2020	%		95	5
Penetration mix 2030	%		95	5
consumption 2030 WOM	tCO2eq	2,058		
manuf em 2030 WOM	tCO2eq	259		
use em 2030 WOM	tCO2eq	533		
WAM use em 2030	*tCO2eq*	206		
2030 av abat cost emiss	€/tCO2eq		**3.52**	
2030 av abat cost cons	€/tCO2eq		**0.16**	
red 2030 emissions	tCO2eq		587	
red 2030 consumption	tCO2eq		2,058	

Sheet	27	**Secondary MV Switchgear (RMU panel)**		
		WOM SF6	**WM SF6**	**WAM Solid (XIRIA)**
Voltage	*kW*	*12 kV*		
Design		*cable-cable-transfomer*		
gas charge	kg	0.7	0.7	0
basic invest cost	€	1,300	1,300	1,300
capital investment cost /unit	€			13
gas cost first fill	€	11	11	0
vacuum chamber	€			250
solid insulation+field control	€			20
transformer protection (1/3)	€			25
Total invest cost	€	1,311	1,311	1,608
GWP of SF6		22,200	22,200	
lifetime	*years*	40	40	40
cost Art 4	€/y	0	1.9	
leakage rate	kg/kg	0.2%	0.2%	
use emissions	kg/y	0.0014	0.0014	
disp emiss factor	kg/kg	1.5%	0.75%	
disp emissions	kg/y	0.00026	0.00013	
manuf emiss factor	kg/kg	1.0%	1.0%	
manuf emiss	kg/y	0.00018	0.00018	
consumption	kg/y	0.018	0.018	
global warming emiss	tCO2 eq	0.041	0.038	
emiss difference to WM	tCO2 eq	0.0029	0.00	0.038
consumption	tCO2 eq	0.3885	0.3885	
cons difference to WM	tCO2 eq	0.00	0.000	0.389
discount rate	%	4%	4%	4%
annuity factor discount		0.0505	0.0505	0.0505
annual invest cost		66.21	66.21	81.24
end-of-life cost	€	0	2	0
annual total cost	€	66	68.1	81.2
add ann cost vs WM	€	-1.88	0	13.2
abatem cost emiss	€/tCO2eq			**347.31**
abatem cost consumption	€/tCO2eq			**33.86**
Penetration 2015	%			15
Penetration 2020	%			75
Penetration 2030	%			90
first fill 2030	ktCO2eq	3,447.3		
Manuf emiss 2030	ktCO2eq	34.5		
use em 2030	ktCO2eq	238.4		
disp em 2030	ktCO2eq	0.0		
2030 av abat cost emiss	€/tCO2eq			**347.3**
2030 av abat cost cons	€/tCO2eq			**33.9**
red 2030 emissions	ktCO2eq			97
red 2030 consumption	ktCO2eq			3,103

Sheet	28	Bus MAC		
		WOM=WM R-134a	WAM R-744	WAM R-1234yf
refrigerating capacity	*kW*	*25*	*25*	*25*
el power	kW	16.7	16.7	16.7
running time	h/y	2,000	2,000	2,000
invest cost hardware	€	13,000	15,080	13,195
refrigerant charge	kg	10.4	10.4	10.4
cost first fill	€	104	42	624
GWP of refrigerant		1,430	1	4
lifetime	*years*	10	10	10
cost Art 3+4	€/y	0		
add maintenance	€/y		50	
leakage rate	kg/kg	0.15	0.15	0.15
use emissions	kg/y	1.56	1.56	1.56
disp emiss factor	kg/kg	0.7	0.7	0.7
disp emissions	kg/y	0.73	0.73	0.73
consumption	kg/y	2.60	2.60	2.60
global warming emiss	tCO2 eq	3.27	0.0023	0.0092
emiss differ to reference	tCO2 eq	0	3.270	3.263
consumption	tCO2 eq	3.718	0.0026	0.0104
cons difference to referer	tCO2 eq	0	3.715	3.708
energy consumption	kWh	33,333	33,333	33,333
cost per kWh	*€*	*0.2*	*0.2*	*0.2*
energy cost	€/y	6,667	6,667	6,667
cost refrigerant refill	€/y	23.40	6.24	93.6
discount rate	%	4%	4%	4%
annuity factor discount		0.1233	0.1233	0.1233
annual running cost	€	6,690	6,723	6,760
annual invest cost	€	1,616	1,864	1,704
annual total cost	€	8,306	8,587	8,464
add ann cost vs referenc	€	0	282	158
abatem cost emiss	€/tCO2eq		**86.1**	**49**
abatem cost consumptio	€/tCO2eq		**75.8**	**43**
Penetration 2015	%		2,5	10
Penetration 2020	%		30	60
Penetration 2030	%		50	100
Penetration mix 2015	%		2.5	10
Penetration mix 2020	%		30	60
Penetration mix 2030	%		0	100
first fill 2030	ktCO2eq	446		
use em 2030	ktCO2eq	1,424		
disp em 2030	ktCO2eq	285		
2030 av abat cost emiss	€/tCO2eq		**48.53**	
2030 av abat cost cons	€/tCO2eq		**42.71**	
red 2030 emissions	ktCO2eq		1,616	
red 2030 consumption	ktCO2eq		1,694	

Sheet	**29**	**Truck MAC**		
		WOM=WM R-134a	**WAM R-744**	**WAM R-1234yf**
refrigerating capacity	*kW*	*8*	8	8
el power	kW	8	8	8
running time	h/y	300	300	300
invest cost hardware	€	300	362	301
refrigerant charge	kg	1	1	1
cost first fill	€	10	4	60
GWP of refrigerant		1,430	1	4
lifetime	*years*	10	10	10
cost Art 3+4	€/y	0		
add maintenance	€/y		0	
leakage rate	kg/kg	0.12	0.12	0.12
use emissions	kg/y	0.12	0.12	0.12
disp emiss factor	kg/kg	0.7	0.7	0.7
disp emissions	kg/y	0.07	0.07	0.07
consumption	kg/y	0.22	0.22	0.22
global warming emiss	tCO2 eq	0.27	0.0002	0.0008
emiss differ to reference	tCO2 eq	0	0.272	0.271
consumption	tCO2 eq	0.3146	0.00022	0.00088
cons difference to referer	tCO2 eq	0	0.314	0.314
energy consumption	kWh	2,400	2,400	2,400
cost per kWh	*€*	*0.2*	*0.2*	*0.2*
energy cost	€/y	480	480	480
cost refrigerant refill	€/y	1.80	0.48	7.2
discount rate	%	4%	4%	4%
annuity factor discount		0.1233	0.1233	0.1233
annual running cost	€	482	480	487
annual invest cost	€	38	45	44
annual total cost	€	520	526	532
add ann cost vs referenc	€	0	6	12
abatem cost emiss	€/tCO2eq		**20.5**	**43**
abatem cost consumptio	€/tCO2eq		**17.7**	**37**
Penetration 2015	%		20	40
Penetration 2020	%		50	80
Penetration 2030	%		100	100
Penetration mix 2015	%			40
Penetration mix 2020	%			80
Penetration mix 2030	%			100
first fill 2030	ktCO2eq	1,554		
use em 2030	ktCO2eq	3,134		
disp em 2030	ktCO2eq	1,647		
2030 av abat cost emiss	€/tCO2eq		**43.09**	
2030 av abat cost cons	€/tCO2eq		**37.22**	
red 2030 emissions	ktCO2eq		4,170	
red 2030 consumption	ktCO2eq		4,017	

Annex VI. Abatement technologies by sectors

This part of the annex gives detailed information on state and potential of technology in key sectors relying on fluorinated greenhouse gases and includes all input information for chapter 6 of the interim report.

The following sectors are included in the analyses:

- Domestic refrigeration
- Commercial refrigeration
- Industrial refrigeration
- Transport refrigeration
- Stationary air conditioning and heat pumps
- Mobile air conditioning of road vehicles
- Mobile air conditioning of ships and rail vehicles
- Blowing agents for foam applications
- Fire protection
- Aerosols (excluding MDI)
- Medium voltage switchgear
- Magnesium industry

After a general description of each sector and its subsectors, a review of present global HFC bank and consumption and a business-as-usual projection until 2030 is given for A2 countries[69] and A5 countries[70]. Subsequently, current and projected F-gas demand and emissions in the respective sector in EU-27 until 2050 are outlined. These data on EU-27 are derived from the WM scenario of the model AnaFgas.

Key abatement options for each subsector are identified, their cost vs. conventional HFC application is assessed and their market potential is estimated. On the basis of a sector penetration mix, which is the set of the most effective alternative options which are mutually not exclusive but complementary, with priority on cost-effective solutions in case of equal reduction potential, average abatement costs (€/tCO_2eq) and related demand/consumption and emission reduction potential in 2030 are calculated for each application sector.

Each section can be read independently from the others. A summary on all sectors is included in chapter 6 of the final report.

[69] A2 countries: Developed countries in the terminology of the Montreal Protocol.
[70] A5 countries: Developing countries in the terminology of the Montreal Protocol.

VI.1 Domestic refrigeration

1.1 General description

Domestic refrigeration covers appliances that are broadly used domestically, including refrigerators (cabinet temperature of approximately +5℃), freezers (approximately -15℃) and combined refrigerator/freezer products. Approximately 100 million such domestic appliances are produced annually – split more or less equally between A2 and A5 countries.

Storage volumes range from 20 to 850 litres per unit. A typical product contains a factory-assembled, hermetically sealed vapour-compression refrigeration system employing a 50 to 250 W motor and containing 50 to 250 g of refrigerant.

Current refrigerant use

The main refrigerants used are HFC-134a and HC-600a. About 60% of current new production (globally) employs HFC-134a, whilst about 40% employs HC-600a. Ca. 1% employs either HFC-152a or HCFC-22 or blends comprising these. This equates to about 3.8 kt consumption of HFC-134a in A2 countries and 7.7 kt in A5 countries.

There are substantial regional differences; the vast majority of European refrigerators and freezers are produced with HC-600a whereas other regions use HC-600a to lesser extent. There is fairly widespread production of HC-600a appliances in Asia and to some extent in South and Central America and Southern Africa; it is virtually non-existent in North America and Australasia.

1.2 Global business as usual trend of HFC consumption until 2030

The global stock is estimated of some 1,400 million units. This corresponds to a halocarbon bank of ca. 60 kt of CFCs (mainly dating from before 2000) about 70% of which is in A5 countries, and approx. 80 kt of HFCs (ca. 60% within A2 countries).

The leakage rate is low, with just 0.3% in A2 and 0.5% in A5 countries. There is hardly any refill in existing systems so that the annual refrigerant consumption consists almost completely of first fill on manufacturing. Bank and annual consumption in 2006 is shown in the following table.

Table VI-1: Global refrigerant bank and consumption for domestic refrigeration, 2006, metric kilo tonnes

2006	A2		A5		World	
Domestic refrigeration	**Bank (kt)**	**con-sumption**	**bank (kt)**	**con-sumption**	**Bank (kt)**	**con-sumption**
CFC-12	16.8	0	43.3	0	60.1	0
HFC-134a	47.2	3,7	34.4	7.6	81.6	11.3
HC-600a		4.6		2.7		7.3
Total		8.3		9.7		

Growth for A2 countries is forecast at approximately +4% per year and +5% for A5 countries. The growth rate is based upon the extrapolation of market data for the period of 1992 to 2008 as detailed in the UNEP 2010 RTOC report.[71]

The current split between the refrigerant types is based on the data in UNEP (2010). From 2010 it is assumed that the use of R22/R152a and associated blends is discontinued, and that R134a is gradually replaced by R600a to some extent even in the BAU scenarios.

The gradual substitution of R134a with R600a in developing countries is based on knowledge and assumptions about the market within Africa, South America and Asia. Certain markets (such as North America) are assumed to continue using predominantly R134a, even though there are legislative moves to enable the wider use of HCs.

The BAU demand for refrigerants in domestic refrigeration is projected to grow significantly until 2030 mainly driven by demand in A5 countries based on strong growth of population and economy.

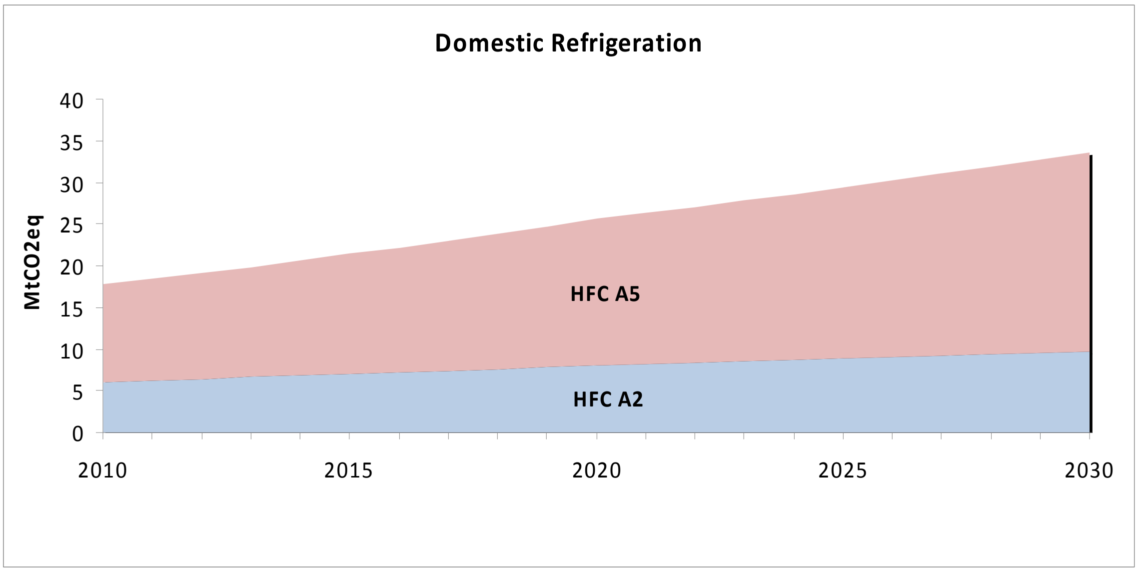

Figure VI-1: BAU HFC-134a consumption trends for Domestic refrigeration, in A2 and A5 countries. Strong growth is projected for A5 countries, from 2010 to 2030.

1.3 HFC demand and emissions in EU-27 until 2050 (WM scenario)

Emissions of HFC-134a from domestic refrigerators in the use-phase are very low and loss is hardly refilled so that the annual demand is limited to first fill into new manufactured systems. Most emissions from domestic refrigerators arise on decommissioning. Currently, only 230,000 units are manufactured with HFC refrigerant, in five countries of the EU-27. The vast majority of new manufactured and new sold systems (98.5% or 15 million units per year) use hydrocarbons (R600a). Data on bank, demand and emissions of HFC-134a is shown in the following table for 2010.

Table VI-2: HFC bank, demand and emissions in EU domestic refrigeration, 2010.

2010	installations (million units)	bank HFC-134a (kt)	demand HFC-134a (kt)	emissions HFC-134a (kt)
Domestic ref.	135	16.5	0.027	0.800

Source: model AnaFgas

[71] UNEP2010: Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (RTOC) – 2010 Assessment.

Under the WM scenario, annual demand of HFC-134a for manufacturing in the EU is forecast to decrease from 2010 onwards to negligible quantities. Emissions during the use-phase will be limited then to units that are imported from outside the EU. Disposal emissions will arise to considerable amount until 2025.

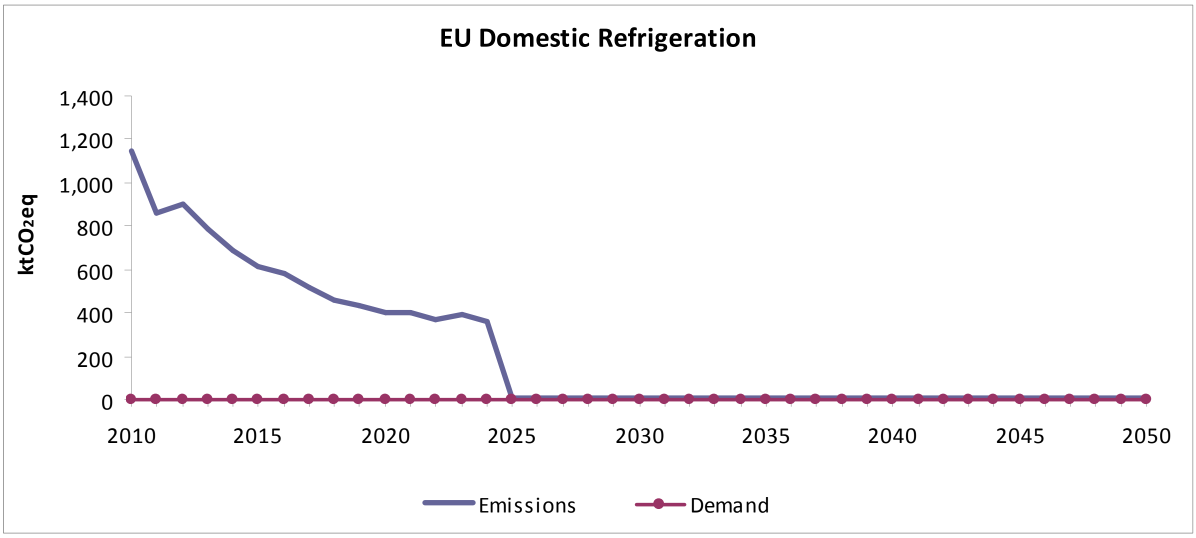

Figure VI-2: HFC demand and (end-of-life) emissions in the EU WM scenario for domestic refrigeration 2010-2050. In Europe, houshold refrigerators and freezers use hydrocarbons as refrigerants. Demand for domestic manufacturing will be of negligible size from 2010 onwards. Emissions from disposal will likewise decrease to marginal amounts until 2025.

Domestic refrigerators containing HFC-134a are subject to Art 4(1) of the F-gas Regulation, which makes refrigerant recovery at end of life mandatory. As household appliances have already been subject to the provisions of the WEEE Directive (collection systems), the additional reduction effect from the F-gas Regulation on the disposal emissions is considered low. In the WM scenario a decrease in disposal emissions from 40 % to 30 % is assumed, within the 2010-2015 periods.

1.4 Key abatement options

Three Abatement Options for the refrigerant R-134a are considered: R600a, R744 and R1234yf.

R600a. The hydrocarbon R600a (isobutane) continues to be the main alternative to R134a. Concerns in connection with the high flammability (classification A3) at the introduction of the refrigerant in 1994 in Europe do no longer exist, particularly as the charges required for domestic refrigeration are well below 150 g. No new alternative has matured to become energy-efficient, cost-competitive opportunities for R134a. While the refrigerant itself is less expensive than HFC-134a, additional investment cost for R600a application arises due to larger size of compressors (although this is disputed by some manufacturers).

R1234yf. Chemical manufacturers developed low atmospheric life unsaturated HFC compounds to replace HFC-134a in automotive air conditioning applications, in particular HFC-1234yf. These unsaturated fluorocarbons are developmental products and evaluation of their use in stationary applications has begun but is not being pursued with high priority in domestic refrigeration which is more demanding than automotive applications.

A preliminary assessment is that HFC-1234yf has the potential for comparable efficiency to HFC-134a. The flammability is reduced (classification A2L) which makes the application easier in countries with still strong reservation about hydrocarbons. Investment costs for equipment are estimated to be 1% higher than for R134a technology due to the larger surfaces of heat exchangers (to account for poorer energy performance). Additional 1% higher investment cost result from the cost of the refrigerant for the first fill.

R744. Currently R744 (transcritical use of CO_2) seems to be the only alternative option with good prospects, in addition to conventional vapour-compression technology for mass-produced domestic refrigeration equipment. Experience is available from a large number of vending machines which have been in use since many years, and are similar, low-charged applications. If applied to domestic refrigeration, for R744 additional cost of +20% are assumed, which is largely attributed to the greater mass of materials necessary to achieve the minimum level of efficiency, particularly for freezers in all climates and for both refrigerators and freezers in warmer climates.

Additional costs for technician training and tooling are negligible regardless of the three technical abatement options under consideration. For all Abatement Options, the energy consumption is assumed to be the same due to the existence or either minimum efficiency regulation or energy labelling rules or both, for the majority of regions.

Individual abatement cost of alternative options

Detailed data on costs, refrigerant consumption and (for Europe emissions are given in the global data input sheets (DIS) for A2/A5 in annex IV, and in EU sector sheets in annex V for Europe where reference for the abatement options is an R-134a system under the F-gas Regulation (slightly higher recovery cost, slightly less disposal emissions). The data on the cost differences of the abatement options to the reference case include a) capital investment cost per unit (e.g. adaptation of production line), b) unit investment cost per unit (e.g. for new components or refrigerant first fill), and c) additional operating cost per unit (e.g. change in energy consumption or service).

For the three individual abatement options the cost difference to the sector-typical HFC reference system is quantified and put in relation to the avoided HFC quantities of this system. The result of the calculation is the annual abatement cost in €/tCO_2eq of an alternative option, as measure of its cost effectiveness.

Because of too high complexity, the calculation of the individual abatement costs for A2 and A5 countries, and for Europe are not repeated here. The calculations are carried out for A2 and A5 countries in the global model on the base of the DIS, and for the EU in the EU sector sheet 1 (annex V). Here, the information might be sufficient that the values range from €1 (R600a) to €267 (R744).

1.5 Market potential (penetration) of abatement options until 2030

R600a and R1234yf would be able to satisfy all situations. However, it is anticipated that in some A5 and A2 countries outside Europe R600a would not be accepted 100%, by 2030. For a small number of units R600a might not be used because of the high flammability of the refrigerant (A 3 classification). The flammability risk of R1234yf (A 2L classification) is lower.

R744 is limited to 30% because the cost of additional materials required to maintain the same efficiency as R134a would be too high, or minimum efficiency could not be achieved within warmer climates to keep the cost within acceptable boundaries.

Based on the assessment of the penetration rates of the three abatement options the sector experts in the project team established for the year 2030 the most effective mix of alternative solutions which complement each other ("penetration mix"), prioritizing cost-effective technologies in case of equal reduction potential. The 2030 penetration mix is shown in the following table for A2 and A5 countries. In the EU the penetration rate of R600a is 100% so that a combination with another technology is not necessary.

A2 - Penetration mix of alternative options in domestic refrigeration 2030			
Alternative option	R600a	R744	R1234yf
percentage	95*	5	0**
A5 - Penetration mix of alternative options in domestic refrigeration 2030			
Alternative option	R600a	R744	R1234yf
percentage	95	5	0**

* for Europe the penetration rate is estimated 100%.

** R1234yf is not included in the mix because of too high abatement cost (low cost effectiveness).

1.6 Sector abatement cost and reduction potential in 2030

Corresponding to the percentage of the individual abatement options in the 2030 penetration mix, the individual abatement cost are aggregated to sector abatement cost, in €/t CO_2 eq.

Global data

The BAU trend of the HFC consumption 2010-2030 has been assessed previously. The reduction of the HFC consumption as a result of the application of most effective set of abatement options can be estimated for the sector, for the year 2030[72].

Sector abatement cost and calculated consumption reduction potential in domestic refrigeration are shown in the following tables for 2030, for A2 and A5 countries.

A2 – consumption abatement vs. BAU in domestic refrigeration 2030		
Sector		Domestic refrigerators
abatement cost	€/tCO_2eq	18.1
consumption reduction	ktCO_2eq	11,200
A5 – consumption abatement vs. BAU in domestic refrigeration 2030		
Sector		Domestic refrigerators
abatement cost	€/tCO_2eq	8.6
consumption reduction	ktCO_2eq	26,500

[72] While the quantity for first fill of equipment becomes zero in the year of introduction of the alternative option and can easily be quantified, the amount for refill decreases only over a number of years as old equipment retires from the stock. The amount of refill in a year depends on the penetration rates in the preceding years.

EU data

The identification of abatement cost and reduction potential for the EU follows the same principle as the calculation of the global values. In addition to the demand of HFCs, for the EU the emissions of HFCs (from use and from disposal) are of relevance. Emissions and demand in the EU-27 are estimated in the WM scenario of the model AnaFgas. It must be noted that the demand will be zero by 2030, and the emissions are very low by then.

The main difference between the global and the EU approach lies in the fact that the HFC reference unit is subject to the F-gas Regulation. This implies for the reference unit on the one hand higher expenses from application of Art 4(1), and on the other hand lower emissions as a result of the improved recovery at end of life[73].

As a consequence, not only the difference in cost between reference system and its abatement option is lower than in the global approach, but also the difference in emissions (not in demand because there is no refill). From this it follows that the specific abatement cost per t CO_2 equivalent are not the same as in the global approach.

EU demand abatement vs. WM trend in domestic refrigeration 2030		
abatement cost	€/tCO_2eq	1.0
demand reduction	ktCO_2eq	12
EU emission abatement vs. WM trend in domestic refrigeration 2030		
abatement cost	€/tCO_2eq	0.4
emissions reduction	ktCO_2eq	12

[73] The quantities in question are rather low. The additional costs from Art 4(1) are estimated at €0.1 per year, and the emission reduction is 3.9 kg CO_2 eq., calculated for one year of the lifetime.

VI.2 Commercial Refrigeration

2.1 General description

Commercial refrigeration equipment is used to maintain two levels of temperature. Chilled food is maintained in the range of +1℃ to +14℃, called medium temperature (MT), where the evaporating temperature for the refrigeration equipment varies between -15℃ and +1℃. Most frozen products are kept at temperatures from -12℃ to -20℃, called low temperature (LT). Usual evaporating temperatures for frozen food are in the range of -35℃ to -40℃. Depending on the evaporation temperature and the type of equipment, a number of different refrigerants are used.

Commercial refrigeration equipment is categorized into three different classes:

- centralized equipment
- condensing units
- stand alone units.

Centralized equipment

… where usually a number of compressors are mounted on a rack in a machinery room and operated in parallel, also called multiplex system. Centralised systems are typical refrigeration equipment of supermarkets. Refrigerants used today are:

- HCFC-22, which is still used for new systems in many A5 countries and was used until the end of 2009 in the USA for new systems,
- R404A which is used for both MT and LT systems worldwide
- HFC-134a which is used for MT applications especially in parts of Europe due to its lower GWP as compared to R404A
- R744 in LT-cascade systems
- R744 for MT and LT in two-stage booster systems, which operate transcritical during warm (above 22℃) outdoor periods.
- And to a lesser extend R290, R1270 or R717 with secondary loop systems and sometimes R744 cascade systems for LT.

Refrigeration capacities vary from 20 kW to more than 1 MW; refrigerant charges vary from 40 to 3,000 kg.

The total number of supermarkets >400 m^2 sales areas was estimated at 280,000 in 2006[74], of which 140,000 were located in A5 countries and 140,000 in A2 countries, thereof 80,000 in Europe[75].

[74] UNEP 2010. Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (RTOC) – 2010 Assessment March 2011, p. 64. The numbers cover a span of sales areas varying from 400 m^2 to 20,000 m^2. Among the worldwide 280,000 are 10,000 very large supermarkets with food sales areas varying between 2,000 and 5,000 m^2). Markets below 400m^2 food sales area and convenient stores are not included.

[75] Our estimates for Europe are higher, with ca. 120,000. Over the last decades, so-called discount markets have significantly gained in importance and amount to ca. 40,000 units (number of units in AnaFgas).

Condensing units

… where one or two compressors are factory assembled together with an air cooled condenser and a receiver on a single frame. Condensing units is typical equipment in the sector of small commercial refrigeration. Refrigerants used today are:

- HCFC-22, in USA (until 2010) and in A5 countries
- R404A
- HFC-134a for hot climates and in parts of Europe for MT due to lower GWP compared to R404A.

In 2006, the global number of condensing units is estimated at 34 million units[76]. In Europe, where the refrigerant charges are higher than in A5 countries (average of 8 kg vs. 4 kg), ca. 2.5 million units are in operation.

Stand-alone units

… where the entire refrigeration system is factory assembled and typically enclosed in one cabinet. Applications are freezers, vending machines and beverage coolers. Typical refrigerants used today are:

- CFC-12 in many existing systems especially in A5 countries
- HFC-134a
- R404A for larger LT units
- R744 for a few ice cream freezers of one ice cream manufacturer and several thousand beverage vending machines of one soft drink manufacturer
- HC (hydrocarbon, mainly R290, sometimes R600a) for bottle coolers and LT cabinets (about 800,000 worldwide).

The worldwide population of vending machines and other stand-alone equipment in 2006 are estimated at 20.5 and 32 million units, respectively[77], with a 50/50 split for A2 and A5 countries. There are some indications that show that these figures might be underestimated. Recent Ecodesign studies inside the EU operated with figures that might show significantly higher numbers of stand-alone units (Ecodesign studies Lot 12 and Entr Lot 1).

2.2 Global business as usual trend of HFC consumption until 2030

In 2006, the refrigerant bank was estimated at 340,000 tonnes and was distributed as follows: 46% in centralized systems, 47% in condensing units, and 7% in stand-alone equipment. The estimated sharing of refrigerants per type in existing systems is about 15% CFCs, which are still in use especially in A5 countries, 62% HCFCs, which are the dominant refrigerant bank and will continue to be for many years, and 23% HFCs which have been introduced in new equipment in Europe and Japan as of 2000[78] although in some cases they were actually already introduced in the 1990s.

[76] UNEP 2010: ibid.
[77] UNEP 2010: ibid.
[78] UNEP 2010: ibid.

Leakage rates range from 1 to 35% from stand-alone equipment to large central multiplex systems. Average leakage rates are stated in the data input sheets (DIS) in annex IV for each type of equipment and each region (A2 and A5 countries) separately.

Annual consumption of all HCFC and HFC refrigerants (new systems plus service of existing systems) is estimated for 2010 to be:

Table VI-3: Global refrigerant consumption for commercial refrigeration 2010 (metric t).

	A2	**A5**	**Total**
Centralized systems	8,900 t	11,300 t	20,200 t
Condensing units	26,800 t	20,400 t	47,200 t
Stand-alone equipment	1,552 t	1,552 t[79]	3,104 t
Total	37,252 t	33,252 t	70,504 t

Under BAU it is expected that there will be a shift away from very high GWP refrigerants (R404A) towards lower GWP refrigerants especially in centralized equipment. Without further legislation, the market share of the different low-GWP options as described below is expected to rise already in the BAU scenario as outlined in Table VI-4.

Table VI-4: Estimated market shares of low-GWP options in commercial refrigeration, BAU until 2030

	2010		**2015**		**2020**		**2030**	
	A2	A5	A2	A5	A2	A5	A2	A5
Centralized systems	1 %	0 %	3 %	0 %	12 %	4 %	25 %	11 %
Condensing units	1 %	0 %	3 %	0 %	14 %	4 %	30 %	11 %
Stand-alone equipment	2 %	0 %	6 %	2 %	20 %	6 %	40 %	20 %

The main reasons for using the low-GWP options are the “green” image which some supermarket chains want to have, the EU F-Gas Regulation with increased service cost for larger HFC systems and the energy savings potentials associated with some of the low-GWP solutions. In addition, the use of HCFCs worldwide will diminish due to the phase-out legislation under the Montreal Protocol – similar to the trend during the last decade away from CFCs.

Despite the rising market shares of low-GWP refrigerants, under the current consumption trends, HFC demand, in particular in A5 regions, is forecasted to grow significantly. HFC demand in A2 countries will slowly increase until 2020, in particular for replacement of HCFC by HFCs, and slightly decrease after 2020.

---

[79] Some industry comments refer to a higher number for A5 countries, still no specific number was provided; as a conservative estimate this number was used in the further analysis.

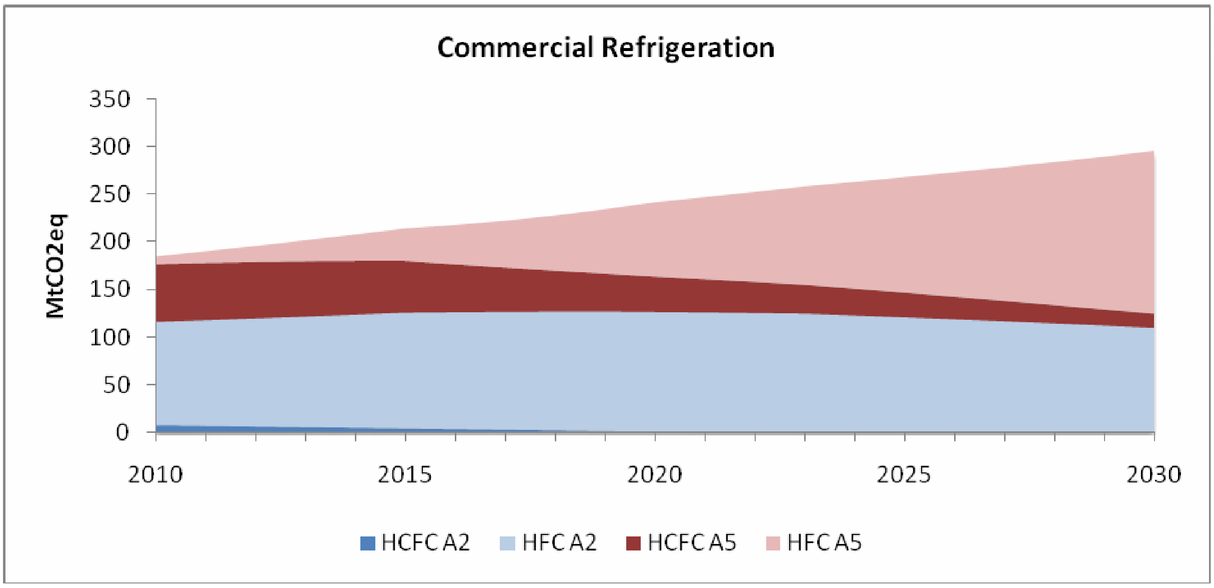

Figure VI-3: BAU demand trends for HCFCs and HFCs in commercial refrigeration. Strong growth is forecast for A5 countries whereas constancy is assumed for A2 countries.

Further details on the demand of HFCs and additional assumptions for the BAU scenario can be found in the data input sheets (DIS) in annex IV.

2.3 HFC demand and emissions in EU-27 until 2050 (WM scenario)

The WM trend for commercial refrigeration in Europe is included in the model AnaFgas. The 2010 bank of HFC refrigerants is estimated 31,900 t in centralised systems (R404A and R134a), 12,500 t in condensing units (R404A) and 2,400 t in stand-alone systems (R134a).

Present leakage rates are 15% for centralised supermarket systems and are assumed to decrease to 9% under the F-gas Regulation until 2015. Leakage rates of condensing units might decrease from 10% to 6%, while the leakage rate of stand-alone equipment should remain at its present low level (1%). Annual HFC emissions (use-phase and disposal emissions) and annual HFC demand (first fill of new systems plus refill for leakage) is estimated in the following table:

Table VI-5: HFC bank, demand and emissions in EU commercial refrigeration, 2010 (metric t)

EU-27 2010	bank	emissions	demand
Centralized systems	31,900 t	5,000 t	7,000 t
Condensing units	12,500 t	1,250 t	2,300 t
Stand-alone equipment	2,400 t	190 t	180 t
Total	46,800 t	6,440 t	9,480 t

Source: model AnaFgas

For future trends, it is assumed that food sales area and thus related refrigerant bank, demand and emissions, show strong growth in large supermarkets and discount markets. By extrapolating high historical growth rates of centralized systems in Europe, doubling of demand and emissions until 2050 is projected. Unlike large supermarkets, the small commercial refrigeration subsector, where condensing units and stand-alone systems are typical equipment, is likely to remain at a constant level in the future. Likewise, the number of vending machines remains unchanged. The resulting trend for emissions and demand of HFCs is shown in figure VI-4 for 2010 to 2050.

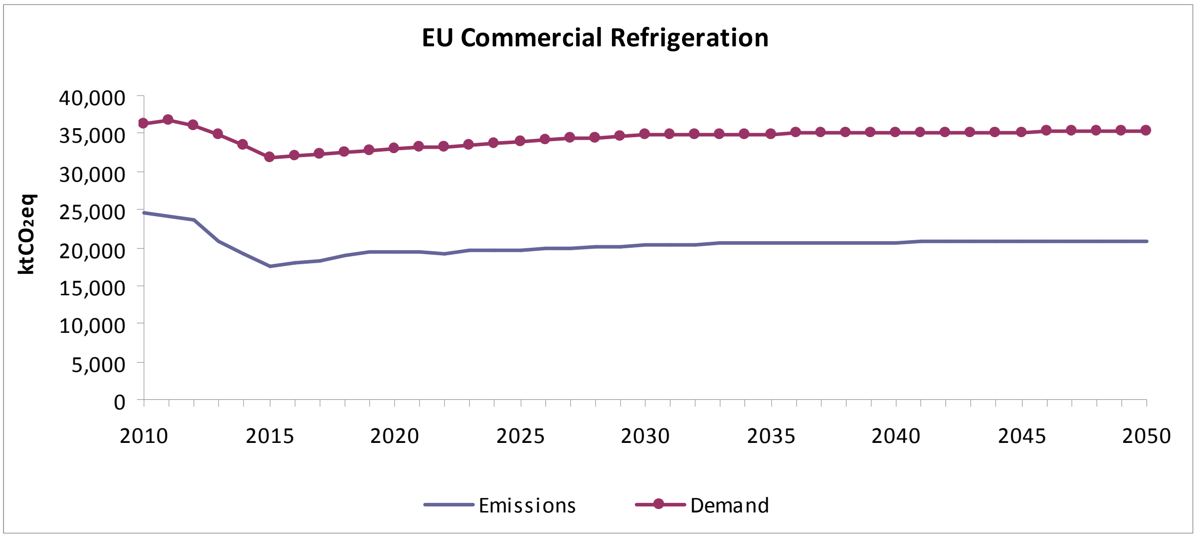

Figure VI-4: Projected HFC emissions and demand (kt CO_2 eq) in commercial refrigeration (2010-2050), for EU-27 under WM scenario. After reductions in 2010-2015 due to F-gas Regulation, constant long term levels for emissions and demand are projected.

2.4 Key Abatement Options

Centralized Systems

Technically feasible Abatement Options for centralized equipment are:

Transcritical R744 (CO_2) system. Two stage (booster) system using CO_2 as the only refrigerant throughout the supermarket. CO_2 is a high pressure refrigerant. The systems are currently designed in a way that the maximum operating pressure inside the shop area is kept below 40 bars. High-pressure lines and components are confined to the machinery room and to the outdoor condenser, which is working as a gas cooler during warm outdoor temperatures. R744-systems are considered standard off the shelf solutions by several European manufacturers. A few European supermarket chains have opted for this kind of system for all their new installations. There have been over 600 such systems installed by mid 2010 mainly in Europe, but also in Africa, Asia and Australia.

The investment costs are estimated 20% higher than for direct R404A systems; in moderate climate the energy consumption is up to 10% lower. However, the transcritical CO_2 system consumes more energy in warmer climates which limits the market penetration to the northern climate regions (in Europe north of the Alps). Special training of installers and service technicians is required.

Central systems with HCs or unsaturated HFCs, and CO_2 pump circulation for MT and CO_2-cascade for LT. Cascade refrigeration systems with CO_2 show the best climate and energy performance. In the cascade configuration a separate refrigeration cycle with HC or unsaturated HFC chills the CO_2 which is pumped to the points of use for normal temperature, and condenses the CO_2 in a second circuit for low temperature. In this process, CO_2 is maintained at relatively low pressures so that standard refrigeration components can be used. The primary refrigeration circuit can be located in a separate room or outdoors so that occupied spaces are free of flammable refrigerants like R290 or R1234yf.

There are over 1,000 R744 cascade LT-systems installed worldwide; typically with R404A and less often R134a as the refrigerant for the top stage. Many manufacturers and installers consider the technology standard off the shelf technology. For larger supermarkets (e.g. above 2,500m^2 sales area) a R744 cascade LT-system can be more cost effective than a standard R404A system due to smaller pipes and components.

Investment cost of HC/CO_2 cascade systems are higher than of conventional R404A systems. We assume 15% additional costs in the next future. The energy efficiency is ca. 7% higher if the primary refrigerant is R290 and ca. 3% higher with HFC-1234yf as the primary refrigerant.

Central HC-system with liquid secondary loop system for MT and CO_2-cascade for LT. Liquid secondary loop MT systems are installed in many supermarkets especially in Luxembourg and Sweden. The energy loss from the pumps for the secondary liquid can be compensated because the primary refrigerant R290 is more efficient than R404A. The systems can be operated with equal energy efficiency as R404A systems if the secondary loop system is designed and operated properly, and is combined with an R744 cascade for LT.

The estimates of costs and market potential (penetration rates) for all AO's can be found in the data input sheet (DIS) in annex IV.

Other Abatement Options are also feasible. For example, Rhiemeier et al. (2008) describe 14 different centralized systems. However, only the Abatement Options described above are deemed to have a large market potential on the global market. On a regional basis, other abatement solutions might also be suitable for centralized systems. For example, Denmark is a playground for new technologies due to the existing HFC-ban (effective since 1st January 2007).

Condensing Units

Technically feasible Abatement Options for condensing units are:

Direct HC-290 or HC-1270. Hydrocarbons are flammable and various national and international standards exist which specify a limit on the charge size – these vary from 0.15 kg, 1.5 kg to 2.5 kg or up to 10 kg or 25 kg in non-public areas. Due to lower density of HCs compared to HFCs together with an optimized charge, HC refrigerants can cover a large extent of condensing unit applications. Components are very similar to those used for HFC installations. If safety standards could be adjusted, HCs could cover virtually the entire range of condensing units. Energy consumption would be 5 to 10% lower than conventional HFC-equipment. The investment cost of direct hydrocarbon systems are about 25% higher due to safety requirements. This disadvantage is compensated by higher efficiency of the refrigerant. Special training for service technician would be required.

Transcritical CO_2. Higher investment cost and lower energy consumption (in northern parts of the world) would also apply to transcritical CO_2 systems. Such equipment is not yet in use, however dynamic development can be assumed if CO_2 refrigerant is used at larger scale in other sectors. At a refrigeration exhibition in Odense, Denmark in March 2010, a small Sanyo R744 condensing unit was shown.

Indirect system with HC or unsaturated HFC, with liquid secondary refrigerant. Indirect systems with flammable refrigerants in the primary circuit in an unoccupied machinery room, in the open air or a special ventilated enclosure can operate over a much wider range of refrigerating capacities, compared to direct systems. This technology would be as energy efficient as a comparable HFC-system only for MT. Low temperature with liquid secondary refrigerant would use more energy due to increased viscosity and reduced heat transfer of the secondary refrigerant. There are several such systems (HC) in Sweden where legislation has favoured secondary loop systems for many years. See data input sheets for details.

Indirect condensing units with R290 or HFC-1234yf cost about 50% more, initially. Additional technical measures are required (e.g. larger heat exchangers) in order to maintain the energy efficiency of direct R404A systems so that the investment cost are the highest of all alternative refrigerant options.

Stand-alone equipment

The Abatement Options for stand-alone equipment are:

Direct HC systems. R290 or R600a in direct systems with charges <150 g is state of the art. In recent years, hydrocarbons have been used in stand-alone refrigerators and freezers on a large scale. It is estimated that about 800,000 units have been produced so far, including ice cream cabinets, bottle coolers, professional kitchen refrigerators and freezers, supermarket display cabinets and water dispensers. Charge sizes up to 1.5 kg are allowed for occupied spaces by the relevant standards[80] if safety requirements are kept. Less restrictive safety standards are possible in the future.

The investment cost of hydrocarbon systems is rated approximately equal to those of HFC systems, or slightly higher (+5%). The energy use is 5 to 15% lower compared to HFC units.

CO_2 systems. The recent development of CO_2 compressors allows using this refrigerant without charge limits. The energy advantage of CO_2 (R744) over HFC-134a or 404A is limited to moderate ambient indoor or outdoor temperature. The investment cost of CO_2 systems is estimated 30% higher because of more complex components

At least one supplier is promoting CO_2 systems for drinks. So far, thousands of bottle coolers and vending machines have been installed. One producer of bottle coolers states that the additional cost will be from +20 to +40% in the near future because of the additional cost for the compressor (more steel) and the additional cost for the heat exchangers although the producer attributes the majority of this cost to a small-scale production. This additional cost would be lower with mass produced components.

Individual abatement cost of alternative options

Detailed data on costs, refrigerant consumption and (for Europe) emissions for abatement options and HFC reference system are presented in annex IV, in global DIS for A2/A5, and in EU sector sheets in annex V for Europe where reference for the abatement options is the HFC system under the F-gas Regulation (more service cost, less demand/emissions). For each individual abatement option the cost difference to the sector-typical HFC reference system is quantified and put in relation to the avoided HFC quantity of this system. The result of the calculation is the specific annual abatement cost in €/tCO2eq of an alternative option, as measure of its cost effectiveness.

Because of too high complexity, the calculation of the twenty individual abatement cost data for A2 and A5 countries, and of the same number of abatement cost data for the EU are not repeated here. The calculations are carried out for A2 and A5 countries in the global model

[80] EN 378-1 Refrigerating systems and heat pumps - Safety and environmental requirements – Part 1: Basic requirements, definitions, classification and selection criteria.

on the base of the DIS, and for the EU in the EU sector sheets 2-4 (annex V). Here, the information might be sufficient that the values are broadly scattered. They range from negative values (e.g. -€45 for stand-alone equipment with R290) to considerably high positive values +€44 (centralised systems with transcritical R744) or even +€108 (condensing units with indirect R1234yf).

2.5 Market potential (penetration) of abatement options until 2030

Without further legislation the most promising alternative choices are R744 for centralized equipment, R744 and unsaturated HFCs with liquid secondary loop systems for condensing units and HCs for stand-alone equipment. Expected market penetration rates for 2015, 2020 and 2030 can be found for each sector split up by A2 and A5 countries in the DIS in annex IV.

If legislation would be changed, e.g. a ban on HFCs (similar to Denmark) or a noticeable GWP tax on HFC refrigerants, the hydrocarbon solutions would gain more importance.

In the case of centralized systems together with R744 cascade for LT it is assumed that any conflicting legal aspects regarding the use of hydrocarbons in refrigeration systems will also be changed in regions where currently, often unclear, restrictions exist. It has to be stated that large amounts of HC circulating inside the sales area is considered unsafe and needs to be avoided. However, if HCs are confined to the machinery room, safety issues can be handled. Currently, because non-flammable alternatives are available, many companies fear the legal consequences if an accident would occur due to the use of HCs as refrigerants. On the other hand it is fully accepted to have natural gas or Liquefied Petroleum Gas (LPG) heating in the same building.

Abatement Options featuring R744 with condensation in outdoor air-cooled heat exchangers are well suited for northern climates from an energy standpoint, i.e. in Europe north of the Alps. They will most certainly use more energy than comparable HFC systems in hot climates with technologies available today. Here the use of cascade or secondary loop systems with HCs is preferable.

The penetration rates in A2 countries (including Europe) of the four alternative technical options which are discussed here for centralised systems are assumed to grow over time and to reach the following 2030 values, each: 90% for HC + liquid secondary + CO_2 cascade, HC + CO_2 secondary + CO_2 cascade, and unsaturated HFC + CO_2 secondary + CO_2 cascade. For transcritical CO_2 systems a maximum market potential of 30% is forecast.

Condensing units. The penetration rates are assumed to grow over time and to reach the following values in 2030, each: 40% R290 direct, 30% R744 direct, 60% R290 indirect, and 60% HFC-1234yf indirect.

Stand alone systems. The penetration rate for new direct R290 systems is estimated at 85% in 2030, and for new systems with transcritical CO_2 at 60%.

Penetration mix

Based on the assessment of the penetration rates of the individual abatement options the sector experts in the project team established for the year 2030 a mix of the most effective alternative technical solutions which complement each other ("penetration mix"), prioirtizing cost-effective solutions in case of equal reduction potential. The 2030 penetration mix for each application sector is shown in percentages, in the following table for A2 and A5 countries. For the EU the same penetrations mix as for the A2 countries is assumed.

A2 2030 - Penetration mix of abatement options in commercial refrigeration						
Alternative technical solution	R290 direct	R290 indirect	R290 CO_2 cascade	CO_2 trans-critical	HFC-1234yf cascade	HFC-1234yf indirect
Centralised systems		90		10		
Condensing units	40	30		30		
Stand alone equipment	85			15		
A5 2030 - Penetration mix of abatement options in commercial refrigeration						
Alternative technical solution	R290 direct	R290 indirect	R290 CO_2 cascade	CO_2 trans-critical	HFC-1234yf cascade	HFC-1234yf indirect
Centralised systems		80	15	5		
Condensing units	60	30		10		
Stand alone equipment	85			15		

2.6 Sector abatement cost and reduction potential in 2030

Corresponding to the percentage of the individual abatement options in the 2030 penetration mix, the individual abatement cost are aggregate to sector abatement cost, in €/t CO_2 eq.

Global data

The BAU trend of the HFC consumption 2010-2030 has been assessed previously. The reduction of the HFC consumption as a result of the application of the most effective set of abatement options can be estimated for the sector, for the year 2030[81].

A2– consumption abatement vs. BAU in commercial refrigeration 2030				
Sub sectors		Centralised systems	Condensing units	Stand alone equipment
abatement cost	€/tCO_2eq	-12.9	1.4	-16.9
consumption reduction	ktCO_2eq	35,300	71,400	4,000
A5 – consumption abatement vs. BAU in commercial refrigeration 2030				
Sub sectors		Centralised systems	Condensing units	Stand alone equipment
abatement cost	€/tCO_2eq	-7,1	-4,9	-40,75
consumption reduction	ktCO_2eq	92,400	109,600	25,500

Sector abatement cost and calculated sector consumption reduction potential for the three sub sectors of commercial refrigeration for 2030 are shown in the above tables, for A2 and A5 countries.

[81] While the quantity for first fill of equipment becomes zero in the year of introduction of the alternative option and can easily be quantified, the amount for refill decreases only over a number of years as old equipment retires from the stock. The amount of refill in a year depends on the penetration rates in the preceding years.

EU data

The identification of abatement cost and reduction potential for the EU follows the same principle as the calculation of the global values. In addition to the demand of HFCs, for the EU the emissions of HFCs (from use and from disposal) are of relevance. Emissions and demand in the EU-27 are estimated in the WM scenario of the model AnaFgas.

The main difference between the global and the EU approach results from the fact that the sector-typical reference unit is a system already subject to the F-gas Regulation. This implies for the reference unit higher annual service expenses on the one hand, which are caused by application of Articles 3 and 4, and lower emissions on the other hand as a consequence of the measures set out by these provisions.

Therefore, not only the difference in cost between reference system and its abatement option is lower than in the global approach, but also the difference in emissions and demand for refill. Hence the specific abatement costs per t CO_2 eq are not the same as in the global approach.

EU-27 – demand abatement vs. WM scenario in commercial refrigeration 2030				
Sub sectors		Centralised systems	Condensing units	Stand alone equipment
abatement cost	€/tCO_2eq	14.6	0.7	-0.3
demand reduction	ktCO_2eq	25,214	8,949	219
EU-27- emissions abatement vs. WM scenario in commercial refrigeration 2030				
Sub sectors		Centralised systems	Condensing units	Stand alone equipment
abatement cost	€/tCO_2eq	23.7	1.2	-0.8
emission reduction	ktCO_2eq	14,741	3,927	149

VI.3 Industrial refrigeration

3.1 General description

Industrial refrigeration systems are on-site built refrigeration systems used in food processing, storage and distribution. Some industrial refrigeration systems are installed for cooling of industrial processes and for leisure purposes (ice rinks and indoor ski-slopes). There might be some overlap at plants with lower capacities to commercial refrigeration.

It should be noted that mass produced chillers are also used in some industrial sectors (for cooling processes) but they are not covered by the industrial refrigeration sector. Chillers are covered in the sectors of stationary air conditioning in the over next section (small and large displacement chillers and centrifugal chillers).

Industrial refrigeration capacities range from 10 kW to 10 MW. The refrigerant charges can also vary between a few kilograms to 80 tonnes. About 75% of the installed capacity is in the food sector and 25% in industrial processes and leisure[82].

Ammonia (R717) has been used for industrial refrigeration for a long time. Ammonia refrigeration systems are more costly, especially in the low capacity range. In A2 countries ammonia has been and still is a commonly used refrigerant. In the 1970s and 1980s CFCs and HCFC-22 were also used in A2 countries. Since the year 2000, HCFC-22 has been replaced in new equipment by the HFC refrigerant R404A, first in Europe, then in other industrialized countries. Currently, the share of ammonia in the total of refrigerants for industrial use is ca. 55% in A2 countries, and 16% in A5 countries. The remainder is R22 and, increasingly, R404A.

In recent years a number of cascade systems with ammonia and CO_2 have been installed in the food industry. In this study, these were handled as (pure) ammonia with respect to additional costs, efficiency and additional relative operating costs.

3.2 Global business as usual trend of HFC consumption until 2030

Consumption figures for 2006 provided here for the sector are based on the best knowledge of the project experts, relevant information from reference reports[83] and interviews. There are limitations to the data in the following tables, as no consistent reporting on consumption and production data for this sector exists.

Table VI-6: Global refrigerant bank and consumption in industrial refrigeration 2006, metric kt

2006 kilo tonnes (kt)	A2		A5		World	
Industrial refrigeration	bank	con-sumption	bank	con-sumption	bank	con-sumption
Large systems	110.5	14.4	63.6	19.8	174.1	34.2
Small systems	36.9	4.8	21.2	6.6	58.1	11.4
All incl. NH_3	147.4	19.2	84.4	26.4	232.0	45.6
HCFC/HFC only	66.3	8.6	70.9	22.2	137.2	30.8

[82] IPCC/TEAP 2005 special report on safeguarding the ozone layer and the global climate system. Issues related to Hydrofluorocarbons and Perfluorocarbons. Cambridge University Press.

[83] UNEP RTOC 2010 Assessment.

The current refrigerant bank amounts to 232 kt in large and small industrial refrigeration equipment, thereof two thirds in A2 countries and one third in A5 countries. The share of ammonia in the total bank is >50% in A2 countries, and 15% in A5 countries. The same ratio of NH_3 to fluorinated refrigerants applies to the annual consumption. Looking at HCFC/HFC refrigerants only, the bank is almost the same size in A2 countries and in A5 countries, with ca. 70 kt each. According to UNEP 2010, in 2006 almost half of the fluorinated refrigerants have already been HFCs, in A2 countries. It is assumed that R22 in A2 countries will completely be changed to R404A and that R22 in A5 countries will be changed to R404A in the future in new systems, both due to the HCFC phase-out under the Montreal Protocol.

In UNEP 2010 the leakage rate for industrial HFC refrigeration systems has been estimated ca 8%, compared to > 20% for HCFC-containing equipment. For further analysis, the 8% rate is used in this report although the project experts hold the position that 8% underestimates the real use-phase emissions, and thus the consumption for annual refill in existing systems.

In the IPCC/TEAP report from 2005 annual growth rates in industrial food processing were estimated at 4% in developed countries and 7% in developing countries between 1996 and 2002.[84]. In the Business as Usual scenario no change is expected for the present ratio between ammonia and F-gases (55% NH_3 in A2, 16% NH_3 in A5) for new installations in 2010, 2015, 2020 and 2030 (based on interviews with stakeholders).

The overall consumption of HFC refrigerants for first fill of new equipment and refill in existing equipment is estimated to grow significantly, both in A2 countries, but particularly in A5 countries. The growth is shown in the following graph.

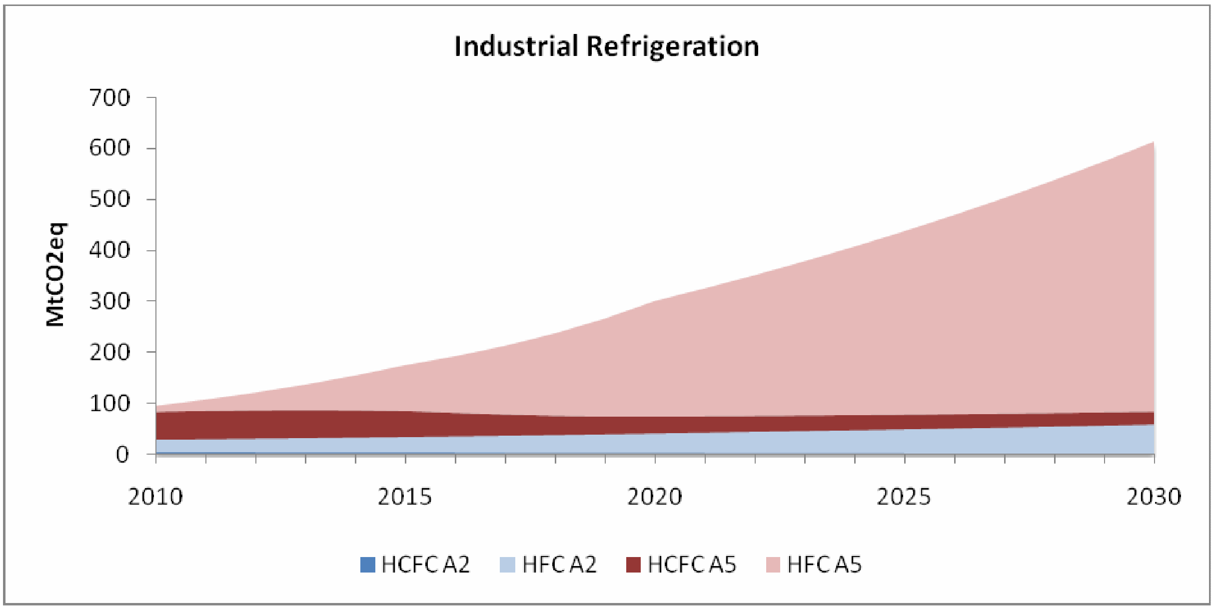

Figure VI-5: Global BAU consmption trends for HCFCs and HFCs in industrial refrigeration.

[84] IPCC/TEAP 2005 special report on safeguarding the ozone layer and the global climate system. Issues related to Hydrofluorocarbons and Perfluorocarbons. Cambridge University Press.

3.3 HFC demand and emissions in EU-27 until 2050 (WM scenario)

In the European food industry, cold storage, chemical and other industries HFCs are already more used refrigerants than R22. Ammonia has always played a major role in industrial refrigeration, accounting for almost 40% of the refrigerant bank in 2010, and more than 40% in new systems. Within the halogenated refrigerants, R22 has been replaced in new systems by R404A, since the end of the 1990s, and in particular since 2001. As the lifetime of industrial equipment averages 30 years, large quantities of R22 are still in use today and must be replaced by 2015 at the latest, mostly by R404A and R407C. Although leakage rates in industrial refrigeration are not as high as in centralised commercial refrigeration, they amount to 8% to 10% per year (without measures).

Current bank, demand for new fill and refill, and emissions of refrigerants in Europe, as included in the model AnaFgas, are shown in the following table.

Table VI-7: Refrigerant bank, emissions and demand in industrial refrigeration 2010, metric t

Industrial refrigeration 2010	bank	demand	emissions
NH_3	22,750	n. e.	n. e.
HCFC-22	12,060	2,000	2,000
R404A/407C	26,600	6,300*	2,590
All incl. NH_3	61,400[85]	-	-
HCFC/HFC only	38,700	8,300	4,590

** The demand level of HFCs is extraordinary high because of the replacement of R22 in existing equipment from 2010-2014. In other years, it amounts to ~ 3,000 tons only.*

In the projection until 2050, the overall refrigerant bank grows slowly, by 3% from 2010 to 2030, and remains unchanged after, with ammonia growing faster, by almost 10% until 2030. At the same time halogenated refrigerants decrease by 3%, from 38.7 kt to 37.4 kt. In the model AnaFgas the steep growth of R404A which substitutes R22 in existing equipment until 2015, will not fully compensate the drop in HCFC-22.

With a few exemptions, equipment in industrial refrigeration is higher charged than 3 kg; in most sectors (cold store, chemical industry, breweries) charges over 100 kg are typical. As a consequence, industrial refrigeration is addressed by all measures of the F-gas Regulation.

Under the WM scenario, as a result of successful application of the F-gas Regulation, the average leakage rates will be reduced to 6% from 2015 onwards. Recovery efficiency at end-of-life is assumed to rise from 70 % in 2010 to 80 % in the year 2015. The trend of HFC demand and emissions is shown in the following graph, expressed in $ktCO_2eq$.

It can be seen that despite of the reduction in emission factors, the emissions (of R404A) will not decrease. This is mainly due to the high GWP of R404A compared to the replaced R22 (GWP 3,922 vs. 1,810).

[85] It should be noted that the 2010 European bank size in AnaFgas (61 kt) is slightly higher than in the recent UNEP RTOC 2010, where the 2006 bank was estimated to 53.8 kt (15.8 kt HCFC, 17.5 kt HFC, and 20.5 kt ammonia).

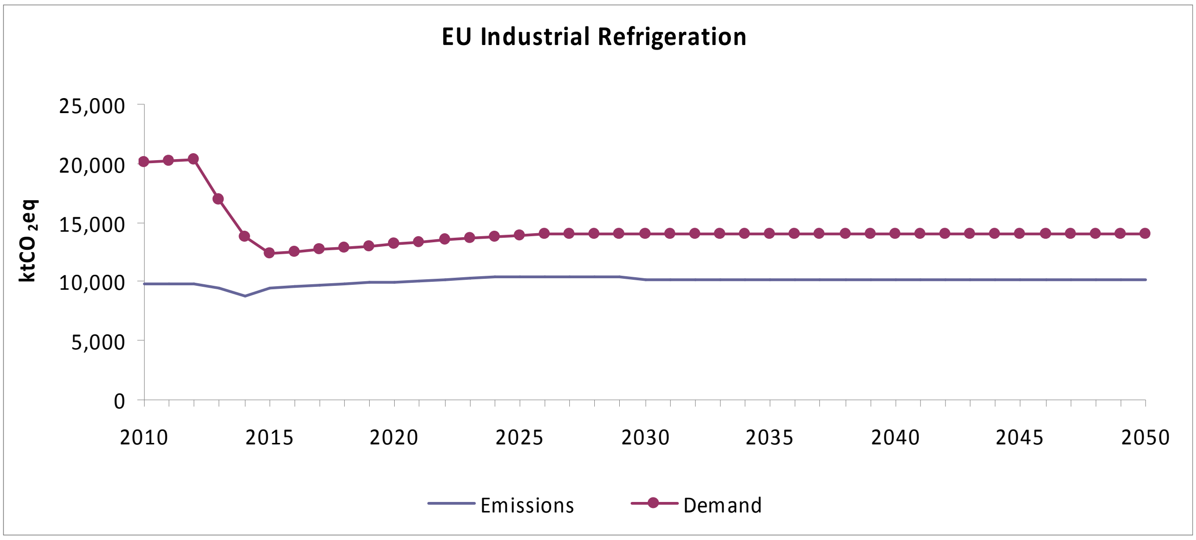

Figure VI-6: Under the WM scenario, HFC emissions from industrial refrigeration are forecast to remain constant from 2010 to 2050 despite the drop in emission factors due to the F-gas Regulation. The high demand values from 2010 to 2015 result from the accelerated phase-out of HCFCs. R22 is substituted in existing equipment by HFCs.

3.4 Key abatement options

Unlike the format for the other sectors and sub-sectors, there is no information on the numbers of systems and no “typical” charge per unit since every industrial refrigeration system is individually assembled.

Ammonia – R717. The basic abatement option alternative to HFCs for industrial refrigeration is ammonia – R717 which has already been used widely in global scale. Ammonia-CO_2 cascade refrigeration systems have been increasingly installed in recent years in industrialised countries, in particular in Europe. According to industrial references, costs for the combined ammonia-CO_2 cascade systems are in the same range as the pure ammonia systems. The number of systems installed is not known, but it is still low compared to the number of pure ammonia systems.

Hydrocarbon or unsaturated HFC. In the future it might be possible that systems with unsaturated HFCs or hydrocarbons become available. These technologies would possibly be used for lower refrigeration capacities and refrigerant charges; special efforts must be made to handle the flammability risk. Currently this option has not become relevant and was therefore not taken account in the analysis.

Hydrocarbon systems are however installed in the petrochemical industry where explosion-proof environment is common.

Cost data for this sector is not readily available, since every system is individually built and there is no central registration of data. The lack of reliable data was also highlighted in the RTOC report 2006[86].

[86] To quote the RTOC 2006 report: Since information on the number of large size refrigeration systems, amounts of refrigerant per system and other specific technical data is virtually impossible to obtain, given estimates on emissions have to be characterised as “qualified guesses”.

Data for this study was gathered through interviews and data sheets exchanged with relevant industries in the sector, both installers and users of industrial refrigeration systems[87]. Special attention was paid on additional costs for abatement opportunities. Available references in RTOC reports and IPCC/TEAP reports have only limited information on costs.
Since the additional costs for ammonia refrigeration systems largely depend on the size of the system, it was decided to undertake the analysis for two representative base cases.

Individual abatement cost of the alternative option R717

Small (medium) base case: 270 kW cooling capacity at three temperature levels. HFC: €425,000 for system. NH_3: additional cost: €132,000 (+31 %). Electricity consumption: 1,800,000 kWh/yr. NH_3: -27% electricity consumption. Operation cost for F-gas system: €100,000 per year.

Large system: 5 MW cooling capacity. HFC: €6 million. Additional costs for similar ammonia system: between 0 and 20%. Electricity consumption: between -10% and -30% (see Global DIS in annex IV). Operating cost for the large system: €1,000,000 per year.

Users of industrial refrigeration systems provided additional data on the service costs for ammonia systems. Spare parts for ammonia systems are more expensive due to the smaller production of such parts, and service on ammonia systems needs well-trained refrigeration technicians. In the analysis, +10% additional operating costs were used for abatement options.

75% of all refrigerant charge is included in large systems and 25% in small systems.

Very small sized ammonia industrial refrigeration systems of < 100 kW may be 100% more costly compared to HFC systems. Hydrocarbon systems might be a more realistic solution, but so far no detailed information is available on this.

The calculated consumption abatement costs of industrial ammonia systems are low. Specific abatement cost of small ammonia systems are calculated at €1.9 (A2) and €1.6 (A5), and for large ammonia systems at -€5.7 (A2) and -€4.0 (A5), respectively. In Europe, where the abatement options are compared with systems under the F-gas Regulation the abatement cost values are even lower. (Calculations are documented in the EU sector sheets 5 and 6 in annex V).

3.5 Market potential (penetration) of the abatement solution R717

The driver for the ammonia abatement option is the high efficiency of the refrigerant and the comparably small additional investment costs for large systems, which results in low additional or even negative annualised cost. Another potential driver is the “green” image, which is associated with natural refrigerant technologies.

The hurdles for implementation of ammonia systems are the relatively high investment costs for small systems and the lack of skilled refrigeration technicians in some countries. In some countries there might be national rules, which make ammonia refrigeration systems more difficult to build (e.g. France).

The maximum market potential for new equipment by 2030 is forecast 95% of the refrigerant mass in new systems in A2 countries (incl. Europe) and 80% in A5 countries.

[87] Interviewed industrial references are operating about 450 industrial systems globally.

As there is only one abatement option considered, a combination of several penetration rates ("penetration mix") does not need to be estimated.

A2 2030 - Penetration rate of abatement option industrial refrigeration	
Alternative technical solution	NH_3
Small equipment	95
Large equipment	95
A5 2030 - Penetration rate of abatement option industrial refrigeration	
Alternative technical solution	NH_3
Small equipment	80
Large equipment	80

3.6 Abatement cost and reduction potential of alternative option 2030

The sector abatement costs are the same as the individual abatement costs because ammonia is the only considered option in industrial refrigeration.

The BAU trend of the HFC consumption 2010-2030 has been assessed previously. The reduction of the HFC consumption from the introduction of the abatement option can be estimated for the two sub sectors, for the year 2030[88].

Global data

Abatement cost and calculated consumption reduction potential for the two sub sectors of industrial refrigeration for 2030 is shown in the following tables, for A2 and A5 countries.

A2- consumption abatement vs. BAU in industrial refrigeration 2030			
Sub sectors		Small equipment	Large equipment
abatement cost	€/tCO$_2$eq	2	-6
consumption reduction	ktCO2eq	4,000	73,800
A5 – consumption abatement vs. BAU in industrial refrigeration 2030			
Sub sectors		Small equipment	Large equipment
abatement cost	€/tCO$_2$eq	2	-4
consumption reduction	ktCO2eq	41,200	781,700

Both in A2 and in A5 countries the abatement costs of the ammonia options are very low (small equipment) or even negative (large equipment).

[88] While the quantity for first fill of equipment becomes zero in the year of introduction of the alternative option and is easily to quantify, the amount for refill decreases only over a number of years as old equipment retires from the stock. The amount of refill in a year depends on the penetration rates in the preceding years.

EU data

In addition to the demand for HFCs, for the EU the emissions (from use and disposal) are relevant and are estimated in the model AnaFgas for the WM scenario.

The European abatement costs are lower than the global values, which mainly results from the fact that the HFC reference system is subject to containment and recovery measures of the F-gas Regulation, with more service cost and less emissions.

EU-27 – demand abatement vs. WM scenario in industrial refrigeration 2030			
Sub sectors		Large equipment	Small equipment
abatement cost	€/tCO_2eq	-15.5	-0.6
demand reduction	ktCO2eq	6,557	2,186
EU-27 – emissions abatement vs. WM scenario in industrial refrigeration 2030			
Sub sectors		Large equipment	Small equipment
abatement cost	€/tCO_2eq	-21.6	-0.9
emissions reduction	ktCO2eq	2,612	8,714

VI.4 Transport Refrigeration

4.1 General description

Transport refrigeration is a niche market compared to other sectors. The largest segment in terms of today's HFC bank is road transport refrigeration vehicles. The second largest category includes (intermodal) reefer containers of which 950,000 units are in operation today[89]. The refrigerant charge ranges between several hundred grams up to 10 kg in the largest road transport units. Most units have a refrigerant charge below 6 kg[90]. Use of HFCs in refrigerated transport by trains, reefer ships and airborne containers is much lower than in reefer containers and road transport. Therefore the other sub-sectors of transport refrigeration are omitted in this study. Latest figures from UNEP RTOC 2010 state the following HFC banks (charge of all existing equipment): road vehicles 14,380 tons, intermodal containers 4,060 tons, refrigerated rail cars 80 tons, merchant, naval, reefer and fishing ships 2,730 tons of HFC (includes air conditioning of the vessels).

When including CFCs and HCFCs in the size assessment of the transport refrigeration sectors, fishing vessels represent the second largest bank with more than 10,000 tons of halogenated refrigerants. R22 is still standard of chilling and freezing equipment in fishing vessels. This is because ship lifetime is very long (up to 40 years) so that refrigerant replacement via new built vessels takes several decades. In the global perspective on A2 and A5 countries, this report excludes the fishing sector from the analysis of alternative abatement solutions for lack of reliable data even in the 2010 UNEP RTOC assessment. The situation is different for the EU for which the fishing sector has been investigated in two recent studies for the European Commission[91]. In the Europe section of this chapter, data and technical abatement options are presented also for fishing vessels. On the other hand, intermodal containers are only discussed under global perspective, not for Europe. This is due to the fact that containers are operated globally and refrigerant consumption or emissions can hardly be attributed to a specific world region. Analysis of reefer containers specific for Europe is not deemed meaningful.

Technical requirements for transport refrigeration systems are very complex. The systems have to operate over a wide range of weather conditions and have to be able to carry any one of a wide range of cargoes at different temperatures, sometimes even at the same time in two different compartments served by the same refrigeration unit. They also have to be very robust and reliable to withstand vibrations and shocks. Yet, they must be compact to maximize cargo space, and lightweight to save energy to move the vehicle.

Most transport refrigeration equipment is – like commercial refrigeration equipment – used to operate at both medium and low temperature. Chilled cargo is maintained in the range of

---

[89] UNEP 2010: ibid.
[90] UNEP 2010: ibid.
[91] Schwarz, W., The analysis of the emissions of fluorinated greenhouse gases from refrigeration and air conditioning equipment used in the transport sector other than road transport and options for reducing these emissions (07010401/2006/445124/MAR/C4).
Schwarz, W., Measures to reduce the climate impact of refrigerant emissions, in: CE Delft, DLR, Fearnley Consultants, Per Kageson, David Lee, MARINTEK, Norton Rose, Öko-Institut, Öko-Recherche, with assistance from DNV on some issues: Technical support for European action to reducing Greenhouse Gas Emissions from international maritime transport (DG ENV.C3/ATA/2008/0016). For the European Commission (DG Environment), Delft, October 2009.

+1℃ to +14℃ called medium temperature (MT) where the evaporating temperature for the refrigeration equipment varies between -15℃ and +1℃. Most frozen cargo products are kept at temperatures from -12℃ to -20℃ called low temperature (LT). Usual evaporating temperatures for frozen cargo are in the range of -35℃ to -40℃. Depending on the evaporation temperature and the type of equipment, a number of different refrigerants are being used. Virtually all new systems utilize R404A and R134a, but also R410A and R407C.

Key features of the two categories analysed in the global part of the report are:

Reefer container equipment

… where one refrigeration unit is connected to one container regardless of the size of the container. 40 ft containers (800,000 units worldwide) are today used to a greater extent than 20 ft containers (150,000 units worldwide)[92]:

- R134a is used in 85% of all new container refrigeration units
- R404A is used for 15% of the new container refrigeration units[93]

Due to the relatively short service life-time (12 to 15 years) of reefer containers, the existing fleet uses the same refrigerants in about the same percentage since the stock renews itself at relatively short intervals. Any reefer container has to be able to transport any kind of refrigerated goods. Therefore the refrigeration unit has to be able to serve all temperature levels. The maximum refrigeration capacity is around 4 kW at a box temperature of –29ºC, around 6 kW at a box temperature of –18ºC, and it is around 12 kW at a box temperature of 2ºC, all rated at the ambient temperature of 38ºC[94]. All units are able to transport any type of cargo in any climates.

The typical refrigerant charge is between 3.8 kg to 5.3 kg per unit with an average of approximately 4.5 kg[95].

Dominated by five manufacturers, about 100,000 new units are built annually[96]. A reefer container refrigeration unit alone costs about € 6,000.

Road transport refrigeration

… one refrigeration unit is usually installed per vehicle. Units of small trucks (vans) are typically powered directly from the vehicle engine. Very small units (for vans) may be powered by DC power from the battery and alternator of the vehicle or belt driven by the van engine. Large trucks and trailers are powered by an independent, usually diesel engine, which is integrated inside the unit. In order to eliminate exhaust emissions, most units also include an electrical motor that can drive the compressor from the electricity grid at stops or for pre-cooling[97]. Typical refrigerants used today are (ranked according to their market penetration):

- R134a
- R404A
- R410A
- R407C

[92] UNEP 2010: ibid.
[93] UNEP 2010: ibid.
[94] UNEP 2010: ibid.
[95] UNEP 2010: ibid.
[96] UNEP 2010: ibid.
[97] UNEP 2010: ibid.

The total world fleet is estimated at 4,000,000 vehicles, of which about 30% are trailers with a box volume of more than 100m^3, 30% are large trucks with a volume between 20 and 60m^3 and 40% are small trucks and vans with a cargo volume below roughly 19 m^3 [98]. Other sources quote much higher numbers - up to around 12 million vehicles[99]. Out of the total number of refrigerated road transport vehicles worldwide, the region of North America shows the highest market share, with approximately 60%. It is followed by Europe with a market share of 20%. The remaining 20% is shared amongst the rest of the countries[100].

The maximum refrigeration capacity ranges from several hundred watts up to 10 kW for the frozen cargo temperatures (-12°C to -20°C) and from less than 1 kW up to 20 kW for the chilled cargo temperatures (+1 to +14 °C). The refrigerant charges are between several hundred grams and 10 kg, usually less than 6kg for small and large trucks. Although small truck units have a lower capacity than large truck units, they include refrigerant hoses that connect the unit with the compressor mounted on the engine block. Trailer units may have a typical refrigerant charge around 7.5 kg[101]. Refrigeration units for vans (direct drive from vehicle engine) cost about € 3,000; for trucks (diesel engine) € 10-20,000 and for trailers approximately € 20,000.

Fishing vessels (Europe)

… are equipped with refrigeration systems for cooling and deep freezing of the catch, with charges from below 100 kg refrigerant in small trawlers to more than 8,000 kg in factory freezer trawlers. Before 2001, standard was direct evaporating equipment with R22. In the last decade, new builds have increasingly been equipped with R404A systems with CO_2 cascade for LT, using the high efficiency of carbon dioxide. The equipment is very large-sized and costly. Typical refrigeration capacity for medium sized vessels (42-70 m length) are 500 kW for freezing plus 500 kW for refrigeration, with charges of 1,000 kg R404A; typical capacities of large fishing vessels (>90 m) are 1,400 kW for freezing plus 1,600 kW for refrigeration, with charges of 3,000 kg R404A. The investment cost amount to € 2.0 million and € 6.0 million, respectively.

4.2 Global business as usual trend of HFC consumption until 2030

The total bank (mainly consisting of HFC refrigerants) for transport refrigeration was estimated to be 24,000 tonnes in 2006, divided into a bank of 4,250 tonnes in reefer containers and a bank of 20,000 tonnes in refrigerated road vehicles.

Leakage rates range from 5% for reefer containers and 15 to 25% for refrigerated road transport in A5 countries respectively. Annual consumption of all HFC refrigerants (new systems plus service of existing systems) is estimated in the following table:

Table VI-8: Global HFC consumption (metric t) in refrigerated transport (2006)

	A2	A5	Total
Reefer Containers	1,100 t	Included in A2	1,100 t
Road transport units	4,850 t	910 t	5,760 t
Total	5,950 t	910 t	6,860 t

98 UNEP 2010: ibid.
99 Infinity Research Limited Inc. 2007
100 Infinity Research Limited Inc. 2009
101 UNEP 2010: ibid.

Under BAU it is expected that there will be a continued shift away from HCFCs towards HFCs. Without further legislation, the market share of the different Abatement Options described below is expected to rise as outlined in the following table:

Table VI-9: BAU market shares of low GWP options in the refrigerated transport sector

	2010		2015		2020		2030	
	A2	A5	A2	A5	A2	A5	A2	A5
Reefer Containers	0 %	0 %	1 %	1 %	5 %	5 %	10 %	10 %
Road transport	0 %	0 %	2 %	0 %	11 %	3.5 %	23 %	7.5 %

The main reasons for using the Abatement Options are the "green" image, which some transport and or food chains want to have. The BAU scenario projects a strong growth of HFC consumption in the refrigerated transport sector in A5 countries.

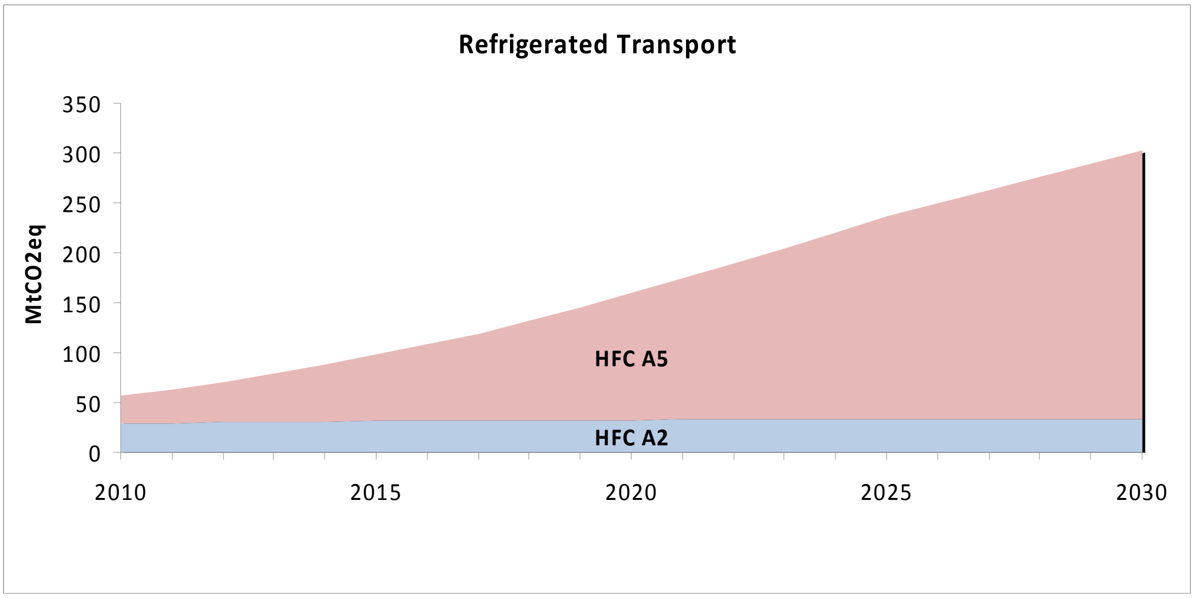

Figure VI-7: BAU consumption trends for HFCs and HCFCs in refrigerated transport. Strong growth is projeted for A5 countries, constant levels are assumed for A2 countries.

4.3 HFC demand and emissions in EU-27 until 2050 (WM scenario)

Transport refrigeration equipment is not subject to Art 3 or Art 4(1) of the F-gas Regulation (2006). The general provision of Art 4(3) for recovery by "appropriately qualified personnel" is not considered to impact the emissions quantitatively. As a consequence, the WM scenario for HFC emissions and demand 2010-2050 does not differ from the WOM scenario.

As initially mentioned, for Europe the following sectors of transport refrigeration are analysed: road transport, subdivided into vans and trucks/trailers, and fishing vessels.

In the model AnaFgas the 2010 bank of halogenated refrigerants is estimated at 630 t in vans (only R134a), 2,900 t in trucks/trailers (R404A only) and 1,200 t in fishing vessels (985 t R22, 190 t R404A). R22 in fishing vessels will be converted to HFC blends until 2015, due to ODS legislation.

Leakage rates are high with 20% for trucks/trailers, 30% for vans, and 40% for fishing vessels. Annual HFC emissions (use and disposal emissions) and annual HFC demand (first fill of new systems plus refill for leakage) is estimated in the following table:

Table VI-10: Annual HFC demand in the refrigerated transport sector in EU-27 (2010), metric t

2008	bank	emissions	demand
Refrigerated vans	628 t	214 t	251 t
Refrig. trucks/trailers	2,855 t	670 t	857 t
Fishing vessels	191 t R404A 985 t R22	77 t R404A 394 t R22	99 t R404A 394 t R22
Total	4,660 t	1,355 t	1,600 t

Source: model AnaFgas

Growth rates are assumed to average +3.3% per year for vans and trucks/trailers so that the vehicle fleet increases from 800,000 units (2008) to 1.6 million units (2050). For fishing vessels no growth in number is assumed. By 2015 all vessels run on HFC refrigerants.

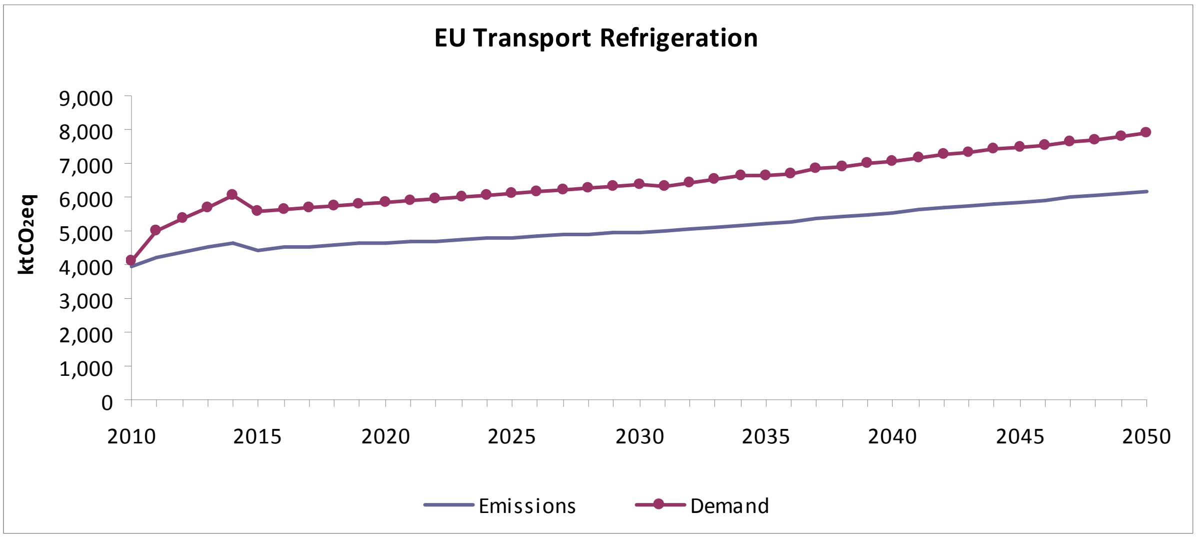

Figure VI-8: HFC refrigerant demand and emissions in European refrigerated transport sectors under the WOM/WM scenario. Emission reduction measures are not included in the present F-gas Regulation. Therefore continuous increase in emissions and demand is assumed from 2010 onwards. The peak in 2014 results from R-22 replacement by HFC blends in existing fishing vessels.

4.4 Key Abatement Options

Road transport refrigeration

The technically feasible Abatement Options for transport refrigeration equipment are[102]:

R290 or R1270. Hydrocarbons might be used in road transport refrigeration equipment. The only real factor against the application of hydrocarbons is the safety concern with regards to flammability. Otherwise, overall performance and efficiency of hydrocarbons may correspond to the best HFC systems[103]. From a legal point of view (current rules and standards), equipment with charges greater than 1.5 kg is in general allowed only if all the refrigerant

[102] Please note that R744 is the only viable alternative for reefer containers due to safety concerns when transporting reefer containers aboard ships below deck.
[103] UNEP 2010: ibid.

containing parts are outdoors or located in a special machinery room equipped with gas sensors and the possibility for forced ventilation in case of HC leakage. In road transport, lower flammability limits could be reached in case of refrigerant leakage under the unit front panels or inside cargo boxes. Efforts have been made to reduce the refrigerant charge through compact heat exchangers. An experimental investigation with R290 used in a system with a mini-channel condenser and evaporator resulted in 120 g refrigerant charge for a refrigeration system with 1 kW refrigeration capacity, with the projection of an improved refrigeration system of 50 g per 1 kW[104].

Already in the 1990s a manufacturer of transport refrigeration devices had equipped a pilot system with hydrocarbon refrigerant. The vehicle had been successfully operated for several years by a German supermarket chain. At that time the existing safety requirements and standards made the use of hydrocarbons economically not feasible. Under modified safety requirements in 2010 a system with propene (R1270) was presented at the International Automobile Fair (IAA). Field tests are clearly foreseen. The investment cost of hydrocarbon based refrigeration plants are estimated 5% higher vs. reference R404A system, as a consequence of safety installations like gas sensor etc.

Indirect systems using HCs as refrigerant are not considered a viable abatement option for transport refrigeration equipment as indirect HC systems are often penalized with a lower overall efficiency (higher fuel consumption), a greater complexity (increased reliability and maintenance cost), higher weight (fuel consumption) and larger size (reduced cargo space) as compared to direct systems with R404A and R134a. Due to the multi-temperature requirements on the refrigeration unit, the secondary refrigerant would have to be frost protected to withstand the low temperatures, resulting in highly additive concentrations and hence high viscosity and low heat transfer characteristics.

R744 (Carbon dioxide - CO_2) has the advantage that it is widely available worldwide but it presents several challenges in transport refrigeration. Under high ambient temperature operation, sophisticated refrigeration cycles (two-stage cycles, work recovery devices, etc.) are necessary to match the system efficiency of equivalent HFC units. The cycle operation is almost always transcritical, which results in compressor discharge pressures up to 5 times higher than those in HFC systems. Therefore, entirely new parts, design approaches, test procedures, service training, etc. are needed to design, build and operate a transcritical CO_2 system. The ability of using CO_2 efficiently in a heat pump cycle for high heating temperatures is an advantage since a significant duty of transport refrigeration units is in heating mode during low outside temperatures.

Prototypes of refrigerated trucks with CO_2 have been tested over several years by the company Carrier and within a research project at a German discounter (Aldi). The test results show that the use of CO_2 as refrigerant in this application is a feasible alternative in moderate climatic zones. Extension to a two-step system could provide further increase in efficiency, especially for low interior and high exterior temperature. The additional investment cost for energetically equivalent CO_2 systems are estimated at 20% per unit.

Compressors, heat exchangers and other parts of transport refrigeration systems have special requirements in terms of robustness, weight, corrosion resistance, etc. Transport

[104] Hoehne, M.; Hrnjak, P. (2004): Charge minimization in hydrocarbon systems. IIR Gustav Lorentzen Conference on Natural Working Fluids 2004, Glasgow, UK.

refrigeration is a niche market. The first prototypes are likely to be based on parts developed for the automotive, commercial or hot water heat pump fields. Rigorous testing and performance verification must be carried out to approve these parts for transport systems. Therefore, even if all technical challenges are resolved, a serial production of such systems is seen as unrealistic in the near future[105].

Unsaturated HFCs might be used in road transport refrigeration equipment of small trucks or vans where the present standard refrigerant is HFC-134a. After the phase-out of R134a in passenger cars in Europe through the MAC Directive it is likely that small refrigerated vehicles of similar design as passenger cars (belt drive) use the same replacement refrigerant which is likely HFC-1234yf although transcritical CO_2 is also possible. The only real factor against the application of unsaturated HFCs is the safety concern with regard to flammability and the low volumetric refrigeration capacity. The investment cost of the system is estimated 5% higher than the conventional HFC system while the CO_2 system, which is energetically superior only in northern regions, is estimated 20% more expensive.

Container transport refrigeration

Flammable refrigerants are no real option for reefer containers on ships. R744 (CO_2) is the only viable alternative due to safety concerns when transporting reefer containers aboard ships below deck. Energy consumption is considered about equal, compared with conventional HFC systems, except for high ambient temperatures and high box temperatures. Like systems for refrigerated road vehicles, R744 equipment for reefer containers cost about 20% more per unit. Prototype systems have been produced.

Refrigeration in fishing vessels (Europe)

Indirect systems with ammonia are possible and are allowed since 2001 by classification bodies and authorities. Condition is that the ship does not carry passengers but a professional crew only. As a consequence, since 2001 almost all new-built large fishing vessels use the high efficiency of NH_3-CO_2 cascade systems for refrigeration and freezing on board. The trend towards NH_3 with or without CO_2 in refrigeration of fishing vessels is so clear that it is already included in the WOM scenario of the model AnaFgas. Energy consumption and costs of the technical solution “natural refrigerants in fishing vessels” have been discussed in a recent study for the European Commission. Compared to a typical refrigeration system with R404A and CO_2 cascade (HFC charge 1,000 kg) a system with ammonia and CO_2 cascade costs about 15% more (€ 2.3 million vs. €2.0 million). Energy consumption is ~ 6% lower because of the superior thermodynamic properties of ammonia.

Individual abatement cost of alternative options

Detailed data on costs, refrigerant consumption and (for Europe) emissions for abatement options and HFC reference systems are presented in the annex, in Global DIS for A2/A5 in annex IV, and in EU sector sheets in annex V for Europe. For each individual abatement option the cost difference to the sector-typical HFC reference system is quantified and put in relation to the avoided HFC quantity of this system. The result of the calculation is the specific annual abatement cost in €/t CO_2 eq of an alternative option, as measure of its cost effectiveness.

[105] UNEP 2010: ibid.

Because of too high complexity the calculation of the eight individual abatement cost data for A2 and A5 countries, and of the twelve abatement cost data for the EU are not repeated here. The calculations are carried out for A2 and A5 countries in the global model on the base of the DIS (annex IV), and for the EU in the EU sector sheets 2 - 4 (annex V). Here, the information might be sufficient that the values range from €3.0 (NH_3-CO_2 for fishing vessels) to €68 (HFC-1234yf for refrigerated vans).

4.5 Market potential (penetration) of abatement options until 2030

Reefer container market is a worldwide business, where the same containers are used in A2 and A5 countries. Any solution introduced into that market has to be feasible on a global scale. In addition, containers are sailed under deck on container ships. Flammable substances are not allowed under current legislation, leaving R744 (CO_2) as the only alternative for reefer containers. As containers equipped with a CO_2 system will – without cycle improvements – use more energy in hot climates than existing HFC units, energetic equivalence is achieved on a global average only. Under these conditions, market penetration for new equipment can reach 100% in 2030.

Road transport refrigeration (truck and trailer) can be distributed locally or across borders (long distance haul), but vehicles usually do not drive over continental borders, i.e. different regional solutions are possible.

R744 (CO_2) has an energy-related disadvantage in hot climates, but works fine in moderate and cold climates. In addition, it can be used with better efficiency in heat pump mode if box heating is required. Market penetration can increase to 45% of the global market, by 2030.

R290 or R1270 (hydrocarbon) is technically the best alternative since energy consumption will be 10 to 15% lower than with existing HFC equipment. It could be used on a broader basis for refrigerated road transport if the legal situation regarding product safety would change. There are millions of vehicles propelled by compressed natural gas (CNG) and liquefied petrol gas (LPG). It is difficult to understand why the same vehicle cannot use 1 to 2 kg HC as refrigerant in the refrigeration system. Refrigerant charges would approximately be half the charge of HFC due to the thermo physical properties of HCs. Some companies in the UK and Australia currently have developed and operate a small number of systems, demonstrating the viability of this concept. The penetration rate can increase to 80% by 2030.

Unsaturated HFCs might be used on a broad basis once they are available and the flammability concerns with the charges in transport refrigeration units are solved. In vans with units for MT, 100% penetration is possible in 2030.

The market penetration of NH_3 or NH_3-CO_2 systems for fishing vessels is estimated to grow to 95% of new equipment in 2030. For ca 5% of the refrigerant quantity in the sector (small vessels with low charges), flammable refrigerants are no viable option, and transcritical CO_2 is from today's view too expensive.

Based on the assessment of the penetration rates of the individual abatement options the sector experts in the project team estimated for the year 2030 the mix of most effective alternative solutions which are mutually not exclusive ("penetration mix"), prioritizing the more cost-effective solutions in case of equal reduction potential. The 2030 penetration mix is shown for each application in the following table for A2 and A5 countries. The EU has no other penetration mix than A2.

A2 2030 - Penetration mix of abatement options in transport refrigeration				
Alternative technical solution	R290 direct	NH_3 CO_2 cascade	CO_2 trans-critical	HFC-1234yf direct
Refrigerated trucks	80		20	
Refrigerated vans			50	50
Reefer containers			100	
Fishing vessels		95		
A5 2030 - Penetration mix of abatement options in transport refrigeration				
Alternative technical solution	R290 direct	NH_3 CO_2 cascade	CO_2 trans-critical	HFC-1234yf direct
Refrigerated trucks	80		20	
Refrigerated vans			50	50
Reefer containers			100	
Fishing vessels		95		

4.6 Abatement cost and reduction potential of alternative options 2030

Corresponding to the percentage of the individual abatement options in the 2030 penetration mix, the individual abatement cost are aggregated to sector abatement cost, in €/t CO_2 eq.

Global data

The BAU trend of the HFC consumption 2010-2030 has been assessed previously. The reduction of the HFC consumption as a result of the application of the set of abatement options can be estimated for the sectors, for the year 2030[106].

Sector abatement cost and calculated sector consumption reduction potential for the three sub sectors of commercial refrigeration for 2030 are shown in the following tables, for A2 and A5 countries.

A2 – consumption abatement vs. BAU in transport refrigeration 2030			
Sub sectors		Refrigerated trucks & trailers (incl. vans)	Reefer containers
abatement cost	€/tCO_2eq	-6.6	9
consumption reduction	ktCO_2eq	25,100	4,500
A5 – consumption abatement vs. BAU in transport refrigeration 2030			
Sub sectors		Refrigerated trucks & trailers (incl. vans)	Reefer containers[107]
abatement cost	€/tCO_2eq	-39.1	-
consumption reduction	ktCO_2eq	310,000	-

[106] While quantity for first fill of equipment becomes zero in the year of introduction of the alternative option and can easily be quantified, quantity for refill decreases only over a number of years as old equipment retires from the stock. The amount of refill in a year depends on the penetration rates in the preceding years.

[107] Due to international trade activities, reefer containers cannot be divided into A2 and A5 fractions. Therefore all units are allocated to A2.

EU data

The calculation of abatement cost and reduction potential for the EU follows the same principle as the calculation of the global values. In addition to the demand for HFCs, for the EU the emissions of HFCs (from use and from disposal) are of relevance. Emissions and demand in the EU-27 are estimated in the WM scenario of the model AnaFgas.

EU-27 – demand abatement vs. WM scenario in transport refrigeration 2030				
Sub sectors		Refrigerated trucks & trailers	Refrigerated vans	Fishing vessels
abatement cost	€/tCO_2eq	2.0	37.2	3.2
demand reduction	ktCO2eq	4,325	516	539
EU-27 – emissions abatement vs. WM scenario in transport refrigeration 2030				
Sub sectors		Refrigerated trucks & trailers	Refrigerated vans	Fishing vessels
abatement cost	€/tCO_2eq	2.6	45.1	3.4
emissions reduction	ktCO2eq	2,990	421	405

VI.5 Stationary air conditioning and heat pumps

5.1 General description

Stationary air conditioning and heat pump equipment is categorised into the following eight different classes:

- Factory sealed (moveable)
- Split system sector
- Multi-split system
- Ducted Sector
- Large Chillers
- Small Chillers
- Centrifugal Chillers
- Heat Pumps

Factory sealed including moveables

Factory sealed, moveable stationary air conditioning covers appliances that are broadly used domestically, including portable (single, double duct type), window units, so-called "through the wall" units and packaged terminal units, all of which are intended to maintain room temperature from approximately +16°C to +26°C. Combined there are approximately 16 million such appliances produced annually – split 60% in A2 countries and 40% in A5 countries. A typical product contains a factory-assembled, hermetically sealed vapour-compression refrigeration system. The cooling capacity ranges from 1 to 10 kW and contains between 300 g to 3 kg of refrigerant, averaging 0.75 kg.

Single split

Split type stationary air conditioning covers appliances that are broadly used domestically and commercially, intended to maintain room temperature to around +16°C to +26°C. Combined there are approximately 66 million such systems produced annually – split 40% in A2 countries and 60% in A5 countries.

A typical product comprises of two elements – a factory-assembled compressor/condenser assembly and a separate indoor evaporator unit, which is connected during installation at the site. The cooling capacity ranges from 2 to 12 kW and contains between 500 g to 5 kg of HFC- or HCFC-refrigerant, with an average of 1.5 kg. A considerable part of split systems are of the reversible type and can also provide heat.

Multi split including VRF

Multi-split stationary air conditioning (which includes variable refrigerant flow) covers installations that are largely used commercially and are intended to maintain room temperature from approximately +16°C to +26°C, and which often also have a heating (heat pump) function. (In cooler, northern climates, the heating function may be the dominant use profile.) Combined there are approximately 3.3 million such systems produced annually – split 60% in A2 countries and 40% in A5 countries. (Note that the production numbers refer to discrete modules – outside units – that may often be combined with one, two or three units to produce a larger capacity system installation.)

A typical product comprises several elements – one or more factory-assembled compressor / condenser assemblies and a number of separate indoor units, which are joined with interconnecting pipe work during installation at the site. The cooling capacity of entire system installations ranges from 10 to more than 200 kW, containing between 5 kg to over 100 kg of refrigerant, whilst the individual modules range from 10 to 50 kW. (Note that the data hereon refers to individual unit modules, and not entire systems.) In this study average charge size is 13.5 kg (8.5 kg pre filled, 5.0 kg topped up on site).

Ducted including rooftop

Ducted type stationary air conditioning broadly covers a number of system categories including rooftop-ducted systems, central ducted systems, and close-control systems. These systems are largely used commercially although sometimes within domestic situations, intended to maintain room temperature to around +16°C to +26°C, and which sometimes also have a heating (heat pump) function, depending upon the particular sub-type. Combined there are approximately 2.1 million such systems produced annually – split 85% in A2 countries and 15% in A5 countries. The production split is more or less equally between the three broad system categories.

Rooftop type ducted systems comprise a single compression system within a packaged unit, from which the ducting is lead into the building. A central ducted system normally comprises a compressor/condenser assembly located outside, feeding refrigerant via interconnecting pipework to a duct-mounted evaporator within the building. A close control system may be based on a direct expansion system with a remote (outside) compressor/condenser assembly, or with an internal compressor and remote condenser, or with the entire integral compression system using a water-cooled condenser. The cooling capacity of such systems ranges from 10 kW to more than 300 kW, containing between 5 kg to over 150 kg of refrigerant. Average size in this report: 10.5 kg (9.3 kg pre filled, 1.2 kg topped up on site).

Large chillers

Large displacement chillers (>350 kW) for stationary air conditioning[108] cover both air-cooled and water-cooled systems, and are generally used for commercial and light industrial applications. They are intended to provide chilled water at temperatures typically between +5°C to +15°C, and sometimes also have a heating function (reverse cycle mode). In total, there are approximately 1.6 million chillers installed globally, and approximately 0.12 million such system produced annually, split approximately 75% in A2 countries and 25% in A5 countries.

Most air-cooled and water-cooled products typically comprise a single packaged factory-assembled evaporator/compressor/condenser unit, although some air-cooled types are supplied with a separate remote condenser to be connected during installation at the site. The cooling capacity ranges from 350 kW to >10 MW and contains between 50 kg to >1,000 kg of refrigerant.

[108] In order to avoid double counting, industrially used large and small chillers are also discussed here, not under industrial refrigeration.

Small chillers

Small chillers (<350 kW) for stationary air conditioning covers both air-cooled and water-cooled systems, and are generally used for commercial and light industrial applications. They are intended to provide chilled water at temperatures typically between +5℃ to +15℃, and sometimes also have a heating function (reverse cycle mode). In total, there are approximately 0.14 million such system produced annually – split 80% in A2 countries and 20% in A5 countries.

Most air-cooled and water-cooled products typically comprise a single packaged factory-assembled evaporator/compressor/condenser unit, although some air-cooled types are supplied with a separate remote condenser to be connected during installation at the site. The cooling capacity ranges from 10 kW to 350 kW and contains between 5 kg to 100 kg of refrigerant.

Centrifugal chillers

Centrifugal chillers for stationary air conditioning[109] cover both air-cooled and water-cooled systems, and are generally used for commercial and some industrial applications. They are intended to provide chilled water at temperatures typically between +5℃ to +15℃, and sometimes also have a heating function. In total, there are approximately 0.35 million chillers installed globally, and approximately 0.014 million such system produced annually, split approximately 60% in A2 countries and 40% in A5 countries.

Most air-cooled and water-cooled products typically comprise a single packaged factory-assembled evaporator/compressor/condenser unit, although some air-cooled types are supplied with a separate remote condenser to be connected during installation at the site. The cooling capacity ranges from 200 kW to >20 MW and contains between 100 kg to some 10,000 kg of refrigerant.

Heat pumps (heating only)

Within this category, heat pumps are those used for heating-only purposes for domestic and small commercial applications. They remove heat from external sources, such as the ground, water or the air or water and reject it to a water-circuit within the building for space and water heating purposes.[110] It is estimated that there are approximately 2.8 million heat pumps installed globally (2008), and approximately 1.4 million such system produced annually (2008), split approximately 80% in A2 countries and 20% in A5 countries; the high ratio of new production to installed base clearly indicates a massive growth in the market.

Some products comprise a single packaged factory-assembled evaporator/ compressor/ condenser unit, which is then connected to the water circuit on-site. Some air-source models may employ a remote condenser to be connected during installation at the site. The heating capacity ranges from around 5 kW to 50 kW (although some commercial products may exceed 400 kW) and contain between 1.5 kg to 15 kg of refrigerant (or significantly more for larger commercial systems).

---

[109] Industrially used centrifugal chillers are also included here, not under industrial refrigeration.
[110] Reversible air conditioners, i.e., those with heating mode, are covered by the relevant air conditioning sector.

5.2 Global business as usual trend of HFC consumption until 2030

The total refrigerant bank for stationary air conditioning is estimated at 1.8 million tonnes in 2008, divided into a bank of 1.0 million tonnes in A2 countries and 0.8 million tonnes in A 5 countries.

The main refrigerants used are HCFC-22, R410A, and R407C. For chillers, R134a and R404A is also employed. Almost 100% of new products within A2 countries use HFCs, except for the minority using R290 for room air conditioners, chillers and heat pumps, R717 for large chillers, or R744 for heat pumps, whilst the majority of new products for A5 countries still employ HCFC-22. Today, refrigerant banks in A 5 countries consist virtually completely of HCFC-22.

The largest sub sector is single split systems, with 40% of the global refrigerant bank in stationary air conditioning. The majority of single split units are installed in A 5 countries, and the refrigerant in the bank is HCFC-22 almost 100%. The second largest sector in terms of refrigerant mass is multi-split systems which comprise ca. 25% of the bank. The majority is installed in A2 countries, which is why the share of HFCs in the bank is comparably high.

Leakage rates in A2 countries range between 3% (moveable systems in Europe) and 8% (multi split), and are estimated for A 5 countries at 10% for all categories. Annual refrigerant consumption for new units plus service of existing units is estimated in the following table:

Table VI-11: Global installations, banks and consumption of refrigerants for stationary air conditioning and heat pumps, in metric kilo tonnes (2008)

2008	**worldwide installations (million units)**	**bank HFC/HCFC (kt)**		**consumption HFC/HCFC (kt)**	
		A 2	A 5	A 2	A 5
Factory sealed	220	60	95	11	13.5
Single split	530	265	410	45	95
Multi split (VRF)	25	235	125	40	35
Ducted (rooftop)	21	220	70	40	10
Large chillers	1.6	170	45	30	12
Small chillers	1.8	50	15	6.5	2.5
Centrifugal chillers	0.35	120	90	10	10
Heat pumps	2.8	4.1	0.7	2.2	0.6
Total		**1,000**	**760**	**172.5**	**168**

Over the next decades, a continued shift away from HCFCs towards HFCs, in-line with the HCFC phase-out plan according to the Montreal Protocol, is expected. Under the BAU scenario a slight increase of hydrocarbons (factory sealed and single split) and ammonia (chillers) is likely, reaching up to 5% of the new equipment by 2030. The gradual increase in the use of R290 for A2 regions is assumed to continue at the same rate since its introduction some ten years ago. In the heat pump sector of A2 countries (space heating), a market share of 15% for non-HFC refrigerants is not unrealistic, by 2030.

HFC demand will grow strongly, mainly driven through overall population and economic growth in A5 countries, accentuated through a strong demand for air conditioning systems in countries such as India and China. The heat pump sector features very high growth rates both in A2 and A5 countries, starting from a low present level of installations.

The future growth rate is not reported elsewhere, so the average growth rate for the current period as reported by BSRIA 2008 is employed almost entirely throughout.

Table VI-12: Assumed annual growth in stationary air conditioning and heat pumps

System type	A2			A5			Source
	2010 - 2015	2015 - 2020	2020 - 2030	2010 - 2015	2015 - 2020	2020 - 2030	
Factory-sealed	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%	-1.8%	BSRIA
Split type	7.0%	4.0%	0.0%	4.7%	4.7%	4.7%	BSRIA
Multi-spilt	5.0%	3.0%	0.0%	9.5%	9.5%	9.5%	Compromise between short term BSRIA forecasts and industry estimates.
Ducted	-0.1%	-0.1%	-0.1%	3.0%	3.0%	3.0%	
Chillers large	1.0%	1.0%	1.0%	6.0%	6.0%	6.0%	
Chillers small	1.0%	1.0%	1.0%	6.0%	6.0%	6.0%	
Centrifugal ch.	-1.0%	-1.0%	-1.0%	1.0%	1.0%	1.0%	BSRIA
Heat pumps	30.0%	25.0%	20.0%	65.0%	55.0%	45.0%	IEA HPC, 2010, EHPA 2009, Industry estimates

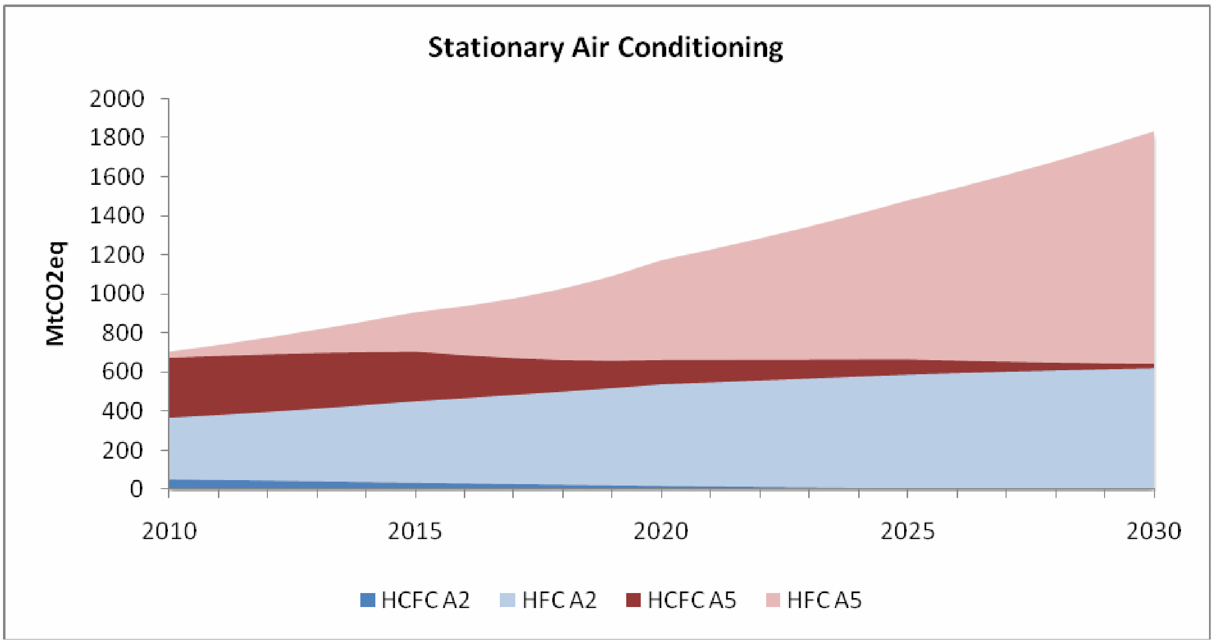

Figure VI-9: BAU consumption trends for refrigerants in stationary air conditioning and heat pump systems in A2/A5 show strong growth, especially in A5 countries.

5.3 HFC demand and emissions in EU-27 until 2050 (WM scenario)

Stationary air conditioning systems charged > 3 kg are fully subject to the containment and recovery measures of the F-gas Regulation. In the model AnaFgas it is assumed that in the WM scenario the use-phase emissions will be reduced by 40% until 2015. End-of-life emissions will decrease from 30% to 20%. This applies to multi-split and rooftop systems and to chillers. Factory sealed and split air conditioners, and by far most heat pumps in Europe have charges <3 kg. This equipment is subject to Art 4(1) of the F-gas Regulation only, which requires recovery by certified personnel. In the model AnaFgas it is assumed that the end-of-life emissions will be reduced from 75% to 35% (from 2015 onwards) while the use-phase emissions in the WM scenario will remain at the same level as under WOM conditions.

From comparison of table VI-11 on global installations with the number of units in the following table VI-13 on the EU-27 it can be seen that Europe plays only a minor role in the world market of factory sealed, single split and multi-split and ducted systems. Its share in these systems is, when looking at the total in A2 countries, much lower than in the population. USA and Japan are much more important users. In the chiller sector, however, Europe's share in the A2 installations is not disproportionate, and in the heat pump sector, Europe represents by far the largest market in the world.

In the model AnaFgas the 2010 bank of halogenated refrigerants is estimated at 130 kt for all eight sub sectors together, with 60% in single split systems. The second largest sub sector is displacement chillers which are divided in large and small systems.

Leakage rates are relatively low and rank in the following order. Factory sealed 3%, heat pumps 3.5%, chillers all sizes 4%, single split and rooftop 5%, and multi-split 8%. Annual refrigerant demand for new units plus service of existing units is estimated in the following table:

Table VI-13: EU-27. Installations, banks and annual demand of refrigerants for stationary air conditioning and heat pumps in 2010, in metric kilo tonnes

	stock (million units)	**bank (kt)**	**demand** (kt)**	**emissions (kt)**
Factory sealed	12.3	9.2	0.3	0.4
Single split	53.7	80.5	6.4	4.0
Multi split (VRF)	0.5	7.23	1.1	0.5
Ducted (rooftop)	0.3	3.2	0.5	0.2
Chillers*	0.7	25.3	3.5	1.1
Centrifugal chill.	0.007	4.6	0.4	0.15
Heat pumps	1.7	4.3	1.1	0.15
Total	**69.2**	**134.3**	**12.5**	**5.7**

* This category includes displacement chillers: small <100 kW and large chillers > 100 kW.

** Demand includes, in addition to refill in existing systems and first fill into domestically manufactured systems, first fill in new pre-charged equipment which is imported in third countries. There are only few EU countries where manufacturing takes place. In the other MS first fill is limited to top-up quantities on installation. (0 kg for factory sealed, 0.125 kg for split, 5 kg for multi-split, 1.2 kg for ducted/rooftop systems).
Source: model AnaFgas.

Heat pumps show the strongest growth. It is assumed that the 2030 stock will be ten times the present number of installation. Very high growth rates in annual sales are also projected for room air conditioners until 2030, in particular for split systems. By 2030, installations and emissions are expected to increase by 62%. Stock and annual sales for chillers and roof top systems are assumed to be rather stable at present level. For multi-split systems (VRF type) a constant increase in the stock is projected until saturation in 2025. Due to the strong increase of room air conditioners, annual HFC demand and emissions are forecast to grow significantly even in the WM scenario. See the graph, which is taken from AnaFgas.

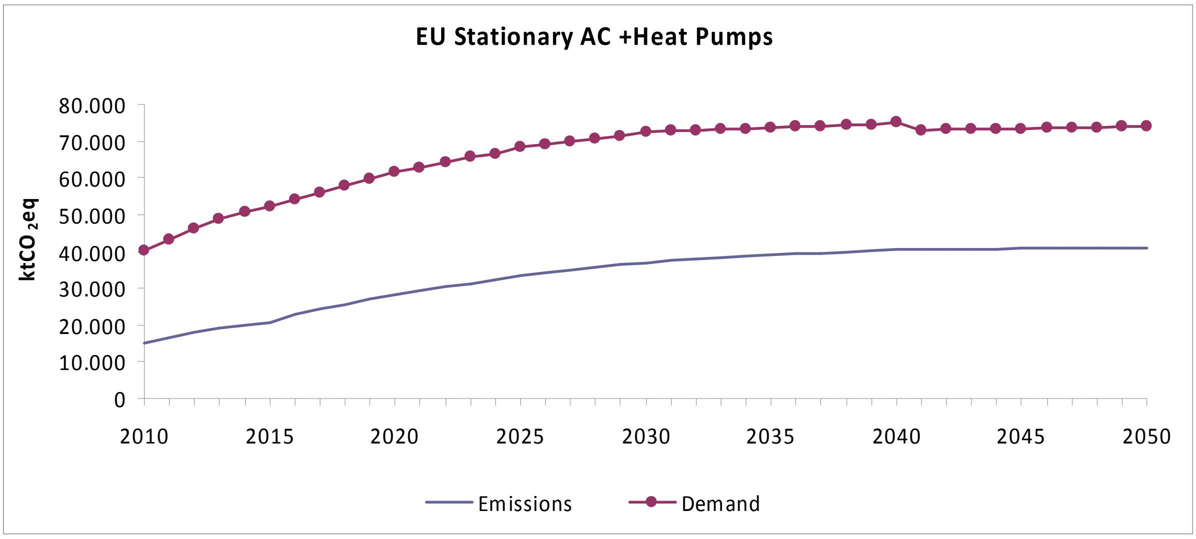

Figure VI-10: Trend of HFC demand and emissions under the European WM scenario in stationary air conditioning and heat pumps. Before in 2035 the market is saturated, considerable growth is assumed, which makes stationary air conditioning the largest individual HFC sector in Europe. The demand includes HFCs in imported pre-filled systems.

Please note that first fill, which is part of the demand includes pre-filled equipment from outside of Europe. It must also be noted that the demand for first fill is not affected by the provisions of the F-gas Regulation.

5.4 Key abatement options

Several Abatement Options are considered throughout the range of stationary air conditioning equipment:

Factory sealed moveable and split systems

Hydrocarbons R290, R1270. This technology is currently used in direct mode in both categories. Because of flammability, charge sizes tend to be limited, which is done through the application of European and international standards. These (voluntary) standards limit the charge to 1 kg (equivalent to around 2.5 kg of HCFC or HFC accounting for density difference), although other standards allow between 1.5 kg to 2.5 kg in direct systems for occupied spaces. Risk analyses for these types of systems indicate low risk provided they are well designed and constructed.

Most moveable systems tend to have charges of less than 500 g so that they can easily be implemented with hydrocarbons (R290). Such systems have already been sold to European market for a long time, e.g. from the Italian manufacturer Delonghi and others in Netherlands and UK.

Split systems with hydrocarbons (R290) are on the market with charges below 1 kg (e.g. from the mentioned Italian manufacturer). The German Technical Cooperation (GTZ) and the Chinese manufacturer Gree have developed a single split system, currently with R290 with charges of up to 350 g for capacities up to 3.5 kW. These systems exceed the European efficiency class A. Additional safety features are incorporated into the system design over and above what the standards require. Devices from further manufacturers are close to market introduction.

HFC-1234yf (unsaturated HFC), **HFC-1243ze** (unsaturated HFC) **or HFC-32** (HFC covered by the Kyoto Protocol) or mixtures of these could also be used. All are flammable refrigerants and international standards exist to handle this; charge size limits correspond to about six times that for HCs (or three times if density differences are accounted for) and therefore they are expected to permit the use of R1234yf or R32 or mixtures in a large proportion of applications, including small sized room air conditioners. Application in the other sub sectors of stationary air conditioning including heat pumps is also possible. For a like-for-like charge the flammability risk should be less than that for HCs based on flammability characteristics. However, because of the thermo-physical properties of R1234yf, the efficiency of this unsaturated HFC with the (preliminary) GWP of 4 in conventional systems is likely to be poor and in order to offset these effects, considerably greater material are required, as indicated in several recent studies[111]

HFC-32 is a technical option for factory sealed and split systems, strongly supported by a leading Japanese manufacturer, with production also in Europe. In the global model of this study, which shall form the basis for a potential international HFC phase-down agreement, conventional HFCs are not considered. For Europe, for which the most possible reduction effect of alternative technical solutions compared with the WM scenario shall be identified, no fluids are excluded from the beginning if they can be presumed to show noteworthy reduction effectiveness against conventional HFC systems. Therefore, R32 is included in comparative analysis of abatement solutions in some sectors. HFC-32 has the GWP 675. Consequently, it must be taken into account that the reduction potential is always lower compared with low-GWP solutions. These will be included in the “most effective penetration mix” first.

Carbon dioxide - CO_2. Broad use of CO_2 cannot be assumed today, however it should be possible in the next future.

R290 and R1270 are energetically superior to all HFC (including unsaturated HFC) refrigerants, thus saving energy cost. Initial investment costs for production line, for training, etc. result in slightly higher costs (0.5%) per unit for R290, CO_2, or unsaturated HFCs. To achieve the required energy label, the product costs (hardware) are marginally less for R290 (- 0.5/-1.5%) because material costs are lower than for HFC systems, vice versa systems with unsaturated HFCs, which show slightly higher unit costs (+6.5/+8.5%). Systems with CO_2 are assumed to cause higher investment cost per unit by 20-25% because of more material weight and in some cases additional circuit components to compensate for poor performance in high ambient temperature. The costs of HFC-32 systems are assumed to range between those of the R410A reference system and a hydrocarbon system.

Multisplit (including VRF) and ducted (including rooftop)

For direct systems such as multi-splits and ducted, the charge sizes are normally incompatible with hydrocarbon refrigerants and therefore indirect systems must be used.

---

[111] E.g., Fujitaka, Akira and Shimizu, Tsutomu et al; Application of Low Global Warming Potential Refrigerants for Room Air Conditioner, 2010 Int. Symp. Next Generation Air Cond. Refrig. Techn., Tokyo, Japan, 2010.; Hara, Hideki and Ohno, Masao et al; Experimental Study of Low GWP Refrigerants for Room Air-Conditioners, 2010 Int. Symp. Next Generation Air Cond. Refrig. Techn., Tokyo, Japan, 2010.

Unsaturated HFCs and R32 could be used in direct systems, because of the lower flammability.

HC indirect. Indirect systems can run with R290 or R1270 with a secondary liquid (water) or with a secondary evaporating fluid (CO_2). The first causes higher investment cost per unit of 16-26%, the second causes + 20/35%. The first system with chilled water can cost more or less than a direct system; however the need to improve the efficiency relative to the HFC reference system causes higher material cost (extra heat exchanger, pump, etc.) in addition to the safety features. In the second case, additional first cost result from the piping system for the evaporating fluid. However, it should be noted that there is considerable range associated with the application of a multi-split/VRF type system and are generally much more costly (often up to 50% or more) than conventional ducted or chilled water systems of similar rated efficiency[112]; although measured efficiency appears to be better it is inconclusive as to whether the additional investment (of 50% or so) in indirect systems would result in significantly greater energy savings.

Transcritical CO_2. A company recently presented a VRF system with CO_2 refrigerant. Systems are about 15-20% more costly than the HFC reference system because of more expensive materials and components.

R1234yf direct. Extra cost of 13% are estimated to arise if HFC-1234yf would be applied.

Chillers including centrifugal chillers

Most chillers are used for cooling capacities higher than those provided by direct systems. The capacities range from 15 kW to more than 3,000 kW or 20 MW for centrifugal machines. The average refrigerant charge in the EU model AnaFgas is 50 kg for displacement chillers running on R407C, R134a, or R410A, and 630 kg for centrifugal chillers with R134a.

All types of refrigerants with low GWP including unsaturated HFCs can be used because the refrigeration system can usually be installed in a separate machinery room with access for authorised persons only or in open air. Chillers are indirect systems per definition.

Hydrocarbons. R290 and R1270 are used mainly in smaller systems, although in most cases there is no limit on charge sizes with the currently available European and some international safety standards. However, where chillers are used in machinery rooms (such as for some water-cooled systems) additional costs may apply for the necessary safety measures, although this is a small proportion of the small chillers market. Whilst R290 and R1270 are currently used in centrifugal chillers in industrial applications, other HCs such as R601 (pentane) and R601a (isopentane) have been proposed for use in centrifugal systems[113].

Investment costs are estimated by 5-6% higher compared to the HFC reference system as a result of higher cost of the production line and the safety features for the units. During operation, the efficiency of R290 is 10% better than efficiency of current HFC systems, a fact which is not considered in the cost estimates.

[112] T. N. Aynur, Variable refrigerant flow systems: A review. Energy and Buildings 42 (2010) 1106–1112. The cost comparison in the study includes the peripheral cost parts.
[113] Maclaine-cross, I. 1999. Replacement refrigerants for water chillers. Proc. UNEP TEAP-IPCC Meeting, Petten, Netherlands.

A similar investment cost surcharge (ca. 5%) must be applied to systems running on **unsaturated HFCs**. Particularly for centrifugal systems, there are now systems available using R1234ze, with the same efficiency as R134a systems.

Ammonia – R717. If ammonia is used, the operation efficiency is even higher (by > 7% vs. reference system), but the investment cost per unit are up to 40% higher, although this is highly sensitive to the capacity of the chiller and the size of the production output.

R717 cannot be used in direct systems (such as for room air conditioners, multi-split, ducted) since the permissible charge size would be too limited. However, it has been used widely in large chillers (for industrial refrigeration) for many decades. More recently it has been increasingly applied for air conditioning application in medium to large sized chillers[114] with many companies promoting them for this end use. Medium sized systems tend to be at higher cost compared to HFC chillers due to material requirements and also small scale of the enterprises specialising in this technology; very large chillers tend to approach cost parity with HFC systems (although R717 would not be used in centrifugal systems). It is generally accepted that due to the necessity for careful design of R717 systems, the lifetime is much greater (one and a half to two times) than that of conventional systems. The excellent thermo-physical properties of R717 enable very high efficiency systems. Special technician training is necessary.

CO_2 systems show the same efficiency as HFC systems only in moderate climate (which lowers the penetration rate) but feature higher investment cost of >30%. However, again, this is deemed to be highly sensitive to the capacity of the chiller and the size of the production output.

Water – R718. This refrigerant has been trialled in the past but has recently been introduced into large centrifugal chillers only by one manufacturer. Due to its thermo-physical properties, application in many other types of systems (such as below 0°C) is impractical. There are no onerous safety related issues with this technology. The product cost might be 20% higher compared to conventional centrifugal chillers because of materials and components associated with different system architecture and parts. The operating costs are not assumed to be higher, because the efficiency should be at least equal[115]. However specialist training would be required.

Heat pumps

Heat pumps with R290 or R1270 had been used already in the 1990s and 2000s when CFCs were banned (R502). The majority of production was stopped due to the introduction of the Pressure Equipment Directive (PED) which imposed addition certification of the types of compressors normally used which would have incurred additional cost implications for manufacturers. As a result, the use of HFC blends R407C, R404A and R410A took over. Today heat pumps with hydrocarbons (R290, R600a) and CO_2 are available for capacities <20 kW. The refrigerants HFC-1234yf or HFC-32 could also be used.

---

[114] E.g., Pearson, A, 2008, Ammonia's Future, ASHRAE Journal, February 2008

[115] Very recently, Japanese electric power companies, Kobe Steel, Johnson Controls and DTI have developed a commercially competitive chiller with water as refrigerant which is expected to be introduced to the market in about 3 years by Kobelco and Johnson Controls. The chiller is at least as energy efficient as the very best HFC chillers and by 10 to 20% more energy efficient than typical existing installations. Demonstration of the technology will be established shortly.

Hydrocarbons are energetically superior to HFC or unsaturated HFC refrigerants, thus saving energy cost. For the same efficiency rating the products cost marginally more (+6% for R290 or R600a) because of additional cost for ventilated enclosure and safe electrics.

Systems with CO_2 are assumed to cause higher investment cost per unit by 12% because of more material weight and to compensate for poor performance in high ambient temperature (although the vast majority of heat pumps is used in moderate climatic zones of Europe). Unsaturated HFCs are assumed to cause higher product costs because the material (refrigerant, compressor, heat exchangers) and the safety features cost about 6% more (like HC systems) than comparable systems running on R410A.

Individual abatement cost of alternative options

Detailed data on costs, refrigerant consumption and (for Europe) emissions for abatement options and HFC reference systems are presented in the annex, in the Global DIS for A2/A5 in annex IV, and in EU sector sheets in annex V for Europe where reference for the abatement options is the HFC system under the F-gas Regulation (more service cost, less demand/emissions). For each individual abatement option the cost difference to the sector-typical HFC reference system is quantified and put in relation to the avoided HFC quantity of this system. The result of the calculation is the specific annual abatement cost in €/t CO_2 eq of an alternative option, as measure of its cost effectiveness.

Because of high complexity, the calculations of abatement costs for A2 and A5 countries, and for the EU are not repeated here. The calculations carried out for A2 and A5 countries are based on the global scenarios for HFC consumption and abatement options as outlined in the DIS (annex IV). Calculations for the EU are based on data specified in EU sector sheets 10 – 16 (annex V). The values are broadly scattered. They range from negative values in most cases where direct R290 is an option to high costs >€100 in some cases of R744 and R1234yf application.

5.5 Market potential (penetration) of abatement options

General remark on the current predominance of HCFCs and HFCs over non-fluorinated refrigerants in stationary air conditioning

Whilst the abatement cost assessment indicates that HC and ammonia chillers offer significant abatement advantages, as well as HC room air conditioners, they are not in widespread use either in A2 or A5 regions. It is not the objective to address the explanation for this in any depth within this study, but the main reasons can be summarised. For ammonia chillers, there is a considerably higher initial cost, which businesses rarely opt to pay for despite them normally being well aware of the long-term advantages and in addition, operators may be concerned with the “unknown” complications and potential safety hazards associated with the use of ammonia. (Whilst the hazards are real, the risks are typically negligible as evidenced by the reliable historical data on incidents and the broad understanding of correct handling of this refrigerant[116].) With regards to HCs, the latter is also generally the case where contractors and (to some extent) users prefer to avoid the additional complications associated with handling safety, whether actual or perceived. As with all cases, perhaps the most significant reason is the established mindset of using HFC

116 E.g., Lindborg A, 2010, Probability in ammonia refrigeration risk assessment, Proc. 2nd IIR Workshop on Refrigerant Charge Reduction, Stockholm, Sweden.

and HCFC technology throughout the majority of users. For the other alternative technical options, both those which are cost-neutral and those with a negative cost-effectiveness, further efforts would be required to encourage their uptake within the market. This could include financial and technical support for manufacturers/producers, education and training for contractors and installers (with distinct short-term gains) and further incentives to end-users, that provide partial reward but also impose the possibility of penalties for using the higher-GWP options.

It should also be noted that, whilst certain abatement options appear to be desirable for a particular sector, they often cannot be assumed to be as uniformly applicable as is the case for certain HFCs and HCFCs. There will nearly always be certain situations (sub-types of systems, installation locations, etc) that will not favour a particular abatement solution, for safety, cost or efficiency reasons, and in these circumstances the use of that abatement option could result in much less favourable cost implications. However, since these situation are seen as exceptions, the costs are considered to be implicit within the overall cost impact for the sector(s).

Carbon dioxide is used in domestic hot-water heat pumps, but not used in room air conditioners at present, mainly due to the perception that efficiency would be low/cost would be high. A very small number of companies are producing a limited number of larger air conditioning systems with R744, including multi-split, ducted and chillers. However, various studies have shown that the efficiency for both air conditioners and (small) chillers comparable to the present state-of-the art can be achievable particularly in temperate climates[117]. Where higher efficiencies are achieved, there is normally a cost implication as a result of additional system components and greater mass of materials. One of the main reasons cited for the higher cost is the low production numbers and most enterprises contacted stated that a large portion of the cost burden would be shed were the economies of scale realised. Various safety standards include requirements for R744; in practical terms, charge sizes are not prohibitive although component designs necessary to meet pressure strength test requirements can contribute to greater material costs. Regardless of the type of system, special technician training is necessary.

---

[117] Jakobsen A, Skiple T, Nekså P, Wachenfeldt B, Skaugen G, 2006, Experimental evaluation of a reversible CO_2 residential air conditioning system at cooling conditions. 7th IIR-Gustav Lorentzen Conference on Natural Working Fluids (GL2006). Paris: International Institute of Refrigeration.
Jakobsen, A, Skaugen, G, Skiple, T, Nekså, P, Andresen, T, 2004, Development and evaluation of a reversible CO_2 residential air conditioning system compared to a state-of-the art R410A unit. Proc 6th Gustav Lorentzen Conference on Natural Working Fluids, Glasgow.
Hafner A, Nekså P, Stene J, 2009, Reversible air-conditioners and heat pumps using carbon dioxide (CO_2, R744) as working fluid . XIII European Congress : the Latest Technologies in Refrigeration and Air Conditioning : all session papers. UNEP; IIR; ATF.
Rekstad H, Skiple T, Skaugen G, Nekså P, 2008, Liquid chiller using carbon dioxide. 8th IIR Gustav Lorentzen Conference on Natural Working Fluids. Paris: IIR.
Jakobsen A, Skiple T, Nekså P, Wachenfeldt B, Skaugen G (2007). Development of a reversible CO_2 residential air-conditioning system. . Proceedings : 22nd International Congress of Refrigeration : Refrigeration creates the future. International Institute of Refrigeration.
Jae Seung Lee, Mo Se Kim, Min Soo Kim, Experimental study on the improvement of CO_2 air conditioning system performance using an ejector, doi:10.1016/j.ijrefrig.2010.07.025
Masakazu Okamoto, Ikuhiro Iwata, Takahiro Ozaki, Tetsuya Okamoto, Katsumi Sakitani, 2010, Development of Residential Multi-split Air-conditioning System (with CO2), Proc. International Symposium on Next-generation Air Conditioning and Refrigeration Technology, Tokyo, Japan
S. Elbel, J.A. Manzione, S.J. Collier, P. Hrnjak, 2010, Compact, lightweight unitary-type air-conditioner using transcritical R744 designed for energy efficient operation in hot climates, Proc 9th IIR Gustav Lorentzen Conference, Sydney, Australia.

Most unsaturated HFCs are a new category of refrigerant, currently with little experimental work available in the public domain and negligible field experience, rendering it difficult to make robust statements about its applicability. Discussions with stakeholders yielded disparate views on its applicability.

Most unsaturated HFCs under discussion are flammable and international standards exist to handle this; charge size limits correspond to about 6 times that for HCs (or 3 times if density differences are accounted for) and therefore they permit the use of HFC-1234yf and others in a large proportion of applications, including room air conditioners, multi-split systems, ducted systems, chillers and heat pumps. The flammability risk is less than that for HCs.

However, because of the thermo-physical properties of HFC-1234yf, the efficiency in conventional systems is likely to be poor and in order to offset these effects, considerably greater material are required, as indicated in several recent studies[118]. Both the greater cost of materials and the high anticipated price of the refrigerant itself (as reported by producers) imply price related market restrictions for some products. It is anticipated that special technician training is necessary.

Market penetration by sub sectors

There is no one specific abatement option that consistently provides the most benefits across the entire sector, nor is there one specific type of system within the sector that always provides the best cost-effectiveness. All penetration rates, estimated in the following section for individual abatement technologies refer to the year 2030.

Detailed cost information and the penetration rates for 2015 and 2020 are contained in the DIS. Please refer to annex IV.

Factory sealed including moveables

It should initially be noted that the energy assumptions for the abatement technologies considered in this section are in line with the draft COMMISSION REGULATION implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans.

Three Abatement Options are considered: R290 / R1270, R744 and R1234yf. The choice of these is based on the 2010 RTOC report and the Decision XXI/9 TEAP report.

R290 / R1270 is limited to 60%, although market data (BSRIA, 2008, 2010) and discussions with appliance associations indicate a much higher figure. It is considered that certain regions have or could impose standards that prohibit[119] its use in the majority of situations.

R744 is limited to 20% since in many cases where factory-sealed air conditioners are used, the climate is warm and therefore additional materials would be required to maintain the

[118] Akira Fujitaka, Tsutomu Shimizu, Shigehiro Sato, Yoshikazu Kawabe, 2010, Application of Low Global Warming Potential Refrigerants for Room Air Conditioner, Proc. International Symposium on Next-generation Air Conditioning and Refrigeration Technology, Tokyo, Japan
Hideki Hara, Masao Oono, Ikuhiro Iwata, 2010, Experimental Study of Low GWP Refrigerants for Room Air-conditioners, Proc. International Symposium on Next-generation Air Conditioning and Refrigeration Technology, Tokyo, Japan
Takashi Okazaki, Hideaki Maeyama, Makoto Saito, Takashi Yamamoto, 2010, Performance and Reliability Evaluation of a Room Air Conditioner with Low GWP Refrigerant, Proc. International Symposium on Next-generation Air Conditioning and Refrigeration Technology, Tokyo, Japan

[119] It should be noted that in most cases, such standards are voluntary and non-mandatory and are ultimately and indication of “good industry practice”.

necessary high efficiency, or minimum efficiency could not be achieved within such climates if the cost were maintained within the current acceptable boundaries.

R1234yf could reach applicability to 70% of situations. This limit is partly due to safety restrictions and partly due to the additional cost implications associated with the larger components necessary to achieve the efficiency requirements and particularly the refrigerant cost.

Single split

It should initially be noted that the energy assumptions for the abatement technologies considered in this section as alternatives to common HFC based single split systems are in line with the draft COMMISSION REGULATION implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans.

Three Abatement Options are considered: R290 / R1270, R744 and R1234yf. The choice of these is based on the 2010 RTOC report and the Decision XXI/9 TEAP report.

R290 / R1270 is limited to 50% in A2 countries and 70% in A5 countries, on account of the different sizes of systems (BSRIA, 2008, 2010). The majority (>60%) of split systems are below 5 kW (equivalent to less than 500 g of refrigerant charge); in Europe the ratio is greater than this. Approximately 80% of split systems would require less than 1 kg of R290/R1270 and further research and development activities on charge size reduction would provide much assistance[120]. (For details see remark on the replacement potential of hydrocarbon refrigerants in split room air conditioners in annex V, following the Data Input Sheet – Stationary air conditioning – single split type).

R744 is limited to 30% in A2 countries and 20% in A5 countries, since in the latter regions the climate is warm and therefore additional materials would be required to maintain the necessary high efficiency, or minimum efficiency could not be achieved within such climates if the cost were maintained within the current acceptable boundaries.

R1234yf would also be limited to 60% in A2 countries and 40% in A5 countries, to a small extent due to safety restrictions but mainly due to the hindrance caused by the additional cost implications associated with the refrigerant, larger components necessary to achieve the efficiency requirements and the servicing costs associated with the cost of refrigerant.

Multi split and ducted systems

Four Abatement Options are considered: R744, R1234yf, R290 / R1270 + liquid secondary and R290 / R1270 + evaporating secondary. It is noted that for multi-split and ducted systems two other Abatement Options could have been considered R717 + secondary and R717 + evaporating secondary – but these have been left out for the time being because the additional cost for using R717 in smaller systems is considered to yield a very small market share.

---

[120] As shown in the special remark in annex V, following the DIS on single split stationary air conditioning, theoretically in Europe 80% of unducted split systems could be used with HCs, however we assume 5% of HFCs is used in floor mounted systems, which reduces the replacement to 75%. In addition, there are ducted splits, none of which can be used with HCs (conservative). This leaves 60% of the HFC mass to be replaced. However, due to the number of situations that have comparably higher heat loads, we reduce this value by 10% to 50% of HFC mass.

R744 is limited to 30%/35% (multi-split/ducted) in A2 countries and 20%/10% (multi-split/ducted) in A5 countries, since in the latter regions the climate is warm and therefore additional materials would be required to maintain the necessary high efficiency, or minimum efficiency could not be achieved within such climates if the cost were maintained within the current acceptable boundaries.

R1234yf would apply to 70% of cases for both categories in both A2 and A5 countries, to some extent due to safety restrictions but mainly due to the hindrance caused by the additional cost implications associated with larger components necessary to achieve the efficiency requirements and the servicing costs associated with the cost of refrigerant.

R290 / R1270 + secondary would apply to 70% (multi-split) and 80% (ducted) of cases in both A2 and A5 countries, partly due to difficulties in positioning the outdoor units and partly due to higher energy consumption or higher cost associated with a more efficient design to match that of the conventional direct expansion multi-split system.

R290 / R1270 + evaporating secondary in multi-split would apply to 20% of cases in A2 countries and 10% in A5 countries. For ducted systems the figures would be somewhat higher, with 30% and 20%, respectively. This is partly due to difficulties in positioning the outdoor units and partly due to higher energy consumption, or higher cost associated with a more efficient design to match that of the conventional direct expansion multi-split system. For A5 countries there is also a further hindrance due to possible complications of high pressure piping and leak control that would render it difficult to use.

Large and small displacement chillers, centrifugal chillers

Four Abatement Options are considered for the two categories: R290 / R1270, R717, R744, and R1234yf. For large chillers, R718 (water) is also considered.

Note that sorption chillers are only cost- and environmentally-effective when waste heat or other heat sources are available, and due to cost savings under these conditions, it is assumed that this choice is BAU and therefore not included as an AO. The choice of these is based on the 2010 RTOC report and the Decision XXI/9 TEAP report.

R290 / R1270 is limited to 40% in A2 countries and 30% in A5 countries for large, and to 80% in A2 countries and 70% in A5 countries for small chillers, on account of the practical safety restrictions for appropriate positioning of chillers.

R717 is limited to 60% in both A2 and A5 countries for large, and 30% in both A2 and A5 countries for small chillers mainly on account of the practical safety restrictions for appropriate positioning of chillers.

R744 is limited to 20% in both A2 and A5 countries for large, and to 30% in A2 countries and 25% in A5 countries for small chillers, since in the latter regions the climate is warmer and therefore additional materials would be required to maintain the necessary high efficiency, or minimum efficiency could not be achieved within such climates if the cost were maintained within the current acceptable boundaries.

R1234yf would be limited to 60% in A2 countries and 40% in A5 countries for large chillers, and to 80% in A2 countries and 70% in A5 countries for small chillers, to a small extent due to practical safety restrictions but mainly due to the hindrance caused by the additional cost implications associated with larger components necessary to achieve the efficiency requirements and the servicing costs associated with the cost of refrigerant.

R718 is nominally limited to 25% in both A2 and A5 countries for large chillers only, partly due to anticipated cost implications, but also due to absence of sufficient information on other implications.

For centrifugal chillers, there is the possibility to use HCs (R290, R1270 and also R601 [pentane] and R601a [iso-pentane] have been proposed), R718 (water) and unsaturated HFCs such as R1234yf and R1234ze (of which products already exist). For HCs the extent of use would be limited to 20% (A2 and A5) because of the rather high refrigerant charges. For R718 it s estimated that this could cover some 30% (both A2 and A5) although it could be considerably greater as the technology further evolves. R1234yf, R1234ze, etc., could extend to 80% (A2) and 40% (A5). Another option is to simply employ a conventional (positive displacement) chiller using any of the abatement options describe above.

Penetration mix

Based on the penetration rates of the individual abatement options the sector experts in the project team established for the year 2030 the most effective mix of alternative technical solutions which complement each other ("penetration mix"), prioritizing cost-effective solutions in case of equal reduction potential. The 2030 penetration mix is shown for each sub sector in the following table for A2 and A5 countries. The EU has the same penetration mix as the A2 countries.

A2 - Penetration mix of abatement options in stationary air conditioning in 2030							
Alternative technical solution	R290 direct	R290 liqu secondary	R290 evap secondary	CO_2 trans-critical	R1234yf	NH_3	R718
Factory sealed	40			20	40		
Single split	40			15	45		
Multi-split		70	0	30	0		
Ducted (rooftop)		65	0	35	0		
Small chillers	50			20	10	20	
Large chillers	15			0	0	60	25
Centrifugal chillers	20				50		30
Heat Pumps	60			20	20		
A5 - Penetration mix of abatement options in stationary air conditioning in 2030							
Alternative technical solution	R290 direct	R290 liqu secondary	R290 evap secondary	CO_2 trans-critical	R1234yf	NH_3	R718
Factory sealed	40			20	40		
Single split	50			20	30		
Multi-split		70	0	20	10		
Ducted (rooftop)		80	10	10	0		
Small chillers	70			0	0	30	
Large chillers	30			10	0	60	
Centrifugal chillers	20				50		30
Heat Pumps	60			20	20		

5.6 Sector abatement cost and reduction potential in 2030

Corresponding to the percentage of the individual abatement options in the 2030 penetration mix, the individual abatement cost are combined to sector abatement cost, in €/t CO_2 eq.

Global data

The BAU trend of the HFC consumption 2010-2030 has been assessed previously. The reduction of the HFC consumption as a result of the application of the optimum set of abatement options can be estimated for the sector, for the year 2030[121].

Sector abatement cost and consumption reduction potential for the three sub sectors of commercial refrigeration for 2030 are shown in the following tables, for A2 and A5 countries.

A2– consumption abatement vs. BAU in stationary air conditioning 2030									
Sub sectors		factory sealed	single split	multi split	ducted rooftop	small chillers	large chillers	centr. chillers	heat pumps
abatement cost	€/tCO_2eq	15.8	16.7	46.3	47.6	22.9	-42.0	16.2	64.2
reduction	ktCO_2eq	13,200	199,400	149,200	50,500	13,800	64,400	9,300	18,000
A5– consumption abatement vs. BAU in stationary air conditioning 2030									
Sub sectors		factory sealed	single split	multi split	ducted rooftop	small chillers	large chillers	centr. chillers	heat pumps
abatement cost	€/tCO_2eq	7.3	9.3	34.4	28.1	-2	-47.9	11.7	45.8
reduction	ktCO_2eq	15,300	657,900	648,200	26,500	18,300	104,700	18,500	23,400

EU data

The estimation of abatement cost and reduction potential for the EU follows the same principle as the calculation of the global values. In addition to the demand of HFCs, for the EU the emissions of HFCs (from use and from disposal) are of relevance. Emissions and demand in the EU-27 are estimated in the WM scenario of the model AnaFgas.

EU-27 – demand abatement vs. WM scenario in stationary air conditioning 2030								
Sub sectors		factory sealed	single split	multi split	ducted rooftop	chillers	Centri-fugal ch.	heat pumps
abatement cost	€/tCO_2eq	4.4	10.8	7.1	3.1	2.2	5.5	74.7
reduction	ktCO_2eq	5,369	45,428	6,426	1,489	6,851	460	6,147*
EU-27 – emissions abatement vs. WM scenario in stationary air conditioning 2030								
Sub sectors		factory sealed*	single split*	multi split	ducted rooftop	chillers	Centri-fugal ch.	heat pumps
abatement cost	€/tCO_2eq	8.9	19.0	13.2	8,2	5.9	11.1	130.2
reduction	ktCO_2eq	2,781	22,970	2,827	573	2,512	82	2,282*

* In Europe, R-32 can increase the penetration mix of alternative technologies in the years 2015-2019 by its indivudal penetration rate. In 2020, the more effective alternatives add up to 100%, without R-32. As a result of the 15-year-lifetime of heat pumps, in 2030 there are still heat pumps with R-32 in the stock, and increase the emission reduction of the mix of R-290, R-1234yf, and R-744 by 113 ktCO_2eq; without R-32 the emission reduction potential would not be 2,282 but to 2,169 ktCO_2eq only. The increase in demand reduction potential from R-32 is lower, with 25 ktCO_2eq in 2030.

[121] While quantity for first fill of equipment becomes zero in the year of introduction of the alternative option and can easily be quantified, amount for refill decreases only over a number of years as old equipment retires from the stock.

The main difference between the global and the EU approach results from the fact that the sector-typical reference unit is subject to the F-gas Regulation. This implies for the reference unit higher annual service expenses from application of Art 3 and/or 4, and lower emissions from regular maintenance and recovery by certified personnel.

VI.6 Mobile air conditioning of road vehicles

In global perspective HFC-134a is the general refrigerant for mobile air conditioning of passenger cars today and in the future. This fully applies to A5 countries. In A2 countries the use of HFC-134a will be limited in the near future because the 2006 MAC Directive includes for Europe a complete phase-out of HFC-134a in new passenger cars from 2017 onwards. As the EU MAC Directive is an already existing political measure, the European phase-out of HFC-134a is part of the global business as usual scenario. Against this background, in this section replacement options by low GWP refrigerants will be discussed primarily for A5 countries and non-European A2 countries. For Europe, where the MAC Directive is integrated in the WM scenario analysis of additional alternative technical solutions to conventional HFC technology is no longer needed.

As the provisions of the current MAC Directive apply to passenger cars only but not to other motor vehicles like buses or trucks, analyses of key abatement options to bus and truck MAC systems and assessment of their market penetration, reduction potential and abatement cost will be carried out in the same way as in the other sections of this annex VI. This means that the alternative technologies are the same for the EU as for the other A2 countries.

Mobile air conditioning is not limited to road vehicles even though road vehicles are the most important application by far, accounting for more than 95% of the sector consumption and emissions. Further sub sectors are ship and rail vehicle air conditioning. It is because of missing global data for A2 and A5 countries that this section excludes ships and rail vehicles from consideration[122]. For EU-27, data on ship and rail vehicle air conditioning are available. These two sub sectors will be discussed separately in the next section (VI.7) with regard to Europe only.

6.1 General description

Mobile air conditioning of road vehicles include (ranked in order of HFC usage): passenger cars, light and heavy trucks, and buses. Numbers of new units manufactured globally in 2007 were 56.3, 12.8, 2.7 and 0.4 million units respectively[123]. The shares of passenger cars and trucks vary from source to source depending on the definition used; nonetheless the total number is always similar, i.e. approximately 70 million passenger cars and trucks together, independent of the source. An estimated 75% to 85% of all new road vehicles worldwide are equipped with an air conditioning system, with the highest quota in passenger cars.

Compressors of road vehicle air conditioning systems are usually belt driven by the vehicle's engine. For most passenger cars, light and heavy trucks, single evaporator systems are used. Some luxury car air conditioning systems as well as bus air conditioning systems operate with two or more evaporators. The only HFC refrigerant used in the road vehicle air conditioning sector is HFC-134a. Passenger cars and light trucks are typically charged with 400 to 800 g, heavy trucks with 0.7 to 1.5 kg, and systems with two evaporators up to 1.8 kg. Refrigerant charges for buses range from 6 to 14 kg – for double-decker and articulated buses also up to 18 kg and more.

[122] Even the 2010 UNEP RTOC assessment provides only poor information on these two sub sectors, primarily because there is no reporting on the maritime sector. This study could not fill the data gap by own research.

[123] International Organization of Motor Vehicle Manufacturers correspondents survey.

The populations, in 2006, are estimated at 600 to 700 million passenger cars, 200 to 300 million light trucks (depending on the definition used), 27 million heavy trucks (based on annual production), and 3.2 million buses.

6.2 Global business as usual trend of HFC consumption until 2030

In 2003, the refrigerant bank was estimated at 375 kilo tonnes and was distributed as follows: 81% HFC (mainly HFC-134a), 4% HCFC mainly in bus air-conditioning systems and 15% CFCs in old systems[124]. UNEP 2006 estimates the total consumption in 2003 for all vehicle air conditioning systems and all types of refrigerants to be 96,000 metric tonnes.

Leakage rates range from 10 to 30%. Average leakage rates are stated in the global data input sheets (annex IV) for each type of equipment and each region (A2 and A5 countries) separately. Annual consumption of all HFC-134a (new systems plus service of existing systems) for 2010 are estimated in the following table:

Table VI-14: Global consumption of refrigerants for mobile air conditioning of road vehicles by vehicle types in 2006 (metric tonnes)

	A2	A5	Total
Passenger cars	54,480 t	16,800 t	71,280 t
Light commercial vehicles	20,800 t	8,100 t	28,900 t
Heavy commercial vehicles	2,848 t	714 t	3,562 t
Buses	2,360 t	5,488 t	7,848 t
Sum	**80,488 t**	**31,102 t**	**111,590 t**

Driven by current European F-gas legislation (MAC Directive) it is expected that there will be a shift away from the high-GWP refrigerant (HFC-134a) towards lower GWP refrigerants (most likely HFC-1234yf) for passenger car air conditioning and subsequently also for light commercial vehicles as they often are built on the same car model.

Table VI-15: Market shares of unsaturated HFCs in BAU (Mobile AC road vehicles)

	2010		**2015**		**2020**		**2030**	
	A2	A5	A2	A5	A2	A5	A2	A5
Passenger cars	0 %	0 %	2 %	0 %	10 %	2 %	30 %	5 %
Light Comm. Vehicles	0 %	0 %	2 %	0 %	10 %	2 %	30 %	5 %
Heavy Comm. Vehicles	no estimate available							
Buses	0 %	0 %	2 %	0 %	8.5 %	2 %	18 %	7 %

Some exports from European manufacturers to A5 countries are expected to run also on R1234yf in the respective country until the first service, when a change to HFC-134a will be most likely. Current development of MAC systems suggests that the same equipment can run with R134a as well as with R1234yf – without any oil or component exchange. It is therefore foreseen by some car manufacturers that service of original R1234yf-systems will be done with HFC-134a because of the price difference between the two refrigerants.

A driving force for the implementation of R744 in vehicle air conditioning might be the growing share of electrical road vehicles. Their waste heat will be too low for heating the cabin and heat pump systems will therefore be considered. Here R744 offers better potential

[124] UNEP 2006.

and better energy efficiency than HFC-1234yf. However in hot climates, R744 use will result in higher energy consumption in air conditioning mode.

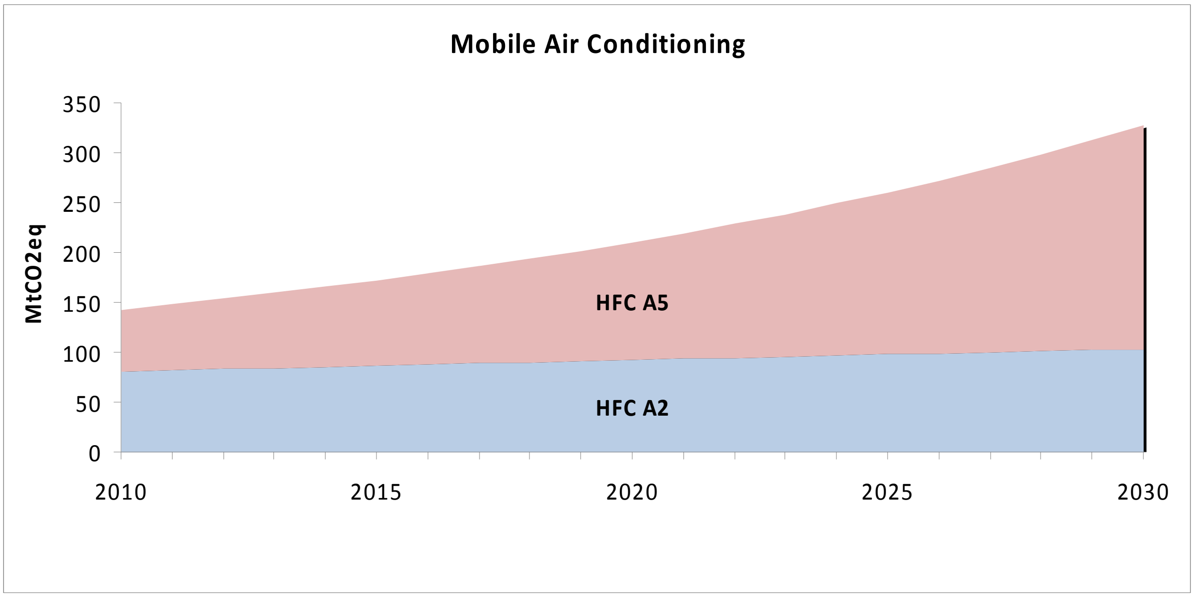

Figure VI-11: Global BAU consumption of HFCs (R-134a) for mobile air conditioning of road vehicles in A2/A5. Strong growth is expected in A5 countries.

4.3 HFC demand and emissions in EU-27 until 2050 (WM scenario)

As a result of the MAC directive demand and emissions of HFC-134a will significanly decrease. Sector emissions will drop until 2030 from currently 35 kt CO_2 eq to 6.5 kt CO_2 eq; sector demand for first fill and re-fill will decrease until 2030 from currently 39 kt CO_2 eq to 10 kt CO_2 eq. After 2030 the remaining emissions will arise from truck and bus systems; the remaining demand after 2030 includes not only trucks and buses but also first fill of systems of passenger cars which are exported to third countries where high GWP HFCs are not assumed to be banned.

After introduction of HFC-134a in new motor vehicles in 1991-1995, the equipment with air conditioners has been constantly increasing. In 2010, more than 90% of the passenger cars in the European stock were equipped with a MAC system, saturation will be not below 95%. The MAC quota of heavy trucks is in the same range, the quota of city buses and light trucks is lower, while coaches are equipped 100% with a MAC system.

Table VI-16: EU-27. Vehicle stock, refrigerant banks, demand and emissions of HFC-134a in air conditioning systems of motor vehicles in 2010, in metric kilo tonnes (source AnaFgas)

	stock units (million)	bank (kt)	demand (kt)	emissions (kt)
Passenger cars	208.3	140.0	23.7	19.7
Buses	0.6	7.0	1.3	1.2
Trucks	12.4	11.5	2.5	1.8
Total	**221.3**	**158.5**	**27.5**	**22.7**

In the model AnaFgas the 2010 bank of HFC-134a refrigerants is estimated at 140,000 (metric) tons in passenger cars, 7,000 t in buses, and 11,500 t in trucks. N1 trucks (called light commercial vehicles or vans) account for 60% of the refrigerant quantity in truck systems.

Leakage rates of passenger cars and light trucks are estimated at 10%, leakage rates of N2 and N3 trucks and of buses are higher with 15%. While the emissions of HFC-134a from passenger cars are assumed to drop from currently 30 kt CO_2 eq to 0.1 kt CO_2 eq until 2030 due to the MAC Directive (if R1234yf is used instead), emissions from trucks and buses, to which the current MAC Directive does not apply, will grow from 4.3 kt CO_2 eq (2010) to 6.7 kt CO_2 eq (after 2030).

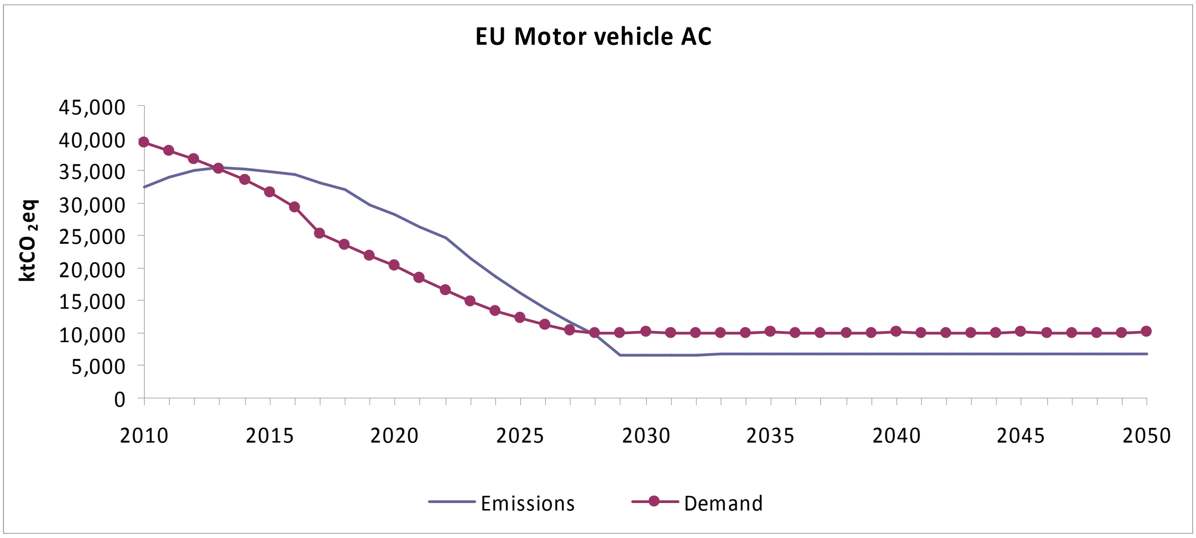

Figure VI-12: HFC-134a demand and emissions from the sector of mobile air conditioning of motor vehicles (passenger cars, trucks, buses) under the WM scenario. The strong reduction trend until 2030 results from the HFC-134a phase-out under the MAC Directive. After 2030 the remaining emissions and demand is caused by truck and bus systems; the demand after 2030 includes not only trucks and buses but also first fill for passenger cars which are exported to third countries where high GWP HFCs are not assumed to be banned.

The number of air conditioned passenger cars is forecast to increase until 2050 by 75%. In constrast, the growth rates for air conditioned trucks and buses in Europe are not considered high. Growth of N1 trucks is assumed to follow the GDP, until 2030. For the period 2030 to 2050 the stock is assumed to be constant. Stocks of N2 trucks and of heavy trucks of type N3 are assumed to be constant from the year 2008 onwards. No-growth assumption also applies to buses (see annex III).

6.4 Key Abatement Options for road vehicle air conditioning

The HFC-free abatement options for road vehicle air conditioning are:

R744 (Carbon dioxide - CO_2) has been shown to be comparable to HFC-134a with respect to cooling performance and fuel use in road vehicle air conditioning systems. Currently, still technical (reliability, leakage, noise) and commercial (additional costs) hurdles exist that will require resolution prior to the commercial implementation of R744 as a refrigerant for car air conditioning.[125]

The ability to use CO_2 efficiently in a heat pump cycle for high heating temperatures is an advantage for high efficiency (Diesel) engines and even more so for electric cars where available waste heat for heating of the passenger compartment is limited.

[125] UNEP 2010: ibid.

R744 road vehicle air conditioning systems are expected to initially cost 20% (buses) to 60% (passenger cars) more than comparable HFC-134a systems. This price premium is expected to disappear over a timeframe of 20 years if series production can be achieved for R744 on large scale.

R1234yf – unsaturated HFC might be used in road vehicle air conditioning systems. The automotive industry is working on solutions to cope with the increased risk of flammability due to the unsaturated carbon bond. Energy efficiency of R1234yf is expected to be on the same level as current HFC-134a systems. The refrigerant is presently more expensive than HFC-134a – by a factor of 10 to 15. MAC systems currently developed for R1234yf are expected to be able to run on HFC-134a without technical changes.

Hydrocarbons – an HC-system with a liquid secondary loop system could provide the possibility of using HCs safely under current legislation. Such systems can be operated in passenger cars and trucks with equal energy efficiency as HFC-134a systems if the secondary loop system is designed and operated properly. Indirect HC systems are expected to use 5 to 10% more energy in bus air conditioners due to longer pipes. Unit costs of such systems are expected to be between 20% (buses) and 30% (passenger cars and trucks) higher due to additional heat exchangers and pumps needed.

In a DX-system, due to the thermophysical properties of HCs only half the refrigerant amount would have to be used compared to today's HFC-134a. The resulting charge would be between 250 and 500 gram. Applying safety features developed for the use of R744 such as explosive fuses triggered by the air bag sensor in case of an accident, in combination with double wall evaporators, the use of HCs in DX systems should be feasible. From an energetic point of view this option would be the best. Energy consumption is expected to be 10 to 15% lower than for an equivalent HFC-134a system. HCs are used as a service fluid in some parts of Australia and the USA. No accidents have been reported even though the number of serviced AC systems in the 100.000s and no additional safety features are applied.

Individual abatement cost of alternative options

Detailed data on costs, refrigerant consumption and (for Europe) emissions for abatement options and HFC reference systems are presented in the Global DIS for A2/A5 in annex IV, and in EU sector sheets in annex V. For Europe, abatement technologies are analysed only for trucks and buses because the replacement of HFC-134a in MACs of passenger cars is already included in the WM scenario. For the three individual abatement options, unsaturated HFC-1234yf, R744, and indirect HC, the cost difference to the sector-typical HFC-134a system is quantified and put in relation to the avoided HFC quantity of this system. The result of the calculation is the specific annual abatement cost in €/t CO_2 eq of an alternative option, as measure of its cost effectiveness.

Because of too high complexity, the calculation of the individual abatement costs for A2 and A5 countries and for Europe are not repeated here. The calculations are carried out in the global model on the base of the DIS, and for Europe in the EU sector sheets 28 and 29. Here, the information might be sufficient that the values are broadly scattered. They range from negative values of -3 €/t CO_2 eq for R744 in passenger cars (A2) to high abatement cost of 48.5 €/t CO_2 eq for R1234yf in buses (Europe).

6.5 Market potential (penetration) of abatement options until 2030

Road vehicle air conditioning is a market segment where only one solution will be accepted on a worldwide basis; this used to be CFC-12 and currently is HFC-134a. The future will show which of the abatement options will have the potential to serve as the worldwide uniform solution for this segment. Apparently car manufacturers prefer a solution where the industry can continue using HFC-134a in those parts of the world where it is not regulated (currently outside EU) but use the new alternative inside the EU. This will favour R1234yf. Its penetration rate for 2030 is estimated at 100% both in A2 and A5.

R744 (CO_2) has a disadvantage in terms of energy in hot climates, but works well in moderate and cold climates. In addition, it can be used with better efficiency in heat pump mode, which makes it the preferred choice for electric vehicles. Depending on the growth in the electric vehicle sector, this could become a driving force for the development of vehicle air conditioning systems. Penetration rate is estimated at 100% (A2) but only 60% in developing countries (A5) by 2030. The 100% penetration rate for A2 countries is based on the assumption that on the annual average in these world regions the energy disadvantage at high ambient temperature is balanced by the advantage at moderate ambient temperature.

R290 (hydrocarbon) is used in direct mode as an uncertified “drop-in” alternative in some countries. It could be used on a broader basis if the legal situation regarding product safety would change. There are millions of vehicles driven by compressed natural gas (CNG) and liquefied petrol gas (LPG). It is difficult to understand why the same vehicle cannot use 300 to 400g HC as refrigerant in the air conditioning system. Refrigerant charges would approximately be half the charge of HFC-134a due to the thermo physical properties of HC-290. Nonetheless, the current legal situation does not allow this abatement option to be used in road vehicle air conditioning systems and is therefore not included in this study. From a technical point of view the penetration rates in 2030 could be 80% (A2) and 40% (A5).

In terms of cost, the changeover to R1234yf would initially increase cost by 10 to 20%, whereas the change to R744 would mean an initial increase by 60 to 70% for the air conditioning system. These cost premiums are expected to fall over time as mass production will be achieved and investments in production and service equipment will be utilized.

A2 - Penetration mix of abatement options in MAC of road vehicles 2030			
Alternative technical solution	R1234yf	R744	HC+ secondary liquid
Passenger cars	0*	100*	0
Buses	100	0	0
A5 - Penetration mix of abatement options in MAC of road vehicles 2030			
A5 2030 - Penetration rate of alternative technical solution			
Alternative technical solution	R1234yf	R744	HC+ secondary liquid
Passenger cars	0	60	40
Buses	35	15	50

* The inclusion of R744 instead of R1234yf in the penetration mix is due to the higher specific abatement cost (€/tCO_2eq) of the R1234yf solution. In the global calculation model the cost effectiveness is the only criterion for inclusion in the mix if the emission reduction potential of two options is equal. The global model does not account for the likely, short-term decision of carmakers to use R1234yf instead of R744 despite of higher cost.

Based on the penetration rates of the three abatement options the sector experts in the project team established for the year 2030 the most effective mix of alternative technical solutions which complement each other (“penetration mix”), prioritizing the more cost effective solutions in case of equal reduction potential. The 2030 penetration mix is shown in the following table for A2 and A5 countries.

6.6 Sector abatement cost and reduction potential of options in 2030

Corresponding to the percentage of the individual abatement options in the 2030 penetration mix, the individual abatement cost are aggregated to sector abatement cost, in €/t CO_2 eq.

The BAU trend of the HFC consumption 2010-2030 has been assessed previously. The reduction of the HFC consumption as a result of the application of the most effective set of abatement options can be estimated for the sector, for the year 2030[126].

Sector abatement cost and calculated sector consumption reduction potential for the sub sectors of air conditioning of road vehicles for 2030 are shown in the following tables, for A2 and A5 countries.

A2 – Consumption abatement vs. BAU in Mobile Air conditioning 2030 (road vehicles)			
Sub sectors		passenger cars	buses
abatement cost	€/tCO_2eq	-3	29
consumption reduction	ktCO_2eq	73,200	2,300
A5 – Consumption abatement vs. BAU in Mobile Air conditioning 2030 (road vehicles)			
Sub sectors		Passenger Cars	buses
abatement cost	€/tCO_2eq	4.2	27.6
consumption reduction	ktCO_2eq	233.700	12,500

EU data

The estimation of abatement cost and reduction potential for the EU follows the same principle as the calculation of the global values. In addition to the demand of HFCs, for the EU the emissions of HFCs (from use and from disposal) are of relevance. Emissions and demand in the EU-27 are estimated in the WM scenario of the model AnaFgas. The abatement options in the EU refer only to trucks and buses because the abatement (phase-out) of HFC-134a in passenger cars is already part of the WM scenario.

EU-27 - Penetration mix of abatement options in MAC of trucks and buses 2030			
Alternative technical solution	R1234yf	R744	HC+ secondary liquid
Trucks excl. passenger cars	100*	0*	0
Buses	100	0	0

* The establishment of the penetration mix for the EU-27 is based on the model AnaFgas. In contrast to the global calculation model, AnaFgas accounts for the likely decision of truck makers to use R-1234yf instead of the more cost effective refrigerant R-744 (see EU sector sheet 29 in annex V).

[126] While the demand for first fill of equipment becomes zero in the year of introduction of the alternative option and can easily be quantified, demand for refill decreases only over a number of years as old equipment retires from the stock. The amount of refill in a year depends on the penetration rates in the preceding years.

EU-27 – Demand abatement vs. WM scenario in mobile air conditioning 2030			
Sub sectors		trucks	buses
abatement cost	€/tCO_2eq	37.2	42.7
demand reduction	ktCO_2eq	4,017	1,694
EU-27 – Emissions abatement vs. WM scenario in mobile air conditioning 2030			
Sub sectors		trucks	buses
abatement cost	€/tCO_2eq	43.9	48.5
emissions reduction	ktCO_2eq	4,170	1,616

VI.7 Mobile air conditioning of ships and rail vehicles in Europe

Introductory note

Mobile air conditioning of vehicles other than motor vehicles is not subject to the EU F-gas Regulation (Articles 3 and 4(1)) or to the MAC Directive. Chapter 8 of the report discusses the policy option to include ships and rail vehicles in an amended Regulation. In this chapter, the question is different: Are there feasible alternative technical choices to abate HFC emissions from and HFC demand for the ship and rail sector?

As mentioned at the beginning of the previous chapter, the ship and rail sub sectors are only analysed for Europe.

7.1 General description of systems

Cargo ships

Standard air conditioning equipment in cargo ships is split systems with direct refrigerant evaporation. In passenger ships indirect systems are installed with circulation of chilled water or cold air.

A condensing unit consisting of compressor and condenser is placed below deck, near to the engine room and the generator. The compressor is open or semi-hermetic (mostly of screw design); the condenser is flooded by sea water so that the liquefaction temperature is kept comparably low (up to maximum 35°C).

The evaporator is placed in the air-conditioning centre on deck, in the living area of the crew. It is connected to the condensing unit by ascending and descending refrigerant lines (liquid and suction) of considerable length, and partly made of flexible hoses. The evaporator in the air conditioning centre directly cools down warm air from the crew's cabins, and the cool air is blown back through the distribution ducts. The evaporating temperature is ca. 0°C so that the air cools down to 15°C. It should be noted that no refrigerant pipes but only air ducts are laid to the cabins.

Typical quantity of refrigerant (generally R134a) in air-conditioning equipment is 150 kg. This is necessary to cool the cabins of a 20-people crew in all climatic zones of the world.

Passenger ships

In vessels with passengers on board like ferries or other passenger ships, the size of air conditioning systems is larger than in pure cargo ships because much more cabins and common rooms need to be air-conditioned. In order to avoid long air ducts or refrigerant lines as required by direct systems, water chillers are installed, saving up to 50% of refrigerant compared to direct expansion. Average refrigerant charge in indirect air conditioning systems on ferries and other passenger vessels is estimated 500 kg of R134a (1,000 kW).

Cruise ships

Cruise liners present a ship type of their own. New built cruise ships have a capacity of more than 2,500 passengers and 1,700 crew members. The refrigeration capacity of the air conditioning system is high, amounting up to 15 MW. It is provided by large water chillers.

For air-conditioning, the refrigerant charge of average sized new cruise liners (80,000 GT) is 6,000-7,000 kg (12 MW), contained in three or four separate refrigeration circuits (one of them serving as spare circuit). Standard refrigerant is R134a.

Other ships such as offshore, research, fire fighting, and search & rescue vessels are treated here in respect to size of air conditioning like cargo ships.

Rail vehicles

In the maritime sector, air conditioning systems are custom made solutions for each individual ship. In the rail sector (rail cars, metro, tram), the number of same size air conditioners is larger, sometimes amounting to 500 identical units; however this number is still small compared with air conditioning of road vehicles. The devices are mostly developed for a particular train type. As a consequence, a multitude of dedicated technical solutions has emerged in spite of minor differences in refrigerating capacity and further boundary conditions.

Generally, the system design depends on the space that is left within the construction of the rail vehicle; the passenger compartment must not be reduced in volume. On this basis, there are roughly four different main types of air conditioning devices: compact roof, compact under-floor, split, and compact central. Most popular in electric rail vehicles (multiple train units, metro-cars, trams) are compact systems inside or on the roof. The space under the floor is chiefly required for electric drive and power supply so that the entire air conditioning system must completely be fitted to the roof of the vehicle. The cooled air flows top-down into the passenger compartment.

The refrigerating capacity for passenger compartments differs by climatic zones but varies within the EU-27 not more than from 20 to 40 kW with few exemptions beyond or under. The refrigerant charges are between 5 and 30 kg, in case of double-decker coaches even 50 kg are possible (for the two decks together). Average size is estimated at 13 kg. The capacity for driver's cabins is lower with 3 to 8 kW, with refrigerant charges of from 1.5 to 4 kg.

7.2 HFC demand and emissions in EU-27 until 2050 (WM scenario)

As already mentioned, mobile air conditioning of ships and rail cars is not subject to the EU F-gas Regulation (Art 3 and 4(1)) or to the MAC Directive. Therefore there is no difference of emissions and demand of HFCs between WOM scenario and WM scenario.

In registers of EU states, there are approx. 9,000 sea-going merchant ships with air-conditioning and - to a smaller extent - provision cooling operational, in 2010. R22 is still mostly used refrigerant; HFCs have been applied first from 2000 onwards. The lifetime of ships averages 30 years. Therefore, the present refrigerant bank in sea going ships consists of HFCs only by less than half. By law, R22 must be replaced in existing ships in the coming years, so that from 2015 onwards only HFCs or other chlorine free refrigerants are allowed to be used. Leakage rates on ships are very high, amounting to >20% (indirect systems) or ca. 40% (direct systems). Ca. 90% of annual refrigerant demand is used for refilling.

The rolling stock of the EU railway-, tram-, and metro operators included 160,000 vehicles in 2010. Approx. 75,000 were equipped with air-conditioners, charged with R134a (75%) or R407C (25%); ozone-depleting refrigerants are no longer in use. Leakage rates of air-conditioning systems of rail vehicles are much lower than those of ships, with 7% per year for the majority of vehicles. Most of the annual refrigerant demand is used for first fill.

Table VI-17: Refrigerants in air conditioning systems of EU registered ships and EU rail vehicles in 2010, metric tonnes

	Units 2010	Bank	Emissions	Demand
Passenger Ships	2,100	650 t 134a 1,090 t R-22	260 t 134a 436 t R-22	344 t 134a 436 t R-22
Cargo Ships	7,500	574 t 134a 605 t R-22	230 t 134a 242 t R-22	286 t 134a 242 t R-22
Rail vehicles	74,000	704 t 134a	51 t 134a	97 t 134a
Total		3,623 t	1,219 t	1,405 t

Source: AnaFgas 2011

The number of ships under flag of EU Member States will not change until 2050. The HFC bank of 2015 (after R22 replacement) will be the same for the coming decades, and so emissions and demand. To date, not a single merchant ship is in service, which uses refrigerants with low or no GWP. This is not assumed to be changed without specific legislation.

The stock of rail vehicles will not change in number of units until 2050, however the share of air conditioned vehicles (passenger compartments) will constantly increase from today's 50% to over 90% in 2050, thus increasing bank, demand and emissions of refrigerants. Without legislation, low GWP alternatives to HFC-134a are not assumed to be introduced.

Projected emissions and demand of HFCs under the EU WM scenario are shown in the following graph for ships and rail vehicles (figure VI-13).

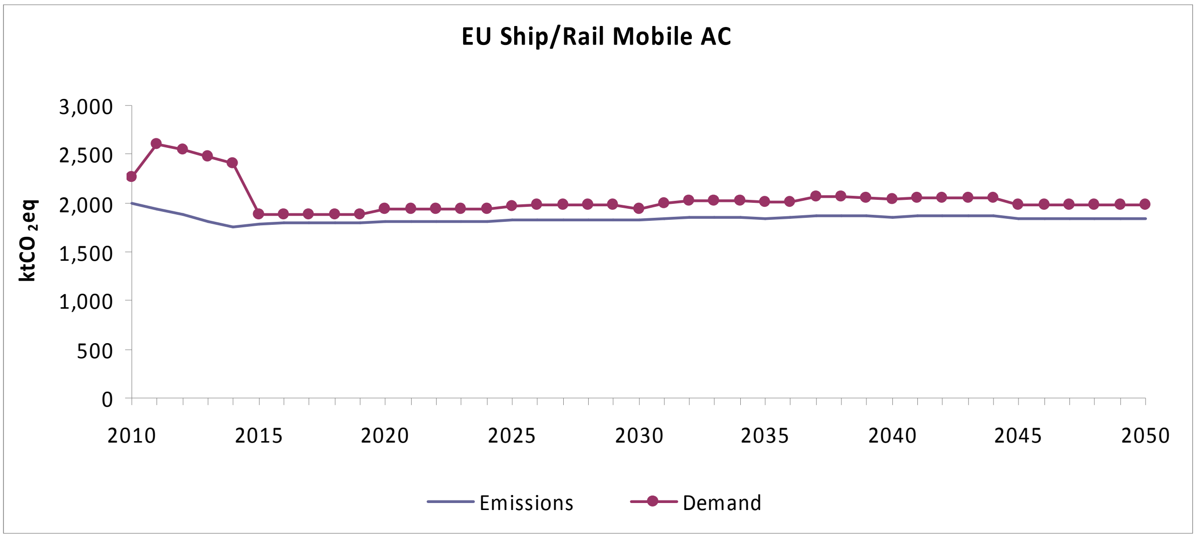

Figure VI-13: HFC demand and emissions of EU ship and rail vehicle air conditioning under WOM/WM scenario. Constancy is assumed until 2050, after R-22 replacement by HFCs 2010-2014. The latter causes a short-term increase/ decrease in demand between 2010 and 2015.

7.3 Key abatement options

So far, use of flammable or toxic refrigerants is not allowed on ships which carry passengers, not even in indirect systems with the primary circuit in a separate room. Therefore not only hydrocarbons but also ammonia and pure unsaturated HFCs like HFC-1234yf cannot serve as alternative technical solutions for non-flammable HFCs. Similar restrictions apply to rail vehicles. As a consequence, amongst low-GWP refrigerants only transcritical CO_2 could be a feasible replacement option. However, all industry experts interviewed for this study reject

CO_2 systems for ship air conditioning because of the poor energy performance in southern marine regions. Non-flammable blends with unsaturated HFCs could become a more realistic alternative to pure HFC-134a if one accepts the still high GWP of ca. 600 (e.g. the blend XP10/DR11).

The situation is different for ships with professional crew only as it is the case on cargo ships and fishing vessels. Here indirect systems with ammonia and secondary brine (air conditioning) or CO_2 (refrigeration of fishing vessels) is possible. The toxicity of ammonia was the main reason why its use was deemed impossible in any ships for a long time. First from 2001, the application was gradually considered controllable, and NH_3 started to be used in large fishing vessels. Meanwhile, classification bodies and authorities have widely ceased their reservation towards NH_3, if exclusively professional personnel are on board, as on both fishing vessels and reefer ships. As stated under "transport refrigeration", for new built fishing vessels, ammonia is of higher importance than HFCs today. To date, not a single cargo ship is equipped with ammonia based air conditioning. Nevertheless, it has already become a realistic option for the nearest future.

Cargo ships

Ammonia with brine. An indirect system based on NH_3 and glycol-brine represents a technically feasible alternative to HFC-134a. Such systems exist on reefer ships for cooling the cargo hold. While energy consumption and energy costs are almost the same (additional energy consumption for the brine pump is balanced by lower energy consumption for the NH_3 compressor), the investment cost of the NH_3 system is considerably higher than that of the HFC system, resulting in additional total cost per year. In addition, the maintenance cost for ammonia systems is higher than for conventional HFC equipment.

EU sector sheet 17 in annex V shows for a standard air conditioning system with 300 kW capacity and 160 kg refrigerant charge (R134a) a comparison of ammonia (indirect) with HFC-134a (direct). The calculated emission abatement cost of €16 / t CO_2 eq is slightly higher than costs of a potential application of Articles 3 and 4 to cargo ship AC (€11). However, the reduction potential for demand or emissions is much higher if ammonia is used because containment and recovery measures can reduce emissions but not stop them.

Blend with unsaturated HFCs. The advantage of non-flammable refrigerants is that the conventional technology of direct expansion can be used. The blend XP10 contains HFC-1234yf mixed with another fluid (presumably HFC-134a) which provides non-flammability at a GWP considerably below that of HFC-134a. To date, only very few data on this blend are available. We can rely only on short-term experience of the blend manufacturer with application in a number of supermarkets (blend is primary refrigerant for MT, with CO_2 cascade for LT). We assume that energy equivalence with HFC-134a can be met with alteration of the equipment at 5% higher investment cost. Under these circumstances the emission abatement cost of €29 /tCO_2eq is somewhat higher compared with the ammonia/brine system. However, the reduction potential of the blend is only 58% of that of the ammonia/brine technology.

Passenger ships including cruise ships

Blend with unsaturated HFCs. As mentioned initially, flammable or/and toxic refrigerants are ruled out from discussion, and the non-flammable carbon dioxide is rejected by the sector experts, for energetic reasons. At the present stage of refrigerant development, the only feasible alternative to conventional R134a systems seems to us to be a blend with unsaturated HFCs. This was discussed as an exceptional, supplementary, case for cargo ships. EU sector sheet 18 in annex V presents a cost-emissions/demand comparison of a conventional average sized air conditioning system (975 kW, 520 kg R134a charge) with the same system operated with the blend XP10 (DR 11). Again, investment costs are estimated 5% higher for the blend systems. While the resulting abatement cost of €35/t CO_2 eq can be considered moderate, the reduction potential is of limited extent because of the GWP 600 of the refrigerant blend.

Rail vehicles

For rail vehicles CO_2 cannot be ruled out from the start as a feasible technical abatement solution. Trains are usually operated in the same climatic regions so that energetic equivalence with HFC systems can be assumed for ca. 60% of the European rail network. This limitation can be accounted for in a maximum 60% penetration rate.

Carbon dioxide (CO_2). Several European manufacturers have already developed prototype CO_2 systems for different types of rail vehicles. On the 2006 International Trade Fair for Transport Technology in Berlin, Innotrans, CO_2 systems were presented for the first time to the public. Some of the displayed prototypes provide a refrigerating capacity of 10 kW, others provide even 16 kW; single systems can be combined to two or three devices per vehicle so that the whole performance range of rail vehicle air-conditioning can be covered.

Experts interviewed for this study expect in the short term both investment costs and operating costs to be significantly higher than conventional HFC systems (average system cost of €25,000), by up to 30 %, if energetic equivalence should be achieved under moderate climate (north of the Alps), at least for the first generation of the serial production.

Since 2006, in Germany a leading supplier of rail air conditioning systems has tested a tram with a prototype CO_2-system of the driver's cabin. Compared to a conventional HFC-134a system the energy consumption of the prototype system is approx. 10 % higher. Further concerns of the system developers are safety reasons, like displacement of atmospheric oxygen in case of leaks.

In the comparative analyses of the CO_2 abatement option in EU sector sheet 19 in annex V, comparably high abatement cost of €400 to €600 per tCO_2eq are calculated. This is not only due to the high additional cost of the equipment but also due to the comparably low emissions from/demand for the conventional system (abatement cost are relative values).

Air cycle. Air is not toxic, not inflammable, and has no direct global warming impact. It is already in use as a refrigerant in air conditioners of rail vehicles as well as in almost all civil air planes. In the German high speed train ICE-3 (introduced in 2000) all 500 individual cars use air cycle systems for air conditioning. Demonstration units with air cycle were also operated in the UK. The British systems were based on the German ICE-3 and were available as an under-floor system for electric trains and as a rooftop system for diesel trains. Due to the single-phase nature (gas without condensation or evaporation) of air cycle systems, the energy consumption in these systems is significantly higher than in vapour compression cycles. Experts estimate the additional energy demand at 20 to 30%. Air cycle systems are lighter than comparable vapour compression systems thus saving energy during the acceleration phase of the train.

One of the interviewed experts stated a limited market potential for air cycle systems in Northern Europe, where high refrigerating capacity is needed only during a few days in the year. Thereby higher energy consumption in the time of high load could be compensated by saving HFC emissions over the whole operating time.

Too many uncertainties about the possible energy performance are the reason why we do not consider this option further in this report.

7.4 Market potential (penetration) of abatement options

The market potential of the discussed alternative solutions until 2030 is estimated as follows. The penetration rates of the blend with unsaturated HFCs for passenger ships (including cruise liners) and cargo ships can increase to 100% of new equipment, by 2030, because the refrigerant blend is not assumed to differ significantly from HFC-134a in technical properties. The 2030 potential for the ammonia-brine system in cargo ships is not estimated 100% but only 90%. There will always be a remainder for which flammable and toxic refrigerants are out of question, even in indirect operation. The penetration rate of CO_2 for rail vehicles is limited to 60%, by 2030.

Based on the penetration rates of the discussed abatement options the project experts established for 2030 the most effective mix of alternative options which are mutually not exclusive ("penetration mix"), prioritizing the more cost-effective solutions in case of equal reduction potential. In two sectors (rail vehicles and passenger ships) there is only one alternative solution so that aggregation is not necessary. The 2030 penetration rates are shown in the following table.

EU-27 - Penetration mix of abatement options in ships and rail vehicles 2030			
Alternative technical solution	NH_3- brine	R744	Blend with unsaturated HFC
Passenger ships			100
Cargo ships	90		10
Rail vehicles		60	

7.5 Abatement cost and reduction potential of alternative options 2030

Corresponding to the percentage of the individual abatement options in the 2030 penetration mix, the individual abatement cost are aggregated to sector abatement cost, in €/t CO_2 eq. The sector abatement cost is calculated for HFC emissions in 2030 and for HFC demand in 2030. The 2010-2050 trends of HFC emissions and demand in the EU-27 has been estimated in the WM/WOM scenario of the model AnaFgas. Abatement cost and calculated emission and demand reduction potential is shown in the following tables, for the EU-27.

EU-27 – Demand abatement vs. WM scenario in mobile air conditioning (ship and rail) 2030				
Sub sectors		Passenger ships	Cargo ships	Rail vehicles
abatement cost	€/tCO_2eq	33.1	15.8	374
demand reduction	ktCO_2eq	160	353	129
EU-27 – Emissions abatement vs. WM scenario in mobile air conditioning (ship and rail) 2030				
Sub sectors		Passenger ships	Cargo ships	Rail vehicles
abatement cost	€/tCO_2eq	35	16.7	502
emission reduction	ktCO_2eq	125	320	26

VI.8 Blowing agents for foam applications

8.1 General description

The foam sector is divided into several applications which are outlined in table VI-18 below. It is important to note that the cost estimates of abatement options differ for each application and are thus calculated separately in the global model (annex IV), and, for Europe, in the EU sector sheets (annex V). Nevertheless, a general discussion of items valid for the whole foam sector precedes the individual analyses of the different applications.

We should thereby distinguish PU and XPS. The first is made of liquid raw materials which are mixed and undergo a chemical bond to create PU. The latter is made of Polystyrene that is melted and should be distinguished from Expanded Polystyrene (EPS) which is a popular packaging material. EPS has not been considered although being also a construction material because the blowing agents used are hydrocarbons (pentane), and no abatement is required. The applications described are the most used ones although in the PU sector there are hundreds of other applications, to mention some: car spoilers, soccer and golf balls, water boilers, mattresses etc. Most of these applications do not use blowing agents or are small consumers with respect to the data available from the UNEP-FTOC reports. The variations in XPS are mainly in properties and predominantly used for solely insulation purposes.

Table VI-18: Classification of the foam sector by three application categories

PU	XPS
Insulation foams for the construction sectors	
Sandwich panels with metal facings, continuous (CME[127])	Foam Boards (XPS)
Sandwich panels with metal facings, discontinuous (DIP)	
Sandwich panels with flexible facings, boardstock (CFF)	
Spray foam (SPR)	
Insulation foam for refrigeration applications	
Domestic refrigeration (DOR) Commercial refrigeration (COR) Refrigerated trucks, reefer containers (RTRU)	
Non-insulating foams for Automotive, furniture sectors, shoe soles etc.	
Integral foams (INT)	

Insulation foam for the construction sector

Sandwich panels with metal facings, continuous (CME)

These sandwich panels are produced in a continuous manner at automated plants whereby the metal faces are profiled and the foam is poured between these panels. At the end of the production line the panels are cut to length and packaged. Almost all the operations are automated.

[127] The abbreviations in the brackets are used for the description of abatement options.

Sandwich panels with metal facings, discontinuous (DIP)

These panels are produced by placing the metal facings, structural supports and other inserts into a press where the foam is poured in between the facings. The difference with the continuous method lies in the variation of panel dimensions especially width. They are used for cold rooms, refrigerated trucks and other applications which require specific dimensions.

Sandwich panels with flexible facings, boardstock (CFF)

The production process is identical to CME but the facings are flexible like e.g. paper, plastics and other materials. The difference is therefore the type of facing material used and in general the production rate for CFF is higher than for CME. At the end of the automated production line the panels are cut to length and packaged.

Spray foam (SPR)

Spray foam is applied directly on the surface of brick walls, concrete floor and roofs by spraying the foam onto it. Spray foam is also suitable for use in existing buildings as insulation refurbishment.

Spray foam is produced by means of small mobile machines that facilitate easy access to roofs and can be easily transported inside of buildings as well. The machines are equipped with hoses and the foam is applied with a spray gun.

Spray foam is a flexible and adaptable solution, can be applied inside cavities, on rough wall surfaces and is used for tanks insulation with good insulation benefits. These benefits are however strongly dependant on the blowing agent used as the foams do not have any facings that could act as a barrier to avoid emission of the blowing agent and reduction of insulation properties.

XPS boardstock (XPS)

The extrusion process is a continuous process whereby polystyrene, blowing agent and additives are fed into an extruder, melted and mixed. Through the extrusion by means of a dye the boards are produced, cooled, cut and packaged. These are automated plants and they work preferable continuously.

Insulation for refrigeration applications

Domestic refrigeration (DOR)

Domestic refrigerators, single door and side-by-side types as well as freezers are characterized by the use of fixtures. The outer metal shell and inner plastic inliner are assembled and foam is injected into the inner space. These plants are highly automated and international brands produce more than one million units a year at one site.

Commercial refrigeration (COR)

Commercial refrigerators, like supermarket open top freezers, display cabinets are manufactured by producing panels of different sizes and then assembling them. These plants are dominated by manual operations due to their different sizes, models and small output rates.

Refrigerated trucks, reefer containers (RTRU)

These panels are produced by placing the metal facings, structural supports and other inserts into a press where the foam is poured in between the facings. After this process the panels are installed onto trailers or trucks and function as insulation. The foaming process is as in DIP but sizes and thickness are different.

Refrigerated trailers and trucks have width limitations imposed by the road code and the usable width by the size of pallets. Therefore, changes to the blowing agents have an impact on the thickness of the insulation as well as an impact on the volume that can be transported.

With regards to shipping containers which were in the past still insulated with HCFC-141b blown foam, the major companies in Asia have all converted to the use of hydrocarbons and European companies have transferred production to lower cost countries.

Integral foam for automotive, furniture sectors

Integral foams (INT)

Integral foam found in steering wheels, armrests and shoe soles have a performance and aesthetical purpose. It is important to note that the blowing agents add to the formation of a good exterior finish and do not have the scope of improving insulation properties.

Integral parts are manufactured by depositing foam into a mould, which will provide the final shape of the product and major producers all converted already to waterblown (H_2O option). In A5 countries still HCFC or HFC blowing agents are used as the function is also a reduction of density, i.e. weight.

8.2 Global business as usual trend of HFC consumption until 2030

The effects of the accelerated HCFC phase-out as agreed under the Montreal Protocol are included in the BAU scenario. This phase-out will most probably cause a shift from HCFCs to HFCs due to budget limitations of the MLF for HC conversions. However there might be productions that will be directly converted to HCs (hydrocarbons). At the moment there are no possibilities to precisely determine the amounts which will be converted from HCFCs to HCs or HFCs. Found below are expert estimates based on the experiences of the authors of this study and the information gathered so far through their participation in the current phase out plan for HCFCs in China and in other countries.

Europe banned HCFCs in 2004 and experienced a difficult transition period due to the lack of availability of appropriate HFCs and the supply differences due to patents. HFC-245fa is typical for the USA and HFC-365mfc is most common in Europe. Europe and Japan do not manufacture domestic refrigerators with HFC foam blowing agents whereas the USA mainly uses HFCs. Other large producers such as China and Korea likewise do not use HFCs. The USA banned HCFC-141b and HCFC-22 in 2008. The remaining HCFCs in foam production were banned in 2010 in the USA.

Studies have shown that the energy consumption of buildings is strongly influenced by the insulation. In A2 countries building standards are increasingly requiring better insulation through more stringent standards which are achieved through increased thickness. In A5 countries the awareness of the need for better insulation has just begun and demand for insulation foam is increasing, especially in China where XPS is growing with double digits.

Remarks to A5 countries' conversion

The phase-out of HCFC and in particular HCFC-141b for polyurethane foam under the Montreal Protocol has started and implementation of conversions on a large scale is expected to start end of 2011 depending on the acceptance of the HCFC phase out management plans of the individual countries. Therefore, the conversion of polyurethane foam production, which partially was due to conversions from CFC to HCFC-141b under the Multilateral Fond (MLF) of the Montreal Protocol, will largely influence the blowing agent market. The uncertainty hereby is the available funds for conversion to HCs and unsaturated HFCs which will be available in considerable quantities first in 2015. Furthermore, in A5 countries the predominant factor for choosing a blowing agent are costs. Therefore, the need arises to provide capital investments and affordable abatement options without market distortion.

The conversion from HCFCs to HFCs cannot be excluded although for example China has already noted that they wish to convert directly to low-GWP blowing agents. The reason is that the equivalent ODP (due to the conversion to HCFCs) has superseded the amount of CFCs of the past. This creates the problem that the number of companies and the amount of HCFCs to be phased out will pose problems to meet the targets of the Montreal Protocol deadlines.

Growth of foam production in A2 and A5 countries

Polyurethane (PU) Foam

The PU industry growth follows closely the annual GDP and growth rates are 3% for A2 countries and 6% for A5 countries, although there are differences in growth due to the shift of production sites to countries with lower workforce costs, especially for the automotive, furniture and domestic refrigeration sectors. It must be noted that in countries like China and India the growth is higher due to the increased need of insulation materials and the delay in implementation.

In A2 countries the market for polyurethane foam is not yet saturated, and more and more insulation is required. The growth projection does not imply the same growth for HFCs because the domestic refrigeration and sandwich panel market will more likely convert to HCs. The applications which require high insulation performance will be predominantly used in technical applications or where space restrictions apply. The standards in construction applications are applicable to all new buildings and the choices for technologies are made according to available common technologies.

Extruded Polystyrene Foam (XPS)

The XPS industry growth follows closely the annual GDP, and the consumption growth for A2 countries is approximately 3% and for A5 countries 6%. However, there are differences in growth because the transport costs are high and thus XPS, like PU, needs to be produced locally. It is important to note that in China the XPS production is currently growing between 10 to 20% annually making China the only A5 country with an XPS production of significance. For Europe, the model AnaFgas does not assume a growth in the XPS blowing agents HFC-134a or HFC-152a.

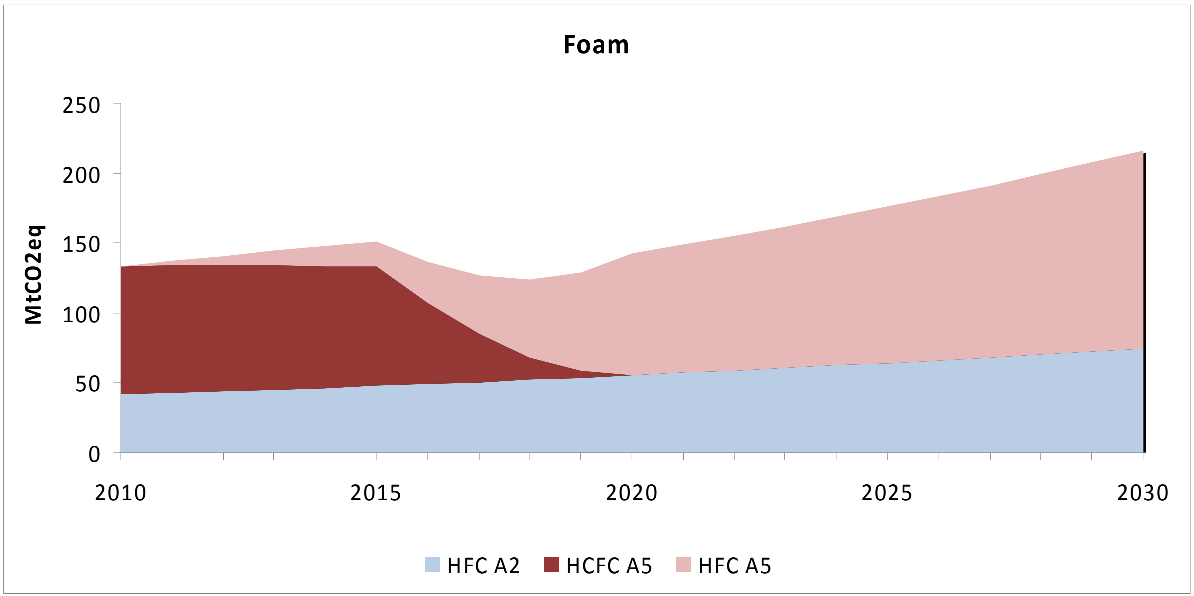

Figure VI-14: Global BAU consumption trends for foam blowing agents show slight growth until 2030.

Overview on the BAU use trend for foam blowing agents by sub sectors

Construction: Sandwich panels with metal facings, continuous (CME)

A2 countries mainly use hydrocarbons (specifically n- and iso-pentane) because of the ban on HCFCs, good properties and low costs while A5 countries mainly use HCFC-141b.

The reason that companies have moved to hydrocarbons is based on economics of scale, standards and combined with good design practice.

Construction: Sandwich panels with metal facings, discontinuous (DIP)

The USA and Japan have mainly converted to HFC-245fa and Europe to some degree to HFC-365mfc/227ea, which are both non-flammable. A5 countries are still using HCFC-141b.

The reason why companies have moved to HFCs instead of hydrocarbons is due to the fact that the companies are small and the panels used for cold rooms and refrigerated trucks have different sizes. This makes the conversion from HFCs complicated the more so as HFCs can be used as a drop-in.

Construction: Sandwich panels with flexible facings, boardstock (CFF)

A2 countries mainly use hydrocarbons (specifically n- and iso-pentane) and A5 countries HCFC-141b. The reason why A2 countries are using hydrocarbons is that the blowing agent does not contribute significantly to the long-term insulation properties. This is because the panels do not have barriers like in the case of metal panels and therefore part of the blowing agent will be emitted during the lifetime.

The reason why companies moved to hydrocarbons is economics of scale combined with good design practice.

Construction: Spray foam (SPR)

The USA have mainly converted to HFC-245fa and Europe to HFC-365mfc/227ea, both non-flammable, and A5 countries are still using HCFC-141b.

The reason why companies have moved to HFCs instead of hydrocarbons is due to the fact that spray foam cannot be used with flammable blowing agents. This limitation occurs as the blowing agent is released into the environment during the foaming process and can lead to an explosive atmosphere. Furthermore, the portable foaming machines are not equipped with and it would be difficult to equip them with appropriate safety equipment.

Construction: XPS Boardstock (XPS)

The USA and Europe have mainly converted to HFC-134a, HFC-152a or HC-CO_2 technology. Japan has moved to the use of hydrocarbons (isobutane mixtures). A5 countries are still using HCFC-142b, HCFC-22 or a combination of the two.

An important reason why companies have moved to HFCs instead of hydrocarbons or CO_2 technology is due to the fact that the investment costs for the latter are high and the technology development is more difficult. The conversion to HFC is easier as it can be used as a drop-in.

With regards to A5 countries nearly all HCFC application takes place in China. Data from 2009 indicates a consumption of approximately 30,000 (metric) tonnes of HCFCs. The demand in A5 countries for increased insulation could boost the production significantly as XPS is easy to produce, easy to use, price competitive, and inexpensive equipment for its production is available for Chinese producers using HCFC technology.

Refrigeration: Domestic refrigeration (DOR)

In Europe, Japan, Korea, China and in large plants in South America the preferred solution is hydrocarbon (mainly cyclopentane), because the polyurethane systems have evolved with performances close to those which are blown with HCFCs since the introduction of this technology in the mid 1990's.

The alternative used in the USA is HFC-245fa because it can be used as drop-in with minor modifications to the production lines and can be easily manufactured locally.

The European alternative HFC-365mfc was not available for a long time due to patent issues and therefore it is rarely used in domestic refrigeration, also because it is flammable without the addition of HFC-227ea.

The reason why companies have moved to hydrocarbons is based on economics of scale combined with good design practice. Nowadays, domestic refrigerators with hydrocarbon-blown foams achieve the highest energy classes. For further improvements, solutions are studied and applied with the use of special foams or other insulation materials where the choice of the blowing agent is not relevant e.g. vacuum panels.

Refrigeration: Commercial refrigeration (COR)

The USA and Japan have mainly converted to HFC-245fa and Europe to some degree to HFC-365mfc/227ea, both non-flammable and A5 countries are still using HCFC-141b.

The reason that companies have moved to HFCs instead of hydrocarbons is due to the fact that the companies are small and the appliances are assembled of different parts. This makes the conversion more complicated and HFC could be used as a drop-in.

Refrigeration: Refrigerated trucks, reefer containers (RTRU)

The USA and Japan have mainly converted to HFC-245fa and Europe to HFC-365mfc/227ea, both non-flammable and A5 countries are still using HCFC-141b. To a large extent in Europe companies have already moved to the use of hydrocarbons. Reefer containers are mainly produced in A5, by means of hydrocarbons.

Companies have moved to HFCs instead of hydrocarbons because the conversion of the plants is costly due to the size of the panels and secondly the production quantities are smaller than in the production of continuous sandwich panels, for example.

Integral foams (INT) for automotive, furniture, shoe industry

The USA and Japan have mainly converted to HFC-245fa and Europe to some degree to HFC-365mfc/227ea, both non-flammable, and A5 countries are still using HCFC-141b.

Non-HFC blowing agents used are hydrocarbons or water-based systems. Water-based systems do not contain additional blowing agents but react chemically to form CO_2 which acts as blowing agent.

Companies have moved to HFCs instead of hydrocarbons because the companies are small and the capital costs do not justify the change. The water-based systems require the addition of in-mould coating, which is an additional cost factor. Larger companies also moved to hydrocarbons depending on the size of the parts and standards.

From the data we received, the consumption could be considerably lower than the extrapolation from the 2005 data, at least in the case of Europe (see model AnaFgas). A factor which plays a role here is that the shoe industry moved outside of Europe and to some extent they used HFC blowing agents. The shoe industry in South America and Asia use ODS blowing agents to a large extent but it is impossible to determine the distribution and the trend generated by export bans to the EU and USA for foam containing HCFC's. For these industries cost factors play a key role and the blowing agent has the benefit of reducing the foam density and therefore costs. An assumption could be that the producers would reframe or significantly reduce the quantities of blowing agent from the moment when the costs for the blowing agents start being significantly higher than for the foam.

8.3 HFC demand and emissions in EU-27 until 2050 (WM scenario)

So far, the foam sectors are not subject to provisions of the EU F-gas Regulation. As a consequence, the WM scenario for HFC emissions and demand 2010-2050 does not differ from the WOM scenario.

In Europe, today about 80% of the XPS products are manufactured with CO_2 + organic solvent as the only blowing agent. Most manufacturers produce the whole product range with panel thickness from 20 mm to > 100 mm without HFCs by using these blowing agents only[128]. In 20% of the XPS foam production two HFC species are used by a few manufacturers: HFC-134a (as a pure gas or in a mixture with CO_2) and HFC-152a. At manufacturing 30% of the applied HFC-134a gas is promptly released to the atmosphere, the rest is enclosed in the foam cells and emitted during the use-phase at an annual rate of 0.75%. If HFC-152a is used for manufacturing, it is released to the atmosphere within short periods of time and cannot serve as a cell gas (no bank).

[128] Thickness over 120 mm can also be achieved with two single panels that are glued together.

In most PU applications which formerly relied on HCFC blowing agents, pentane (n-, iso-, or cyclopentane) has become established as standard. Spray foam is the only PU application sector where HFC blowing agents clearly dominate. In contrast to all other PU foam applications, spray foam relies by almost 100% on non-flammable agents. HFCs in this sector include HFC-365mfc (usually blended with HFC-227ea to reduce flammability) and HFC-245fa, which are both liquid at normal temperature and therefore easy to process. We estimate that spray foam, which is traditionally used in the construction sector in Spain and Portugal, accounts for two thirds of the European use of HFC-365mfc and -245fa. One third is used for "other" applications like discontinuous and continuous panels, appliances, block foam, etc.

Bank, demand and emissions of HFCs in the European PU and XPS foam sectors are shown in the following table for 2010, in metric tonnes.

Table VI-19: Foam blowing agents in Europe 2010 (metric tonnes)

	Bank 2010 (t)	Demand (t)	Manufacturing emissions (t)	Use-phase emissions (t)
XPS with 134a	19,711	2,862	859	148
XPS with 152a	-	3,711	3,711	-
PU spray foam 365mfc/245fa	34,265	4,903	616	514
Other PU foam 365mfc/245fa	14,685	2,101	264	147
Total	68,661	13,577	5,450	742

Source: AnaFgas 2011

PU spray foam includes 50% of the HFC bank, two thirds of the annual quantity for manufactuing and more than 50% of the use-phase emissions. Most manufacturing emissions (in metric tonnes) are caused by XPS with HFC-152a (emission factor 100%), followed by XPS with 134a (emission factor 30%), PU spray foam (emission factor 15%), and other PU foam (emission factor 10%).

In the model AnaFgas, the growth in production of PU products including spray foam is not assumed to cause an increase in HFC use and HFC manufacturing emissions, which are projected to remain at 7,000 t and 880 t, respectively (HFC-365mfc/227ea and HFC-245fa together). The constant level of HFC application, however, increases the bank and thus the use-phase emissions which are projected to grow from ~ 600 t in 2010 to 1,800 t in 2030, and 2,800 t in 2050. Use phase emissions exceed manufacturing emissions from 2015 onwards.

Constancy of production and market is also projected for HFC blown XPS foam until 2050, based on the trend in the years 2003-2008. Unchanging volume of HFC-134a for manufacturing results in a steady increase in the HFC-134a bank, and thus in HFC-134a use-phase emissions. Disposal is not assumed to take place before 2050.

The following graph, which is taken from the model AnaFgas, shows for the EU PU and XPS sectors the trend in demand and emissions of HFCs from 2010 to 2050.

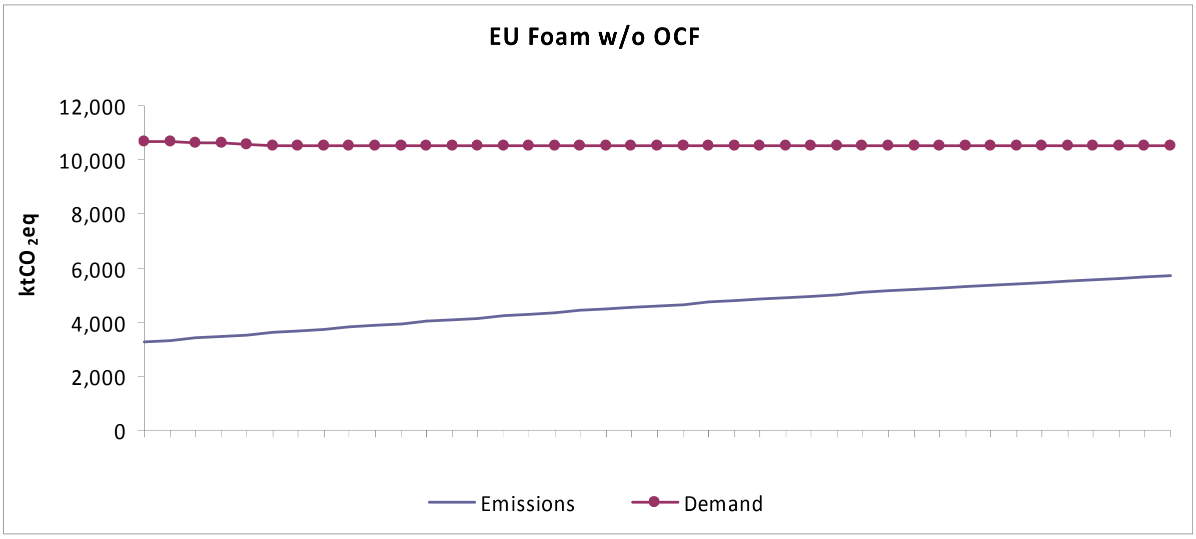

Figure VI-15: HFC use and emissions in the PU and XPS foam sectors in EU-27 under the WOM/WM scenario. While the annual application is assumed to remain unchanged, emissions from use continue increasing as the bank grows. Disposal emissions do not occur until 2050 because of the 50-years lifetime of the foam.

8.4 Key abatement options

General methodological remarks on blowing agents

Consumption estimation vs. emissions estimation

Since there is no natural unit size in foam production as in the other sectors (e.g. one refrigerator, one air conditioning system), incremental costs of abatement options in the foam sector are calculated on the basis of the incremental cost for new or the conversion of existing production lines.

Abatement cost are the cost for the replacement of one ton (1,000 kg) of blowing agent used for the production of foam in one year; this means that the replaced ton of blowing agent serves as calculation "unit". The replaced ton of blowing agent is recalculated in tonnes of CO_2 equivalent by means of the relevant GWP values to achieve specific abatement costs (€/t CO_2 eq).

It must be emphasized that the quantity of blowing agents can be estimated much easier than emissions. For emissions calculation one must know how much of the applied blowing agent is released to the atmosphere during manufacturing ("manufacturing emissions") and how much remains in the foam cells from which it is released to certain extent over the entire use phase ("bank emissions") and at end-of-life ("disposal emissions"). As blowing agents are, in contrast to refrigerant containing systems encapsulated inside the foams and are not refilled in the use-phase, annually used quantity of blowing agents is equal to the use for manufacturing, and no break down into the three emission categories is necessary. For the global scenario (A2 and A5) only the consumption in the described sense must be estimated. The emissions assessment will become relevant for the EU scenario and is discussed separately.

Differences in cost and insulation properties between blowing agents

The focus of this study is mainstream abatement options observable within the industry trends in the foam sector. These options provide sufficient abatement potential if their application is further promoted. Future developments have been considered within the limits of available data.

Generally, for all applications, solutions not involving HCFCs and HFCs are technically available. For all applications where insulation is a major performance factor, the change of the blowing agent implies the change of insulation properties. Generally, from the conversion of CFCs to HCFCs, HCFCs to HFCs and HFCs to HCs, the insulation quality decreases. In order to compensate for the loss in insulation properties, the cost for increased thickness of the insulation material has been considered. This approach allows a comparison without discrimination of options as well as the possibility to choose, because all the blowing agents would be available for use.

In integral foams for example, where insulation does not play a role, solutions include water-blown systems (i.e. polyurethane systems which create the blowing agent through chemical reaction and do not require physical blowing agents).

The largest portion of the abatement costs can be attributed to the incremental operating costs which are driven by the blowing agents. The cheapest blowing agents are hydrocarbons and HCFCs. HFCs are approximately 3 to 5 times more expensive than HCs and unsaturated HFCs are 2 to 3 times more expensive than HFCs. This is the reason why the use of hydrocarbons can result in negative incremental operating costs and can compensate for higher capital costs.

Due to the flammability of HC blowing agents, the production lines need to be adapted to ensure the safe use of flammable blowing agents. That means that foaming equipment, mixing, storage and foaming fixtures have to be modified or exchanged completely. Costs for conversion of the production line range from €250,000 to €500,000. In comparison, the conversion to non-flammable blowing agents would be in the range of 10,000 to 50,000 €.

Abatement options for HFCs are mainly applicable to A2 countries and abatement options for HCFCs to A5 countries. In A5 countries, the options considered do include intermediate conversions from HCFCs to HFCs, which are not included in the cost estimation or consumption savings.

Change of technology requires research as well as requalification of the products and trial periods. All options have, of course, to adhere to the local standards.

Role of unsaturated HFCs

There are synthetic alternatives to HFCs under development and to some extent available, namely unsaturated HFCs, often called HFOs. Producers announced in inverviews that these will be commercially fully available around 2015. Costs will be considerably higher than for HFCs and therefore will not represent a likely alternative for A5 countries. For A2 countries, the introduction is likely only when specific properties are required, e.g. when insulation properties have to be achieved within a certain thickness.

In the assessment of abatement options we do not refer to particular types of unsaturated HFCs like e.g. HFC-1234ze or similar[129], but use the general term “unsaturated HFCs” for this class of chemicals. This is because several types are still under development, and it is not yet clear which ones will turn out the most appropriate and most common agents.

[129] In addition to HFC-1234ze (HBA-2), further potential unsaturated HFC blowing agents with GWP <15 are being discussed, like e.g. AFA L1 or HFC-1336mzz-Z (FEA-1100).

Criteria for new blowing agents

Furthermore, the alternative blowing agent needs to provide equivalent physical properties and long term aging properties. Preference is also to achieve similar or better thermal insulation properties since at the moment the difference between non-HFC boards and HFC XPS boards, particularly with HFC-134a but not with HFC-152a, is approximately 1 to 2 mW/m.K (in the long term) dependent on the quantity and processor know how. This is translated in an equivalent of 3-7 mm increase in board thickness. Therefore, the costs for this increase of thickness have been evaluated.

In summary a new blowing agent needs to have:

- Low-GWP, equivalent of hydrocarbons
- Same or better insulation properties
- Wide commercial availability[130]
- Economical viability to achieve equivalent U or R values by increasing the board thickness compensating lower insulation properties[131]
- Adherence to the applicable standards in vigour, i. e properties and performance.

An additional point which is important for XPS is the flammability of the material. Therefore, at this stage the preferential options for replacement of HFC and HCFC are CO_2 + organic solvent and unsaturated HFCs. The first have already been widely practiced and unsaturated HFCs would be a technically viable alternative to HFC-152a and HFC-134a XPS producers. For PU applications, the preferences go into the direction of hydrocarbons or unsaturated HFCs as experimental data show good performance results. For small companies a viable alternative would be water blown as new systems have considerably improved.

Nevertheless, unsaturated HFC in foams still have work to do to provide commercial data and assure a wide availability in order to avoid market distortions.

Abatement options in detail

The technical abatement options are presented in the overview table VI-20 by replacement/conversion from one blowing agent type to another, independent of the world region and the particular applications for which the replacement is assumed. This approach is deemed feasible because the main differences between the individual abatement options exist between the blowing agents, not between the applications which will be presented in the subsequent overview. In the following table VI-20 the blowing agents are distinguished by their commercial name, ergo their chemical composition. The performance of the blowing agents will result in change of properties, especially in changes to the thermal conductivity or its reciprocal thermal insulation performance. Differences in insulation performance result in differences in foam thickness and, consequently, cost of raw material which is a basic constituent for the concluding assessment of the specific abatement cost per t CO_2 eq of each individual alternative technical solution.

[130] Availablilty may also imply that more than one company is on the market. If e.g. for political reasons a supplier is not allowed to export to certain countries, there is a direct impact on the conversion.
[131] The U-value (or U-factor), more correctly called the overall heat transfer coefficient, describes how well a building element conducts heat and the R-value is the inverse of the U-value, reference EN ISO 6946. These values are used in the construction industry to calculate the insulation properties of buildings.

Key abatement options for the foam industry in Europe

In the European XPS sector, both for XPS foam blown with HFC-134a and for XPS blown with HFC-152a, CO_2/hydrocarbons (incl. organic solvents) and unsaturated HFCs come into question as alternative blowing agents. The advantage of the first solution is low cost for blowing agent; the disadvantage is more cost for material which must be thicker to compensate the loss in thermal insulation. Unsaturated HFCs are not assumed to reduce the thermal insulation properties; however, the cost of these blowing agents is considerably higher than that of HCs or organic solvents.

In the European spray foam sector, alternative blowing agents must be non-flammable. Therefore, hydrocarbons are ruled out; however, in addition to unsaturated HFCs, water/CO_2 is a possible technical solution. Although CO_2 which arises from added water can serve as blowing agent, it is rarely used on its own because the insulation value of the product is then significantly lower (-17%) because CO_2 does not remain in the foam as a cell gas, unlike HFC-365mfc or HFC-245fa and probably unsaturated HFCs.

In the remaining PU applications, conversion from HFCs to pentane (n-, iso-, or cyclopentane) is technically feasible and already completed to large extent. The loss in insulation is less than 5% (-1 mW) and can in most cases be compensated easily by thicker foam. Unsaturated HFCs are also a possible technical alternative, which, however, is more costly than HCs because of the high price of the blowing agent.

Table VI-20: Overview of abatement options in the foam sector in A2 and A5 countries

1. Polyurethane foam	
From HFC 245fa to hydrocarbon (HC)	The HFC provides better thermal insulation of the foam of 1 - 2 mW/m.K (milliwatt per metre and Kelvin) which translates into the use of less foam, or more foam with the use of hydrocarbons. Therefore increased thickness of the foam is assumed and included in the cost calculation.
From HFC 245fa to H_2O	The HFC provides better thermal insulation of the foam of 4 - 5 mW/m.K which translates into the use of less foam or more foam with the use of water-based systems. Therefore increased thickness of the foam has been calculated to compensate for the insulation value loss in spray foam applications, but not for integral foam.
From HFC 365mfc/227ea to HC	Same change in thermal insulation and foam thickness as with HFC-245fa
From HFC 365mfc/227ea to H_2O	Same change in thermal insulation and foam thickness as with HFC-245fa
From HFC 365mfc/227ea or HFC-245fa to unsaturated HFC	There are several companies working on new blowing agent class but unsaturated HFCs are not expected to be available before 2015. Therefore, they are not a short-term option and the future is not clear as it will depend on the markets' development and potential use. Seemingly, their performance will be equal to HFC-365mfc and 245fa. What can be noted is that the flammability issue for foams is not clarified. Secondly, the costs of unsaturated HFCs will be approximately 2 to 3 times the costs of HFCs and the incremental operating cost will rise considerably.
From HCFC 141b to hydrocarbon (HC)	HCFCs provide better thermal insulation of the foam of 1 to 2 mW/m.K. This translates into the use of less foam or more foam with the use of hydrocarbons. Therefore an increased thickness of the foam has been assumed and included in the calculation.
From HCFC 141b to H_2O	HCFCs provide improved thermal insulation of the foam of 5 to 6 mW/m.K which translates into the use of less foam or more foam with the use of water-based systems. Therefore an increased thickness of the foam has been calculated to compensate for the insulation loss in spray foam and other insulation foams but not of integral foams.
2. XPS foam	
From HFC 134a to hydrocarbon (HC) *Note: in this option hydrocarbons refer to isobutane but also ethanol which is not a hydrocarbon but considered as such in the analysis*	HFCs provide better thermal conductivity of the foam of 1 to 2 mW/m.K which translates into the use of less foam or more foam with the use of hydrocarbons. Therefore an increased thickness of the foam has been assumed and included in the calculation.
From HFC 134a to unsaturated HFC	Not much data is available but we assume that the thermal conductivity is equivalent to HFC-134a. The flammability of unsaturated HFCs for foams, which are different from the refrigerants, is still under investigation. Considering however the high processing temperatures (>100℃) it is most likely that they are flammable under these conditions.
From HFC 152a to HC	HFC-152a has a GWP of 140 and therefore is the least unacceptable HFC-option at the moment. It is not used to improve the thermal insulation but to achieve thickness above 60-80 mm when the technology is not available to perform it with HC (CO_2+organic solvent in this case) only.
From HCFC 142b to hydrocarbon (HC)	HCFCs provide better thermal insulation of the foam of 2 to 4 mW/m.K which translates into the use of less foam or more foam with the use of hydrocarbons. Therefore an increased thickness of the foam has been assumed and included in the calculation.
From HCFC-142b / -22 to HC	This is mainly an application used in A5 countries for costs reasons and therefore considered. There are however no thermal insulation benefits on the long term.

8.5 Market potential (penetration) of abatement options until 2030

The market potential of the discussed alternative solutions until 2030 is estimated as follows:

Hydrocarbons are proven blowing agents in the foam sector. The water-CO_2 reaction for PU foam and the use of CO_2 with organic solvent for XPS foam have also proven to be excellent in practice. All these options are already available, and their market potential (penetration rate) can be estimated 100% already in 2015.

The situation is different for unsaturated HFCs which are currently not yet commercially available in sufficient quantitities for all potential applications and countries. Chemical manufacturers have announced that by 2015 the supply of unsaturated HFCs will be high enough for the foam sector.

The blowing agent demand from the foam sector is determined by the need for new production lines that replace old ones which have reached end of lifetime. Given 10 years average lifetime of the production equipment, only one tenth of the existing facilities create demand for alternative blowing agents in 2015. In the global model and in the EU sector sheets, however, not only replacement of old production lines with new ones is assumed, but also conversion of existing facilities to the applicability of alternative blowing agents. Therefore, the penetration rate of unsaturated HFCs must be considerably higher than for regular facility renewal only. The foam experts in the project team estimate a continuous increase of market potential: 30% in 2015, 70% in 2020, and 100% in 2030.

Based on the penetration rates of the individual abatement options and the individual abatement cost per t CO_2 eq (which have been calculated separately in the global model and are not presented here because of too high complexity) the sector expert established for the year 2030 the most effective set of alternative technical options ("penetration mix"), which are comparable and complementary with each other, prioritizing the more cost-effective solutions in case of equal reduction potential. By 2030, HCFCs will have been phased-out completely also in A5 countries so that only replacement or conversion from HFCs to alternative blowing agents are considered.

The 2030 penetration rate combinations are shown in the following tables for each sub sector of PU and XPS insulation for construction, refrigeration, and integral skin.

Insulation foams of PU and XPS for the construction sector

A2 - Penetration mix of abatement options in construction foam 2030			
Alternative technical solution	HC	H_2O	unsat. HFC
Sandwich panels with metal facings, continuous (CME)	90		10
Sandwich panels with metal facings, discontinuous (DIP)	90		10
Sandwich panels with flexible facings, boardstock (CFF)	90		10
Spray foam (SPR)		50	50
XPS Foam Boards (XPS)	85		15
A5 - Penetration mix of abatement options in construction foam 2030			
Alternative technical solution	HC	H_2O	unsat. HFC
Sandwich panels with metal facings, continuous (CME)	90		10
Sandwich panels with metal facings, discontinuous (DIP)	90		10
Spray foam (SPR)		50	50
XPS Foam Boards (XPS)	85		15

PU Foam for refrigeration applications and integral skin

A2 - Penetration mix of abatement options in refrigeration and integral foam 2030			
Alternative technical solution	HC	H_2O	unsat. HFC
Domestic refrigeration (DOR)	100		
Commercial refrigeration (COR)	100		
Refrigerated trucks, reefer containers (RTRU)	90		10
Integral foams (INT)		50	50
A5 2030 - Penetration mix of abatement options in refrigeration and integral foam 2030			
Alternative technical solution	HC	H_2O	unsat. HFC
Domestic refrigeration (DOR)	100		
Commercial refrigeration (COR)	100		
Refrigerated trucks, reefer containers (RTRU)	100		
Integral foams (INT)		100	

Penetration rates and mix in Europe

XPS

From a technical point of view, lower insulation values could be compensated by increased thickness of the products. Space constraints which require extra insulation performance, which can be achieved with HFC-134a only, constitute a small market segment of XPS products in Europe.

It is assumed that the market potential for HC-CO_2 blown XPS products is limited to 85% of that of HFC-134a blown products, while the products blown with unsaturated HFCs can replace HFC-134a blown products by 100%, thus filling the 15% “gap” from application of HC/CO_2. By 2020, these penetration rates can be reached.

In current application of HFC-152a, the market potential for the two alternative blowing agents is assumed to reach 100% in 2020 at the latest.

PU spray foam

The individual technical market penetration of water/CO_2 blown foam is estimated at 100% already in 2015 if one disregards additional costs. The new unsaturated HFC could be used at 50% in 2015 and at 100% from 2020 onwards. The penetration rate mix as of 2020 is assumed to include the water/CO_2 technology and the unsaturated HFC solutions at 50%, each.

Other PU foam

In the remaining PU applications, conversion from HFCs to pentane (n-, iso-, or cyclopentane) is technically feasible and already completed to large extent. The loss in insulation is less than 5% (-1 mW) and can in most cases be compensated easily by thicker foam. The market penetration of HC blowing agents is estimated at 95% already in 2015. A small segment of foam products with extra high insulation performance remains where HFCs cannot be replaced by HCs, according to the current state of knowledge. Individual market penetration potential of unsaturated HFCs is assumed to reach 100% in 2020.

The most effective set of alternative technologies which complement each other (penetration mix) is estimated as shown in the following table. In case of equal reduction potential, the more cost-effective solution preferred.

EU-27 - Penetration mix of abatement options in the foam sectors 2030			
Alternative technical solution	hydrocarbons (organic solvents)	unsaturated HFCs	water/CO_2
XPS with 134a	85	15	
XPS with 152a	100		
PU spray foam		50	50
Other PU foam	95	5	

8.6 Abatement cost and reduction potential of alternative options 2030

Corresponding to the percentage of the individual abatement options in the 2030 penetration mix, the individual abatement cost are aggregated to sector abatement cost, in €/tCO_2 eq.

Global data

The BAU trend of the HFC consumption 2010-2030 has been assessed previously. The reduction of the HFC consumption as a result of the application of the complementary set of abatement options can be estimated for the sector, for the year 2030.

Sector abatement cost and calculated sector consumption reduction potential for the sub sectors of foam blowing for 2030 are shown in the following tables, for A2 and A5 countries.

Insulation foams of PU and XPS for the construction sector

A2 – Consumption abatement vs. BAU for foam blowing agents 2030						
Sub sectors		CME	DIP	CFF	SPR	XPS
abatement cost	€/tCO_2eq	4.9	7	1.35	9.3	1.3
reduction	ktCO_2eq	6,500	11,000	1,300	18,700	42,100

A5 – Consumption abatement vs. BAU for foam blowing agents 2030					
Sub sectors		CME	DIP	SPR	XPS
abatement cost	€/tCO_2eq	2.2	3	5	8,1
reduction	ktCO_2eq	9,500	39,800	48,500	16,800

PU Foam for refrigeration applications and integral skin

A2 – Consumption abatement vs. BAU for foam blowing agents 2030					
Sub sectors		DOR	COR	RTRU	INT
abatement cost	€/tCO_2eq	8	17	5.9	10.5
reduction	ktCO_2eq	10,800	4,400	1,600	3,600
A5 – Consumption abatement vs. BAU for foam blowing agents 2030					
Sub sectors		DOR	COR	RTRU	INT
abatement cost	€/tCO_2eq	4	13	6.4	10
reduction	ktCO_2eq	53,300	10,800	6,400	6,300

Cost assessment for Europe

Conversion from XPS with 134a. A comparative analysis on the relationship between production cost and demand/emission reduction has been carried out for conversion of a typical production line with HFC-134a to the use of the blowing agents CO_2/organic solvents or unsaturated HFC-1234ze (see sector sheet 23 in annex V). Reference is a production line with annual output of 2 million square metres of panels with 50 mm thickness (weight 2,600 t), and an equipment lifetime of 10 years.

Additional investment costs arise for the new production line, and for technology-change (design modification, raw material tests); additional operating cost arises for the change to different raw material and for the increase in material thickness in order to balance lower insulation performance in case of organic solvent/CO_2. Annual savings arise from the use of organic solvent, which is relatively inexpensive, and over-compensate additional investment and operating costs. This leads to negative abatement cost per t/CO_2 eq both for emissions and for applied quantity. If HFC-134a is replaced by unsaturated HFC, which is more expensive than HFC-134a, the specific abatement costs become positive, ranging € 28 /tCO_2eq. For details of the calculation see sector sheet 23 in the annex V.

Conversion from XPS with 152a. A basic analysis of the conversion of HFC-152a to the blowing agents CO_2/hydrocarbons or HFC-1234ze has been undertaken (see sheet 24). Reference is a production line with the same technical specifications as the HFC-134a line.

Additional investment cost arise for the new production line and for technology-change; additional operating cost are caused by the change to different raw material, but not for increase in material thickness because there is no loss in thermal insulation for HC/CO_2 blowing agent, and even a gain of 6% for HFC-1234ze.

Annual savings from the use of HC/CO_2 blowing agent, which is relatively inexpensive, over-compensate the additional annual cost, and lead to negative abatement cost (savings) of € -1.60 per t/CO_2 eq. Like HFC-152a, the HC/CO_2 blowing agent is not a cell gas, so that annually used quantity and emissions are the same; therefore the abatement costs of demand and of emissions are also the same. If HFC-152a is replaced by unsaturated HFC, which is more expensive, specific abatement cost are higher and range at €138 t/CO_2 eq although the insulation performance improves by 6%.

Conversion from HFCs in PU spray foam. A basic cost-emissions-assessment on the conversion from HFCs to water/CO_2 or unsaturated HFCs (for details see sector sheet 25 in the annex V) indicates that specific emissions abatement cost could range at € 51/t CO_2 eq for conversion to water, and at € 72/ t CO_2 eq for conversion to unsaturated HFCs. In contrast, the specific abatement costs for the annually used quantity are low, ranging between €8 and €12, because the applied amount is much higher than emissions. While the high emissions abatement cost from application of unsaturated HFCs are not surprising, due to the high price of the blowing agent, the high cost from the use of water/CO_2 result from the decrease in insulation performance of the foam by approx. 17%. The high additional material cost cannot be balanced by the savings from the inexpensive blowing agent. The high abatement costs might be a problem in the sector which is characterised by a large number of small and medium enterprises[132], especially in Spain and Portugal.

EU-27 – demand abatement vs. WOM/WM scenario in the foam sectors 2030					
Sub sectors		XPS with 134a	XPS with 152a	Spray foam	Other PU
demand abatement cost	€/tCO_2eq	0.3	-1.6	10.0	0.2
demand reduction	ktCO_2eq	4,092	460	4,801	2,058
EU-27 – emissions abatement vs. WOM/WM scenario in the foam sectors 2030					
Sub sectors		XPS with 134a	XPS with 152a	Spray foam	Other PU
emission abatement cost	€/tCO_2eq	1.0	-1.6	61.6	3.5
emission reduction	ktCO_2eq	1,553	460	1,369	587

Conversion of HFCs in other PU applications. In the remaining PU applications, conversion from HFCs to pentane (n-, iso-, or cyclopentane) is cost effective where technically feasible. For 5% of the applications where extra high insulation performance is required, high emission reduction cost from the use of unsaturated HFCs must be accepted.

[132] Presentation by Mike Jeffs: "HCFC replacement in foams" given at UNIDO conference, Oct 2010.

VI.9 Fire protection

9.1 General description

Before the Montreal Protocol, HFCs were not used in fire protection. Their usage, which started in 1995, is a result of their adoption as Halon alternatives, despite being inferior to Halons both in terms of cost and performance.

For fixed fire suppression systems, about half of former users of Halon-1301 choose non-gaseous (not-in-kind) agents, such as water, water mist, dry chemical, foam and aerosols. The other half choose gaseous (in-kind) clean agents like carbon dioxide, inert gases, or HFCs. HFC systems replaced and still replace approx. 25% of existing and retired Halon equipment. Most widely used HFC type is HFC-227ea with almost 90% and HFC-23 with ca. 10% of the HFC market. HFC-125 is also in use to small extent, but not discussed further in this section.

Portable fire extinguishing systems, which use HFC-236fa, are not considered here because of their minor quantitative importance.

Like Halons, HFCs are “clean” agents, meaning that they vaporize readily and leave no residue after use. This makes them suitable for the protection of occupied space and of installations like telecommunication switch rooms, computer and electronic control rooms, hazards aboard ships, libraries, archives, etc. HFC flooding systems are not inexpensive; therefore they are typically used in comparably small rooms of up to 400 m^3 volume.

9.2 Global business as usual trend of HFC consumption until 2030

According to a model of banks and emissions of Halons, developed by the UNEP-HTOC, 50 kt of Halon-1301 were still in use in 2005, thereof 40 kt in A2 (most in Japan), and 10 kt in A5 countries[133]. The global bank of HFCs was estimated in SROC at approx. 27 kt at the end of 2004[134]. The share of A5 countries is estimated 2 kt.

The model assumptions for the forecast until 2030 are as follows.

Banks

In A2 countries the HFC bank increases to the present size of the combined bank of Halons and HFCs, which is 65 kt. This implies annual HFC quantities for new equipment of 2.5 kt, which is less than the annual reduction of Halons of 4 kt. After the complete phase-out of Halons in 2015, the HFC consumption continues at the same level as in the 20 years before for new systems and, in addition, replaces HFCs of decommissioned old equipment.

In A5 countries the process is similar, starting 2005 from a combined Halon-HFC bank of 12 kt. While for A2 countries no growth in the combined bank is assumed until 2030, for A5 countries doubling to 24 kt is projected.

Annual consumption until 2030

The HFC demand includes agents not only for new equipment but also for refill for use-emissions. Annual loss resulting from leakage, fire, and false alarm is estimated 2.5% of the

[133] May 2009 TEAP XX/8 Task-Force Report, 63.
[134] SROC, Chapter 9: Fire Protection, 363.

bank in A2, and 3% of the bank in A5 countries[135]. The total annual HFC consumption in A2 and A5 countries, which amounted to 3.4 kt in 2005, is forecast to increase to 7.7 kt in 2030.

Table VI-21: Global bank and consumption of fire extinguishing agents for fixed systems, 2005, in metric kilo tonnes.

2005	A2		A5		World	
Fire protection kilo tonnes	bank	con-sumption	bank	con-sumption	bank	con-sumption
Halon-1301	40	1.0*	10	0.3*	50	1.3*
HFC-227ea	22.5	2.8	1.8	0.3	24.3	3.1
HFC-23	2.5	0.3	0.2	0.03	2.7	0.3
Total	65	4.1	12	0.6	77	4.7

** Use for refill only (halons)*

HFC split in HFC-227ea and HFC-23

Data on the HFC-split are rare. Verdonik[136] used a composition of 97.5% HFC-227ea and 2.5% HFC-23 for his emissions model. Our approach uses a split of 90% HFC-227ea and 10% HFC-23. The higher share of HFC-23 is based on our knowledge of sales quantities in the EU, where e.g. in 2008 the sales quantity of HFC-23 amounted to 0.2 kt, of an HFC total of 1.2 kt[137]. In our global model, the share of 10% HFC-23 in HFC use and bank is kept constant until 2030.

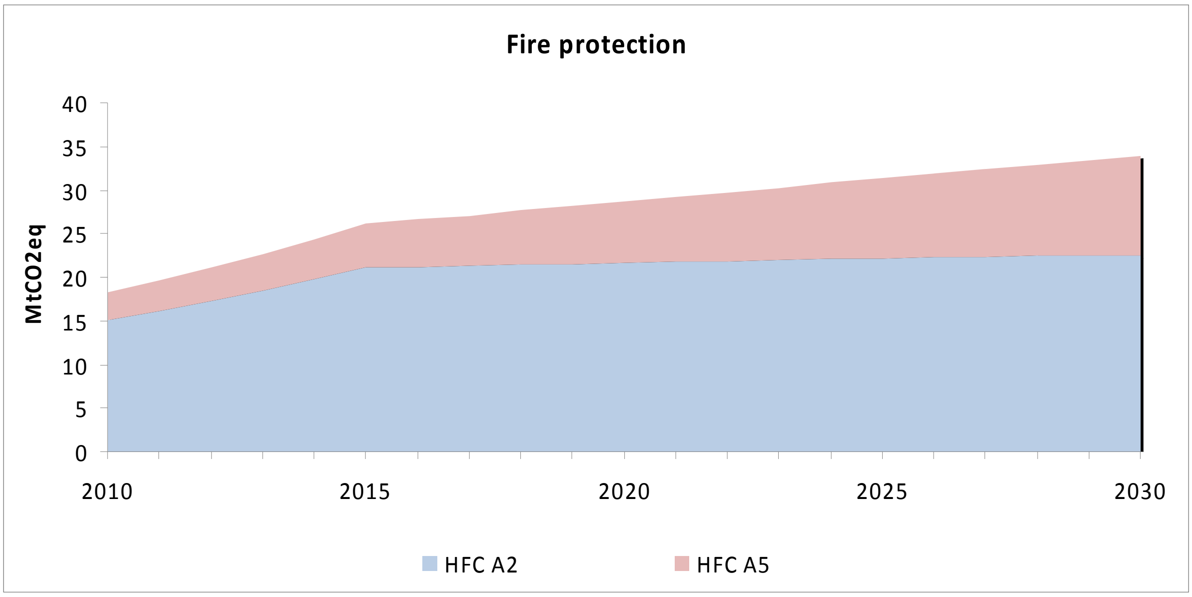

Figure VI-15: Global BAU consumption trend for HFCs in fire protection (fixed systems). Halons, which are replaced until 2015, are not shown in the graph.

[135] It must be noted that use phase emissions arise not only on site but to some extent during the check of the cylinder tightness which is implemented in several European countries once in the equipment lifetime; for this check the cylinders are completely discharged and recharged.
[136] Verdonik, D.P., 2004: Modelling Emissions of HFCs and PFCs in the Fire Protection Sector, Proceedings of the 15th Earth Technologies Forum, April 13-15, 2004, Washington, DC, USA, 13 pp.
[137] Model AnaFgas.

9.3 HFC demand and emissions in EU-27 until 2050 (WM scenario)

Fixed fire protection systems are fully subject to the measures according to Art 3 and 4 of the F-gas Regulation. This means for the WM scenario that the emission factors for use-phase and disposal should decrease. It is characteristic of the sector that the equipment must satisfy very high safety requirements and standards so that regular control measures have always been common practice. Only in a minority of cases increase in intensity and frequency of equipment check will be necessary. The containment and recovery measures by certified personnel acc to Art 3 and 4 of the F-gas Regulation are therefore not assumed to show substantial additional reduction effects to the existing use phase emissions. As a consequence, in the model AnaFgas the use-phase emission factor decreases from 2.5% to 2.3 % (see annex III).

Similar applies the end-of-life emissions. Most emissions do not arise on site when old equipment is decommissioned because the F-gas containing bottles are simply removed from the piping and returned for off-site recycling and reclamation. End-of-life emissions are mainly reclamation emissions. As the reclamation plants are not subject to the provisions of the F-gas Regulation, a specific reduction effect from that law cannot be assumed. In AnaFgas, the disposal emission factor decreases from 10% to 9%.

Table VI-22: Bank, demand and emissions of HFCs in European fixed fire protection systems, 2010 (metric tonnes)

2010			
Fire protection	**bank**	**demand**	**emissions**
HFC-227ea	8,800	940	225
HFC-23	3,300	213	78

Source: model AnaFgas 2011

The decrease in emission factors is assumed to take place in the 2010-2015 periods. After, they remain unchanged until 2050.

For the projections of future bank and annual demand it is assumed that in consequence of the strong competition from other fire extinguishing agents only until 2015 HFC based fluids will be filled in additional new systems which increase the equipment stock. From then onwards, new HFC based equipment only replaces retired installations, keeping the banks at the 2015 level. This applies to both HFC-227ea and HFC-23.

The following graph shows for HFC-227ea and HFC-23 the combined annual emissions and demand in the WM scenario 2010-2050.

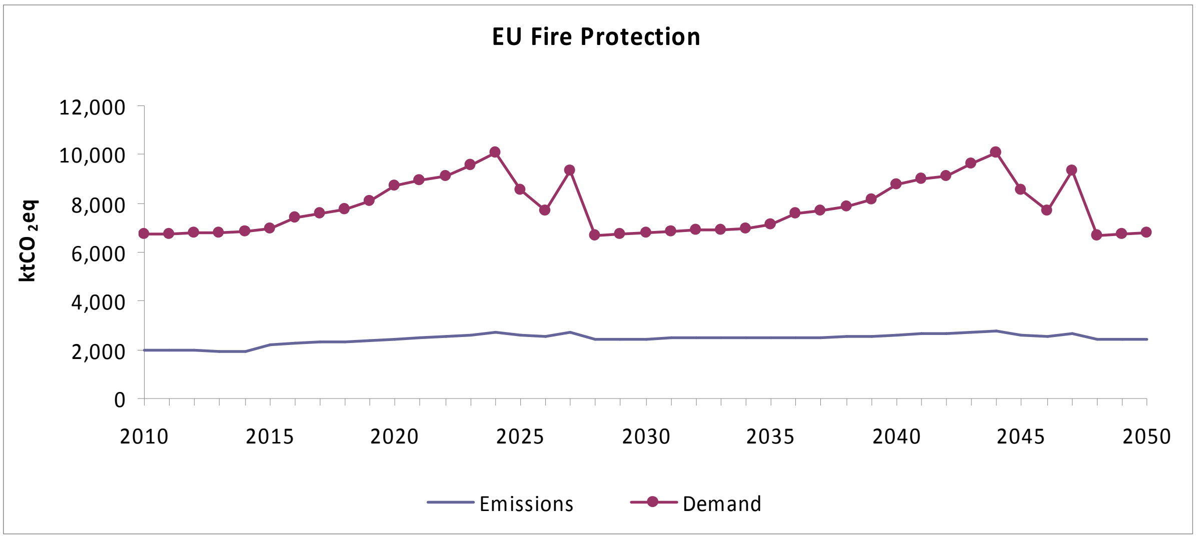

Figure VI-17: Demand and emissions of HFC-227ea and HFC-23 in European fire protection systems under the WM scenario. No growth is assumed after the Halon replacement which is completed in 2015.

9.4 Key abatement option

In recent years a low GWP alternative fluid (GWP 1) with equivalent extinguishing properties had been introduced to the market with still growing success, the perfluoro-ketone FK 5-1-12 (Novec™ 1230). Its manufacturer and most European specialist equipment distributors rate FK 5-1-12 to be a feasible substitute for almost all applications of HFCs – for both HFC-227ea and HFC-23. Although distributors of HFC systems deny such a large coverage only very few irreplaceable applications have been named on request.

FK 5-1-12 which is at room temperature not a gas but a liquid which is vaporised on application, shows similar qualities to HFCs, with the same discharge time (10 seconds). It uses the same pressure system as HFCs (42 bars with 90 bar maximum). The gas concentration (charge) must be 20% higher compared to HFC-227ea (35% compared to HFC-23), thus requiring more space for the cylinders depending on the situation. The investment cost of the equipment including fire detection system, aspirating system, specific piping is 15% higher than the equivalent HFC-227ea installation, and the same as for equipment with HFC-23.

The gas cost per kg is higher. In 2010 the price difference between FK 5-1-12 (Novec™ 1230) and both HFC-227ea and HFC-23 was 80% (€22 vs. €12).

For Europe, we have contrasted the alternative technical solution FK-5-1-12 with the sector typical WM reference systems for a room of 400m^3 volume. The HFC-227ea system has equipment cost of € 10,000 and a gas charge of 135 kg; the HFC-23 system has equipment cost of € 11,500 and a charge of 122 kg. The relevant values of the FK-5-1-12 system are equipment cost of €11,500, and a gas charge of 166 kg. The detailed calculations are presented in the EU sector sheets 20 and 21 in annex V.

The TEAP 2009 Report states that “the fluoroketone (FK-5-1-12) that was very new on the market when the SROC was written has gained some use as an alternative to halon-130”. FK-5-1-12 is currently projected to be about 2% of the former halon 1301 usage, taking up what was initially filled by PFCs and displacing equally HFCs and inert gases for the remainder”. Apparently, the TEAP experts expect for FK-5-1-12 a reduction of HFC emissions and consumption under BAU (globally) or, under WM scenario for Europe. Our analysis includes the reduction effect of the alternative technical option in addition to both scenarios.

9.5 Market potential (penetration) of the abatement solution

While equivalent application of FK-5-1-12 and HFCs (HFC-227ea and HFC-23) with respect to fire suppression qualities is hardly controversial, distributors of HFC based fire extinguishing equipment indicate that space and weight were crucial factors for replacement of HFCs by FK-5-1-12: For the same effect, the quantities of FK-5-1-12 must be 20% higher than those of HFC-227. Additional weight might be a limiting factor in air crafts, and limited space (sometimes additional cylinders must be installed) might hamper the application of FK-5-1-12 in some further cases.

The SROC 2005 Report quotes a position claiming HFC-23 to be a unique Halon replacement in “low-temperature applications such as those found on the oil and gas industry on the North Slope of Alaska” [138]. In literature we could not find further applications where HFC-23 was indicated necessary. It should be noted that e.g. in EU-27 Spain is the main user of HFC-23 with more than 90% of the total sales quantities and the climate there is very different from that close to the Arctic Circle.

In the HFC-227ea case, we account for limiting factors like space or weight by reduction of the maximum market penetration, and apply for the possible market share in new equipment which comes into question for HFC-227ea in 2030, not 100% but only 90% in A2, and 80% in A5 countries There is, however, no reason why the penetration rate of 100% for HFC-23 should be reduced.

The alternative option is already commercially available. The response time of a policy to increase the use of FK-5-1-12 may be very short.

A2 2030 - Penetration rate of abatement option in fire protection	
Alternative technical solution	FK 5-1-12
equipment with HFC-227ea	90
equipment with HFC-23	100
A5 2030 - Penetration rate of abatement option in fire protection	
Alternative technical solution	FK 5-1-12
equipment with HFC-227ea	80
equipment with HFC-23	100

As there is only one abatement option considered a combination of several penetration rates (“penetration mix”) is not necessary.

[138] The quote is as follows: “HFC-23’s high vapour pressure and low boiling point make it a unique replacement for halon 1301 in large-volume, low-temperature applications such as those found on the oil and gas industry on the North Slope of Alaska (Catchpole, 1999)”. IPCC/TEAP Special Report: Safeguarding the Ozone Layer and the Global Climate System, p. 372.

9.6 Abatement cost and reduction potential of abatement option 2030

The abatement costs of the fluoro-ketone option expressed in €/tCO_2eq are calculated for the two sub sectors in the global model for A2 and A5; their calculation for Europe is presented in the EU sector sheets in annex V.

Global data

The BAU trend of the HFC consumption 2010-2030 has been assessed previously. The reduction of the HFC consumption as a result of the introduction of the abatement option can be estimated for the sector, for the year 2030[139].

Abatement cost and calculated consumption reduction potential for the two sub sectors of fire protection for 2030 is shown in the following tables, for A2 and A5 countries. The sub sectors HFC-227ea and HFC-23 systems are combined to one sector.

A2 – consumption abatement vs. BAU in fire protection 2030		
Sub sectors		FK-5-1-12
abatement cost	€/tCO_2eq	4
consumption reduction	ktCO_2eq	21,900
A5 - consumption abatement vs. BAU in fire protection 2030		
Sub sectors		FK-5-1-12
abatement cost	€/tCO_2eq	4
consumption reduction	ktCO_2eq	12,900

Both in A2 and in A5 countries the abatement cost of the FK-5-1-12 option is comparably low, with € 4 per tonne CO_2 equivalent.

EU data

The estimation of abatement cost and reduction potential for the EU follows the same principle as the calculation of the global values. In addition to the annual demand of HFCs, for the EU the emissions of HFCs (from use and from disposal) are of relevance. Emissions and demand in the EU-27 are estimated in the WM scenario of the model AnaFgas.

EU-27 – demand abatement vs. WM scenario in fire protection 2030			
Sub sectors		HFC-227ea	HFC-23
abatement cost	€/tCO_2eq	7.4	1.0
demand reduction	ktCO_2eq	2,578	2,946
EU-27 – emissions abatement vs. WM scenario fire protection 2030			
Sub sectors		HFC-227ea	HFC-23
abatement cost	€/tCO_2eq	22.3	3.1
emissions reduction	ktCO_2eq	440	961

[139] While the quantity for first fill of equipment becomes zero in the year of introduction of the alternative option and is easily to quantify, the amount for refill decreases only over a number of years as old equipment retires from the stock. The amount of refill in a year depends on the penetration rates in the preceding years.

The main difference between the global and the EU approach results from the fact that the sector-typical reference unit is subject to the F-gas Regulation. This implies for the reference unit higher annual service expenses from application of Art 3 and 4, and lower emissions from regular maintenance and recovery by certified personnel. As aforementioned the special effect of the F-gas Regulation on costs and emissions in the fire protection sector is small. The abatement cost for demand and emission reduction, and the reduction potential by 2030 is shown in the following table.

The lower abatement cost and higher emissions reduction potential of HFC-23 compared to HFC-227ea result from the significantly higher GWP of HFC-23, with 14,800 vs. 3,220.

VI.10 Aerosols (excl. MDI)

10.1 General description

In the 1970s, aerosols accounted for more than half of the worldwide consumption of CFCs, and were mostly used for household and cosmetic sprays. Today, more than 98% of non-medical aerosols use non-halogenated, low-GWP propellants like hydrocarbons, dimethylether, etc. The remaining aerosol products use HFCs for applications where flammability is a concern or where HFCs provide a health benefit for the user. The latter is the case with metered dose inhalers (MDI) for the treatment of asthma and further respiratory diseases. MDIs have just recently completed the substitution of CFCs with HFCs. Although MDIs can be replaced by powder inhalers (DPIs) for application of identical drugs, which is underlined by high application quotas of DPIs over almost 90% in several European countries, this sector is excluded from subsequent assessment because this form of aerosols represents a use which requires special investigation by experts (e.g. from the medical and pharmaceutical industry).

The vast majority of non-medical aerosols with HFCs are technical products. In terms of volume, the most important applications include air dusters, freezer and cleaning sprays, which are mainly used in service of electronics. HFC-134a is a propellant gas that provides safe application in the presence of potential ignition sources, on hot surfaces, on equipment under voltage, etc. HFC-152a, which is flammable, is also in use, often in mixtures with HFC-134a.

There is no clear definition of “technical aerosols”, therefore nobody exactly knows which applications actually rely on non-flammable ingredients or propellants and which applications could be considered unnecessary[140]. There is still a number of consumer sprays for use in household or cosmetics which could do it without HFCs. This likewise applies to so-called novelty aerosols for noise making or similar purpose, for which the use of HFCs has been prohibited in the EU as of 2009. As application of aerosols is emissions from aerosols, alternative solutions to HFCs are of significance for climate protection in those applications where non-flammable propellants or ingredients are necessary.

10.2 Global business as usual trend of HFC consumption until 2030

Reliable data on the global HFC quantity used for non-medical aerosols are hardly available. In the SROC, estimates of the use (emissions) are presented for Europe, USA, Japan and Rest of the World, expressed in tCO_2eq (2nd AR). Under the assumption that HFC-134a accounts for 90% and HFC-152a for 10% of the total, the following quantities can be estimated for the current global consumption in metric kilo tonnes, and recalculated in global warming consumption/emissions according to the GWP values of the 4th AR).

[140] In Germany, every year 50 tonnes of HFC-134a are filled in aerosol cans which serve as so-called pipe-cleaners (Rohrreiniger) to remove clogged toilet pipes. Freezer sprays are apparently used also for medical/cosmetic uses: cooling the skin after laser treatment for removing tattoos. http://www.candelalaser.com/products/gentleyag/GentleYagBrochure.pdf

Table VI-23: Global HFC consumption for aerosols 2010, metric kt and kt CO_2 eq.

2010	Europe*	USA	Japan	A5	World
HFC metric kt	2.7	7.2	2.1	5.4	17.4
HFC ktCO₂eq	3,900	9,300	2,700	7,000	23,000

** European data include only HFC-134a, without 50 t for novelties, acc to model AnaFgas.*

In the SROC Report in 2005 it was estimated that over the 10 year period from 2000 to 2010 the consumption in A2 countries would slightly decrease by 10%, while in A5 countries (Rest of World) the consumption would double (+2.7 kt). There is no projection for the future.

For projections of future consumption/emissions, we assume the quantity in developed countries to be constant at the 2010 level. The quantity used in developing countries is estimated to grow at an annual rate of 1%. This means a growth from today's 5.4 kt to 6.6 kt (2030) and 8.0 kt (2050).

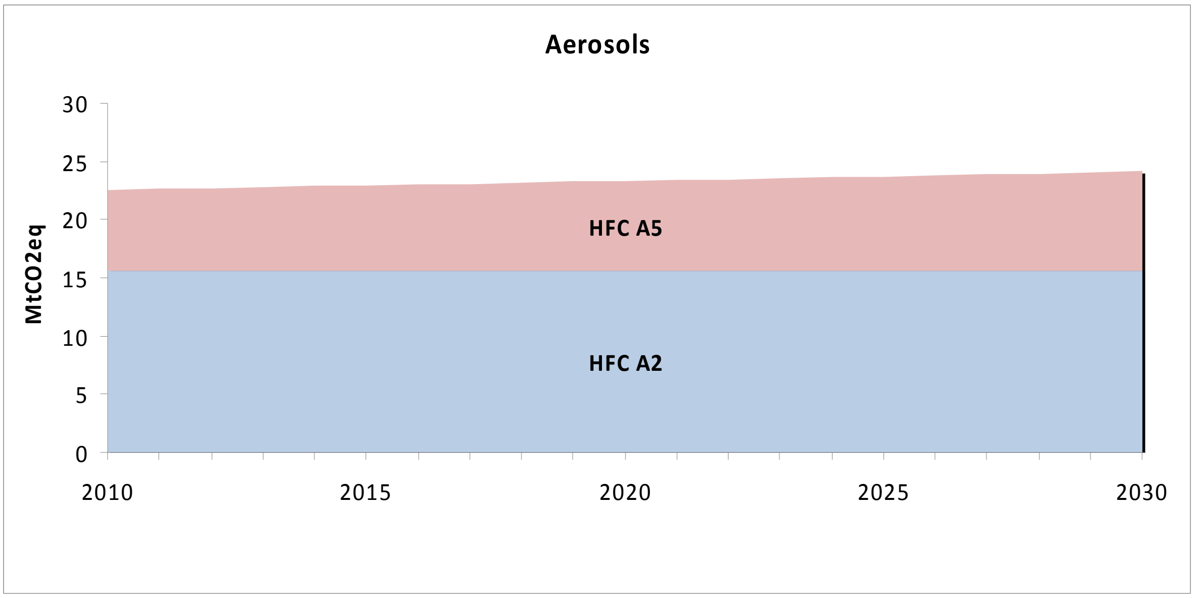

Figure VI-18: Global BAU consumption of HFCs for the aerosol sectors (without MDIs).

10.3 HFC demand and emissions in EU-27 until 2050 (WM scenario)

Article 9 of the F-gas Regulation prohibits placing on the market of HFCs in aerosols for decoration and entertainment (so-called novelty aerosols). In the model AnaFgas, this leads to emission reductions from aerosol applications by 300 kt CO_2 eq per year from 2010 onwards in the scenario with measures (WM). The remaining HFC quantity for the aerosol sector of 2.7 kt of HFC-134a is used for technical (general) aerosols (in addition, 50 t for novelties, in preparations < GWP 150).

Technical aerosols are not subject to any specific provisions of the 2006 F-gas Regulation. In the WM scenario which is the same as the WOM scenario the amount of HFCs for all general aerosols is kept constant at the 2008 level, with 2,700 t of HFC-134a for General Aerosols.

Table VI-24: Demand/emissions of HFCs in the aerosol sector in EU-27, 2010, metric tonnes and tonnes CO_2 equivalent

2010	Demand/emissions of HFCs (HFC-134a)
HFC metric kt	2.7
HFC kt CO₂ eq	3,800

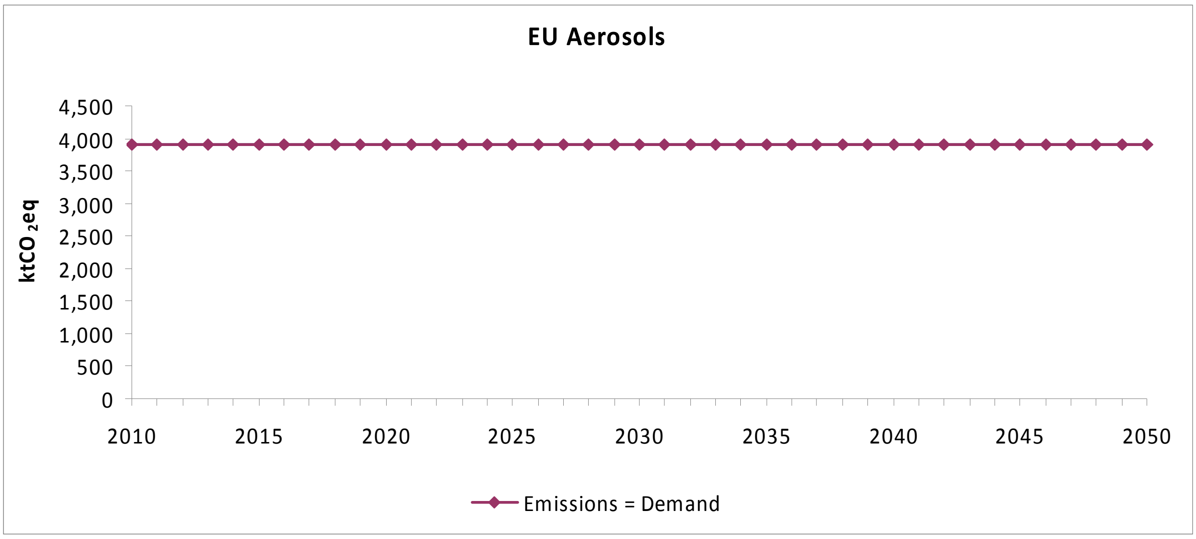

Figure VI-19: HFC demand and emissions in the aerosol sector under the WOM/WM scenario in EU-27. No growth is assumed over the 2010-2050 periods.

10.4 Key abatement option

Since 2009, HFC-1234ze is available, which is non-flammable at room temperature (< ~ 30°C) and thus a feasible alternative to HFC-134a as aerosol gas. The characteristics are very similar to those of HFC-134a and the gas can be referred to as a near drop-in replacement for this application. The GWP amounts to 6, according to the producer (Honeywell).

The company Microcare, a manufacturer of chemicals for precision cleaning in electronics, has already introduced HFC-1234ze in three of their best-selling technical aerosols (a freezer, a cleaner, and an anti-duster) to the European market. At the same time, the company continues selling three identical products containing HFC-134a. The only relevant difference is the price: A can containing 280 grams of HFC-1234ze costs € 4.10 more for end-users and € 3.50 more for whole-sellers than the product containing HFC-134a. From this difference, specific abatement cost of € 10.00 /t CO_2 eq can be calculated (for details see sector sheet 22 in the annex V). This value is used in this study not only for Europe but also for the total of A2 countries, and to A5 countries.

10.5 Market potential (penetration rate) of abatement option

It is estimated that HFC-1234ze (or similar chemicals with low GWP) is applicable to the vast majority of technical aerosols presently containing HFCs. The European Aerosol Federation FEA advises against the idea that HFC-134a could be substituted “simply 1 to 1 by HFC-1234ze”. In reality, the need for reformulations, testing, re-design, etc. had to be taken into account. Therefore, we do not consider short-term replacement of HFCs possible. It is estimated that in A2 countries the 2015 market penetration of HFC-1234ze could be around 30%. By that time, the limiting factor is the availability of the chemical. Until 2030, there might be enough of the low-GWP fluid on the market, and there might be further technical solutions which raise the market potential of propellants with low GWP close to 100%. Here, we consider only HFC-1234ze and estimate the 2030 market penetration for A2 countries at 95%. For A5 countries, the penetration rate could be 10-20% lower.

A2 - Penetration rate of abatement option in aerosols 2030	
Alternative technical solution	unsaturated HFC
aerosols	95
A5 2030 - Penetration rate of abatement option in aerosols 2030	
Alternative technical solution	unsaturated HFC
aerosols	85

10.6 Abatement cost and reduction potential of alternative option 2030

The abatement costs of the option unsaturated HFC in €/tCO_2eq are calculated in EU sector sheet 22 (annex V) and have already been presented under "10.4 key abatement option".

Global data

The BAU trend of the HFC consumption 2010-2030 has been assessed previously. The reduction of the HFC consumption as a result of the introduction of the abatement option can be estimated for the sector, for the year 2030.

A2 – Consumption/emissions abatement aerosols 2030		
Sub sectors		unsaturated HFC
abatement cost	€/tCO_2eq	10
consumption reduction	ktCO_2eq	16,300
A5 – Consumption/emissions abatement aerosols 2030		
Sub sectors		unsaturated HFC
abatement cost	€/tCO_2eq	10
consumption reduction	ktCO_2eq	8,000

EU data

The abatement cost of the option unsaturated HFC is the same as for A2/A5 countries. The reduction potential for demand/emissions against the WM/WOM scenario can be estimated by application of the 2030 penetration rate to the forecast emission/demand quantities in the model AnaFgas.

The abatement cost for demand and emission reduction, and the reduction potential by 2030 is shown in the following table.

EU-27 – Demand/emission abatement vs. WM scenario in aerosols 2030		
		HFC-134a (90%) HFC-152a (10%)
abatement cost	€/tCO_2eq	10
demand/emission reduction	ktCO_2eq	3,630

VI.11 Medium voltage switchgear in Europe

11.1 General description

The high voltage switchgear sector is divided in high voltage > 52 kV and medium voltage 1-52 kV. Rated voltage below 1 kV is called low voltage.

In high voltage switchgear of the closed system type, SF_6 is standard gas for both insulation and switching/arc quenching. So far, alternatives to SF_6 are not yet available.

Medium voltage (MV) is used for distribution of electricity from high voltage to the low voltage network. MV equipment at the interface with high voltage is called primary distribution MV switchgear; equipment at the interface with low voltage is called secondary MV switchgear.

In primary MV switchgear both SF_6 and SF_6 free solutions are common. The mostly used alternative to SF_6 technology is air insulated switchgear (AIS). All European manufacturers of MV switchgear produce the two systems. SF_6 systems, charged with ca. 6 kg of the gas, are compact whereas AIS has larger volume and is applied where space constraints do not exist. SF_6 free primary MV is not an alternative but a supplement to SF_6 insulated primary MV switchgear.

At the interface of medium voltage and low voltage, so-called secondary distribution MV switchgear is used. The systems commonly work with SF_6. The equipment is “sealed for life” which means that enclosed SF_6 should not escape over the whole 40 years lifetime, except due to external action. Over 90% of the secondary MV switchgear installations in Europe are so-called Ring-Main-Units (RMU) of up to 24 kV, compact systems in transformer stations for switching of cables and for protection of the transformer. Usually, a RMU comprises three SF_6 filled compartments (“panels” or “feeders”), thereof two panels are for the cables and one for the transformer. Each panel is charged with 0.6 – 0.7 kg of SF_6.

11.2 SF_6 bank and emissions in secondary MV switchgear in EU-27

In the model AnaFgas, data on SF_6 in electrical switchgear are distinguished between high and medium voltage only for a few countries. A further distinction of the medium voltage sector into primary and secondary equipment is not available for any country. On request of the project team, the European association of switchgear manufacturers, T&D Europe, estimated the EU market for MV secondary distribution switchgear from 1991 onwards (1991 is the first year when sealed pressure MV systems with SF_6 were sold) based on market data of their member companies[141].

In addition the SF_6 amount in kg per functional unit (“panel”) was estimated.

Table VI-25: Installations, bank, annual demand and emissions of SF_6 in the sector of secondary MV switchgear in EU-27 in 2010

Secondary MV switchgear	installations (units)	bank (t)	demand (t/year)	manufacturing emissions (t/year)	lifetime emissions (t/year)
	2,866,800	2,265	155	1.5	4.5

The association holds the position that the current annual sales to the European market will remain constant at approx. 220,000 units over the next decades. This means that the SF_6

[141] T&D Europe, SF_6 Task Force: Letter to Öko-Recherche, 3 February 2011.

bank grows annually by ca. 150 t until 2030. After 2030, decommissioning of old equipment begins and growth of the bank decelerates. This implies that use phase emissions grow less quickly after 2030 and disposal emissions start increasing.

Equipment "sealed for life" is not refilled during lifetime. All SF_6 quantity used in the three EU countries where MV switchgear is manufactured to large extent[142] is used for first fill of systems. Emissions on manufacturing are estimated 1% of the annually applied SF_6 amount. Lifetime emissions are estimated at 0.2% which is default value in the 2006 IPCC Guidelines for MV switchgear[143]. The disposal emission factor, which is relevant from 2030 onwards, is estimated 1.5% in the WOM scenario. SF_6 containing switchgear is subject to the recovery Art 4 (1) of the F-gas Regulation, and in the WM scenario it is assumed that disposal emissions will decrease from 1.5% to 0.75% at end-of-life when certified personnel carry out recovery.

In the WM scenario the bank will grow to 5,370 t in 2030 and 6,211 t in 2050. Emissions from manufacturing, operation, and disposal grow to 12.3 t in 2030 and 15.1 t in 2050, which is 273 $ktCO_2eq$ in 2030 and 336 $ktCO_2eq$ in 2050. Annual SF_6 demand remains at constant levels of 155 t.

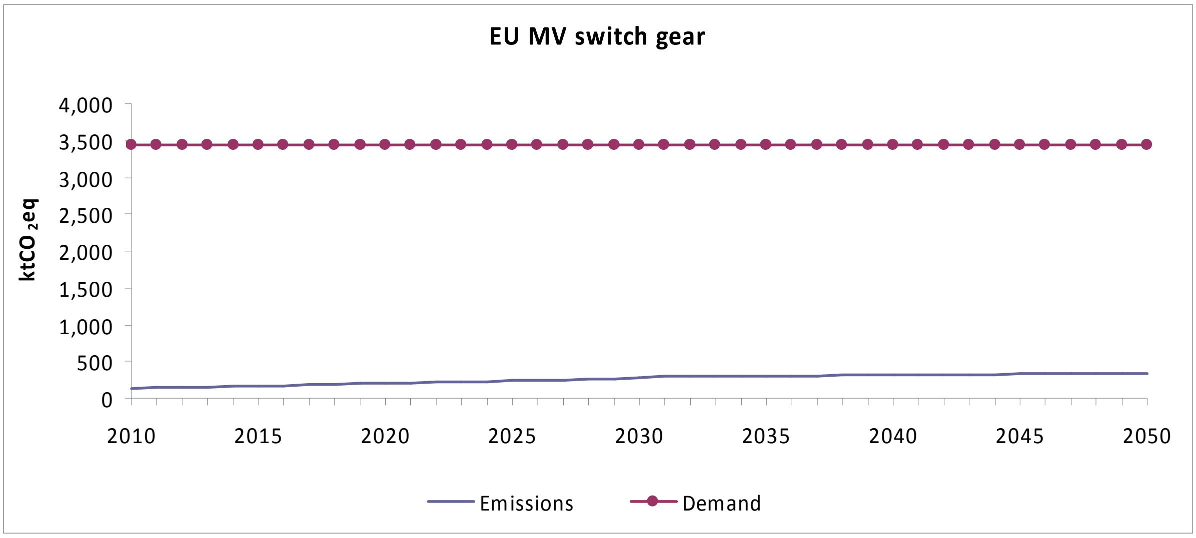

Figure VI-21: SF_6 demand and emissions in the sector of secondary distribution MV switchgear under the WM scenario in EU-27. No growth is assumed over the 2010-2050 periods for the annual demand for manufacturing. The emissions, which are very low in comparison, are growing to 15.1 metric tons by 2050, which are 336 kt CO_2 eq.

11.3 Key abatement option

As of 2002, as an alternative to the conventional SF_6 technology, SF_6 free secondary MV switchgear has become available which replaces SF_6 in insulation by solids and in switching by a vacuum chamber. The SF_6 free equipment is technically equivalent with SF_6 based systems and fulfils the same technical standards. Its market share is estimated at about 2% in 2010.

---

[142] These three countries are Germany, France and Spain. The fourth European country with large production quantities for the EU market is Norway.

[143] The German T&D switchgear industry report under their voluntary monitoring commitment only 1% lifetime emissions and 0.4% manufacturing emissions for 2010.

Operating costs for switchgear of any technology are minimal, whereas the differences in investment cost between SF_6 free and SF_6 based MV switchgear (Ring Main Units) is considerable. In the following the calculation in the EU sector sheet 27 is summarised.

While in conventional MV switchgear SF_6 is used for insulation and switching at the same time, insulation in the SF_6 free technology relies on solid materials (cast resin) which cause higher cost of ca. €10 per panel (€20 for the solid material vs. €11 for the SF_6 charge). The key cost difference, however, results from the vacuum chamber, which enables the system to switch the current without SF_6. The cost of this component is estimated at approx. €250, and there is no counterpart in SF_6 based equipment. As a consequence, the investment cost for an SF_6 free panel exceeds the €1,300 for the SF_6 reference unit by ca. €300 if further minor cost items like specific transformer protection (€25) and field control (€20) are also accounted for. In addition, capital cost (1% per unit) would arise for conversion of production lines if further manufacturers would opt for the alternative solution.

On an annual basis (40 years lifetime), additional cost of ca. €13 are estimated, which are related to avoided SF_6 amount of 18 grams per year. With regard to global warming, 18 grams of SF_6 relate to ca. 400 g CO_2 eq so that specific demand abatement costs of €33.9/t CO_2 eq arise.

While the demand abatement cost can be considered moderate, the emission abatement costs are significantly higher. Emissions on an annual basis amount to 1.7 grams or 38 g CO_2 eq. The resulting emissions abatement cost amount to €347 / t CO_2 eq.[144]

11.4 Market potential and abatement cost 2030 and 2050

The technical market potential of SF_6 free secondary MV equipment is estimated at 15% in 2015 and is projected to grow to 90% until 2030. By then, most production facilities in Europe could be converted for the alternative product.

EU-27 – demand abatement vs. WM scenario in MV switch gear 2030 and 2050			
MV switch gear		2030	2050
abatement cost	€/tCO_2eq	33.9	33.9
demand reduction	ktCO_2eq	3,103	3,103
EU-27 – emissions abatement vs. WM scenario in MV switch gear 2030 and 2050			
MV switch gear		2030	2050
abatement cost	€/tCO_2eq	347.3	347.3
emissions reduction	ktCO_2eq	97	232

[144] The annual emissions total 0.24% of the charge. The EU-based manufacturer of the SF_6 free secondary MV switchgear, Eaton, claims in a letter to Öko-Recherche (8th July 2011) "that the estimated emissions from MV switchgear are considerably higher than the numbers used. Conservative estimates indicate that real SF_6 emissions from MV switchgear are at least around 6.5%". In our opinion which relates to the 2006 IPCC GL, the company confuses emission data about HV switchgear ("closed pressure") with emission data about MV switchgear ("sealed pressure").
In addition, Eaton states that end-of-life costs for SF_6 containing switchgear are "around EUR 700 per unit" so that "the emission abatement cost are negative and in the range of EUR -16 and EUR -251". In our view, there is no evidence for this cost estimate.

The abatement cost for the demand amount to €32 /t CO_2 eq in 2030. The abatement cost for the emissions are significantly higher, with €347 /t CO_2 eq. The achievable reduction of demand is of considerable order of magnitude, with 3,100 ktCO_2eq. The emissions reduction potential, however, is comparably low, with 97 kt CO_2 eq by 2030.

It should be noted that as a consequence of the long lifetime of 40 years, by 2050 still 34% of the installed equipment contains SF_6, representing additional reduction potential afterwards.

VI.12 Non-ferrous metal industry in Europe

12.1 General description

The F-Gas Regulation prohibits the use of SF_6 in magnesium die-casting as of 1 January 2008 except where the annually used quantity is below 850 kg per year (Art 8(1)). Remaining SF_6 emissions from the magnesium sector arise from gravity (sand) casting, magnesium recycling, and from die casting in foundries with use of SF_6 quantities <850 kg/a.

A recent study on behalf of the EU Commission[145] has investigated state of technology and abatement options this sector. The use of HFC-134a and SO_2 as cover gases are identified as technical options for the replacement of SF_6 in magnesium industry. Both gases have been introduced in some large magnesium casting facilities already.

12.2 SF_6 use and emissions from non-ferrous metal industry in EU-27

In the WM scenario in model AnaFgas, used quantities and emissions in magnesium casting amount to 22.4 t of SF_6 and 21.5 t of HFC-134a (which is an accepted alternative to SF_6).

Table VI-26: Use and emissions of SF_6 (and HFC-134a) in magnesium die casting in 2010

2010		
Mg casting	**use**	**emissions**
SF_6	22.4	22.4
HFC-134a	21.5	21.5

12.3 Key abatement option

From the conversion of large Mg die casting facilities, experiences on abatement technology are available and include the use of SO_2 or HFC-134a for small die casting facilities <850kg/a. As for the recycling of Mg die casting alloys, conversion to SO_2 is possible.

12.4 Market potential and abatement cost

The market potential of abatement technologies in magnesium die casting <850 kg/a and recycling of Mg die casting alloys is estimated 100% in 2015. By then, most production facilities in Europe could have converted to either SO_2 or HFC-134a.

The abatement cost for both use and emissions are relatively low at €0.4 /t CO_2 eq in 2030. The achievable reduction of use and emissions of this open application is comparably low at 250 kt CO_2 eq by 2030.

EU-27 – use/emissions abatement vs. WM scenario in magnesium casting in 2030		
Magnesium casting		SO_2, HFC-134a
use/emission abatement cost	€/tCO_2eq	0.4
use/emission reduction	ktCO_2eq	250

145 Öko-Recherche 2009: Service contract to assess the feasibility of options to reduce emissions of SF_6 from the EU non-ferrous metal industry and analyse their potential impacts. Final Report, on behalf of the European Commission.

Annex VII. Analysis of key impacts

This annex VII shall provide a summary of the most important likely environmental, economic and social impacts of the different policy options which are discussed in chapter 8 of the Final Report. This analysis shall point to particular impacts (key impacts) which on the basis of our study merit careful consideration or further analysis.

The key impact categories considered are listed in table VII-1.

Table VII-1: Impact categories considered

Overall impact areas	Impact categories
Environmental impacts	Reductions of direct GHG emissions
	Effect of indirect emissions related to energy
	Ecotoxicity of alternative substances
Economic impacts	Marginal abatement costs for F-gas emissions
	Direct annualised net costs to industry sector
	Direct annualised net costs per operator
	Administrative costs on EU businesses
	Costs for public institutions
	Third countries and international relations
Social impacts	Investment costs of equipment. Sales of equipment suppliers
	Effect on service companies
	Employment
	Health and occupational risks

The short list of policy options resulting from the screening process undertaken in chapter 8.2 will affect a limited number of industries. Table VII-2 presents an overview which stakeholders might be affected by certain policy options. Impacts for third countries relate to the fact that F-gases are traded internationally either in bulk or contained in pre-charged equipment.

For some impact categories quantitative analyses have been undertaken. These include:

- Environmental impacts: Direct emission reduction potential, indirect emission reduction potential.
- Economic impacts: marginal abatement costs, direct costs per industry sector and per individual operators.
- Social impacts: investment costs for equipment/gains of equipment suppliers, reduction in service and maintenance activities.

Other impacts are assessed qualitatively including

- Economic impacts: Administrative costs on EU businesses; costs for public institutions; third countries and international relations.
- Social impacts: Employment, occupational health.

	C-1 Voluntary agreements	D-3 Improve recovery and containment	D-4a Ban the use of SF_6 in open applications	D-4b Ban the POM of certain open applications containing HFCs	D-5 POM bans in certain closed applications containing F-gases	D-6 Limits for placing on the market of HFCs	D-8 Destruction of HFC-23 em. from halocarbon production
Remaining sub-options after screening	All VA As suggested	Art 3+4 to refrigerated trucks+trailers	SF_6 in Mg industry	Technical aerosols, XPS foam	Refrigeration and AC equipment, fire protection equipment	Implementation of a potential international HFC agreement OR separate measure at EU level	Consistency with potential international HFC agreement
Commission	x	x	x	x	x	x	x
Member State governments	x	x	x	x	x	x	x
Industry							
EU producers of F-gases	x			x	x	x	x
EU importers of F-gases	x			x	x	x	
EU exporters of F-gases							
Distributors of F-gases			x		x	x	
Manufacturers of equipment containing F-gases	x				x	x	
Operators of equipment and systems containing F-gases							
Stationary refrigeration	x				x	x	
Stationary AC					x	x	
Mobile refrigeration		x				x	
Mobile AC						x	
Fire protection	x				x	x	
Refrigeration and AC servicing companies		x			x	x	
Producers of products containing F-gases	x			x		x	
Magnesium die casting and recycling of Mg alloys			x	x			
Semiconductor industry	x						
EU producers of HCFCs	x					x	
Consumers/households	x	x		x	x	x	
Third countries	x			x	x	x	

VII.1 Option C-1 "Voluntary Agreements"

Different voluntary agreements have been considered in further analyses. Each of the proposed voluntary agreements refers to one sector which sometimes includes several subsectors (as listed in annex VI and chapter 6) (table VII-2).

Such agreements are non-regulatory instruments, thus, regulatory action addressing the same sectors would not be necessary. It should be noted that a functional body is needed to assure compliance to the agreed targets and achieve related emission reductions.

It is assumed that subsequent to each VA, industry in EU-27 would no longer place on the market products and equipment containing F-gases covered by the relevant VA. For assessing the likely effects, it is assumed that the industry would opt for alternative options as assumed in the mix established in annex VI and chapter 6. All suggested VA could start immediately.

Table VII-2: Parameters for voluntary agreements in different sectors

Voluntary agreements	**Industry body to potentially include**	**Objective of VA**	**Emission reductions 2030 (kt CO_2 eq)**	**Abatement cost (€/t CO_2 eq)**
Commercial refrigeration				
Centralized systems	Consumer Goods Forum (EU section), EPEE	Replacement of HFCs in new commercial refrigeration equipment	14,741	23.7
Commercial hermetics			149	-0.8
Condensing units			3,927	1.2
Photovoltaic industry				
Photovoltaic industry to replace SF_6 and NF_3	Manufacturers (mainly in Germany)	Replacement of NF_3 by elemental fluorine in chamber cleaning	80 (SF_6) 20 (NF_3)	+/- 0
Foam				
XPS foam (HFC-134a)	EXIBA	Replacement of HFC-134a as blowing agent	1,553	1.0
Semiconductor industry				
Semiconductor industry	ESIA	Further reduce emissions of NF_3, PFCs, SF_6, HFC-23	Not estimated	
Fire protection				
Fire protection equipment with HFC-23	EUROFEU	Replacement of HFC-23 in new fire protection equipment	961	3.1
Halocarbon production				
HFC-23 by product emissions	CEFIC	Destruction of HFC-23 emissions to the extent technically feasible	370	<2
Total*			**21,801***	

* including photovoltaic industry, excluding semiconductor industry

Environmental impacts

Direct emissions

The total reduction potential for direct emission of all VAs amounts to 21,801 kt CO_2 eq in 2030 compared to the WM scenario of the model AnaFgas. On the basis of the assumed penetration mixes for the different sectors, new emissions of alternative refrigerants, foam blowing agents, and fire extinguishing agents could comprise 4,300 t hydrocarbons, 1,400 t CO_2 (refrigerant), 200 t unsaturated HFCs, and 120 t fluorinated ketones. Their global warming potential is calculated at 16 kt CO_2 eq which decreases the overall emission reduction potential by 0.07%.

Indirect emissions related to energy

Alternative technical solutions for refrigeration and foam blowing show at least equal energy efficiency as reference F-gas technologies (see chapter 6). Where an abatement technology does not show at least identical energy efficiency, due to lower thermodynamic performance of the refrigerant, or due to poorer insulation performance of the blowing agent, additional technical measures are assumed to increase the energy efficiency to the level of the reference systems. This leads to higher investment costs, which are accounted for in the abatement cost assessment in the relevant EU sector sheets in annex V. Additional technical measures in the foam sectors are increased thickness of the boards to compensate for higher thermal conductivity of the blowing agent (which increases the demand for raw materials and thus the operational cost).

In foam blowing the energy efficiency of the abatement technologies in the penetration mix is the same as in the reference systems. In commercial refrigeration the energy efficiency of the technologies which are represented in the mix is higher compared to the common HFC technologies. Energy consumption does not play a role for fire protection equipment. As a result, in commercial refrigeration indirect emissions from abatement technologies are lower than from HFC reference technologies.

With regard to energy related emissions, the total reduction potential of all VAs amounts to 514.5 kt CO_2 eq in 2030 compared to the WM scenario of the model AnaFgas.

Ecotoxicity

When released to the atmosphere in large quantities, certain substances (or their decomposition products) used in abatement technologies can damage the environment.
Hydrocarbon (HC-290, HC-600a) emissions can lead to production of ground level ozone and formation of photochemical smog, which might eventually impact the air quality on regional scale. Directive 2008/50/EC on ambient air quality and cleaner air for Europe recommends measurements of ozone precursor substances including propane and other non-methane volatile hydrocarbons.

Unsaturated HFCs are likely to be used as substitutes for HFCs in commercial refrigeration and XPS foam blowing. Decomposition processes of these substances lead to the formation of hydrofluoric acid/ hydrogen fluoride (HF; toxic)[146]. Like HFC-134a, unsaturated HFCs 1234yf and 1234ze form ca. 10% trifluoroacetic acid (TFA). The release of HF and TFA can

[146] ILK Dresden, Dr. Siegfried Römer: Presentation at the German DKV Conference in November 2010: Complex chemical interactions of low GWP refrigerants and construction materials in mobile applications (in German).

cause acidification of ecosystems, in particular aqueous ecosystems as it impacts the ph values.

Within the VA for the fire protection sector, the fluorinated ketone FK 5-1-12 is used as substitute for HFCs. Decomposition products formed through thermal degradation of this fire extinguishing agent include hydrofluoric acid (HF; toxic) and trifluoroacetic acid (TFA; toxic), to similar degree as HFC-23.

The quantities of emissions of alternative substances are rather small and are not assumed to damage the environment more than the HFCs they are likely to replace.

Economic impacts

Marginal abatement costs of F-gas emissions

Marginal abatement costs vary between sectors and subsectors and range between ca. -0.8 €/t CO_2 eq (commercial hermetics) and 23.7 €/t CO_2 eq (commercial centralized systems).

Direct net costs to industry sectors

Direct net costs to industry sectors differ largely and are by far highest for commercial centralised systems (419 M€/year), followed by condensing units (105 M€/year). These two sectors account for 99% of the costs arising in the 6 sectors where HFC emissions are released. Low direct net costs occur for abatement in the 4 remaining sectors such as commercial hermetics (-0.12 M€/year), XPS production (1.2 M€/year), fire protection (+3.2 M€/year), and HFC-23 emissions from halocarbon production (0.55 M€/year).

Basis of the cost calculation is the number of replaced units in the different sectors in 2030, which are estimated in the model AnaFgas. The operators of refrigeration and fire protection equipment and of XPS production lines are facing investment costs for abatement technologies, which are higher than those for conventional HFC systems (see cost data in the relevant EU sector sheets). However, operators save on the cost for energy (commercial refrigeration equipment) and, except where unsaturated HFCs are used, for refrigerants and blowing agents. Moreover, the costs that arise from the application of Articles 3 and 4 of the F-gas Regulation to stationary refrigeration and fire protection equipment are no longer necessary. Additional maintenance costs arise only for ammonia-based equipment and systems with transcritical use of carbon dioxide since only for these technologies increase in maintenance requirements is expected, compared to conventional HFC technologies.

The net sector costs are shown on an annual basis for each sector in table VII-3. They are calculated in comparison to the costs of HFC systems under the WM scenario, which are subject to Articles 3 and/or 4(1) of the F-gas Regulation (see EU sector sheets in annex V). The total additional net cost for the 6 HFC sectors is 529 M€/year in 2030. These net costs include both the (annualised) investment cost for equipment including first fill of equipment (both discounted at 4%) and the, mostly negative, operating cost for energy, maintenance, and refill of leakage.

Direct costs per operators (end-users)

It is assumed that the number of operators in a sector is the same as the number of units in a sector.

Annualized net costs per operator range from negative cost -€ 0.02 (2 Cents) for commercial stand-alone equipment (based on hydrocarbons in direct mode or CO_2) to positive annualised net cost of € 2,283 for centralised commercial systems (supermarkets), and even € 98,000 for XPS production lines.

The annual financial charge to end users seems to be viable for commercial condensing units (€ 2.9) and fire protection installations (€ 130). The refrigeration sub sector with very high additional annual net cost per operator is centralised refrigeration at € 2,283. It should be considered that owners of supermarkets, like all operators in commercial refrigeration, are not private households but commercial entities with comparably high financial resources.

In the XPS sector, the additional manufacturing net costs for a new production line with blowing agents alternative to HFC-134a amount to 98,000 €/y. Considering an annual output of a typical production line of ca. 75,000 cubic metres of foam, and a wholesale price of € 300 per cubic metre foam board, the annual production is worth over 20 M€. Compared to this, the additional cost of 98,000 € account for just 0.5% of the annual output of products, and thus represents viable financial load to the operators[147].

Administrative costs on EU businesses

Self- or co-regulated instruments such as voluntary agreements result in very low administrative costs for public institutions as industry bodies usually carry out agreed measures such as monitoring, data analyses and evaluation. However, this means that additional administrative costs for montitoring, data collection, data aggregation and evaluation will occur for the industry. The additional costs strongly depend on the actual monitoring and data collection procedures and whether such data is already collected by individual undertakings and forwarded to associations that are frequently responsible for the implementation of voluntary agreements.

Costs for public institutions

No information available, so far.

Third countries and international relations

Import to or export from the EU is of minor importance for refrigeration equipment. This also applies to XPS foam products. Information on external trade with fire protection equipment is not yet sufficiently available.

It is likely that quantities of HFCs imported from outside of EU-27 will decrease over time which will affect production facilities, mainly in USA and Asia, where HFC manufacture largely takes place today (chapter 3.1). It should, however, be realised that the chemical industry can compensate loss in HFC sales by gains in sales of unsaturated HFCs.

Social impacts

Investment costs of equipment. Sales of equipment suppliers

Investment costs for new equipment to be paid by operators exclude first fill with refrigerant or fire protection agent, and, in the XPS sector, the blowing agent. On an annual basis, the cost of equipment alone range from 0 €/y (fire protection equipment) to 752.7 M€/year

---

[147] It must be stated that the share of 0.5% only applies to the blowing agent penetration mix of 85% organic solvent and 15% unsaturated HFCs. If we consider only the 15% of products (2 production lines) for which the use of unsaturated HFCs is necessary, the additional annual costs are not only 98,000 €/y but 2.7 M€/y (for these 2 lines) as a result of the high expenses for blowing agent (see EU sector sheet 23). The share of the additional cost is no longer 0.5% but increases to 13% (if the price of the concerned products will not be increased).

(condensing units) and 773.9 M€/year (centralized systems). The total annualised equipment cost in the affected sectors amount to 1,611 M€/year. This sum is the equivalent to the additional annual sales of equipment suppliers. These will receive additional earnings of 1,611 M€/year from manufacture, delivery and installation of systems of alternative technologies.

Effect on service companies

After replacement of HFCs in commercial refrigeration and HFC-23 in fire protection, servicing activities according to Articles 3 and 4(1) of the F-gas Regulation are not required any more. This leads to a loss in service turnover of 345 M€/year. New servicing needs arise for CO_2 systems and cause gains of 57 M€/year. Net loss at service companies is 289 M€/year. Losses are particularly high for condensing units (-186 M€/year) and rather low for service of fire protection equipment (-2.2 M€/year).

Employment

The increase in sales at equipment suppliers is expected to lead to the creation of new jobs. The job creation could be high at manufacturers/installers of condensing units and centralized systems, medium at companies for commercial stand-alone equipment, and low at suppliers of XPS production equipment. Furthermore, jobs would also be created at manufacturers/installers of HFC-23 by-product abatement technology.

Specialized providers of service and maintenance are the actors who are facing strongest reduction in activities and turnover, with the consequence of increased job risk.

It must, however, be considered that in Europe, there service companies who limit their business activities to leak checking and recovery rarely exist. The providers of service and maintenance are largely involved in installation of new equipment or in its on-site erection. Vice versa, specialised, large-scale manufacturers of refrigeration and fire protection equipment are rarely limited to production, but are also involved in service and maintenance of equipment, and in the implementation of Art 3 and 4 of the F-gas Regulation at their customers. It is possible that both equipment suppliers and service companies would benefit from the realisation of the option “Voluntary Agreements”.

Health and occupational risks

Most substances used in abatement technologies are flammable. Common HC refrigerants such as R290 and R600a are classified by ASHRAE in the safety group A3 (high flammability) and show low flammability level (LFL) of ca. 2% concentration in a room. Unsaturated HFC refrigerants which are also likely to be used as substitutes for HFCs show higher LFL (> 5.5%) and have recently been classified as “mildly flammable” (A2L), which is the new sub class of A2, for which the application is less restrictive than for A3 refrigerants.

The unsaturated HFC-1234ze which is considered a possible alternative blowing agent for XPS foam is not flammable at room temperature (<30°C). However, the process temperature in foam blowing is significantly higher than 30°C so that adequate safety measures must be kept in the factory, comparable to those when hydrocarbons/organic solvents or HFC-152a are used.

It should be noted that the XPS products themselves do not contain flammable gases because hydrocarbons are completely released to the atmosphere on manufacturing, if they are used as blowing agents.

Health risks from flammable refrigerants (hydrocarbons, unsaturated HFCs) for non-professionals are met by technical safety standards and safety installations (charge limits in occupied spaces, operation in indirect mode for higher charges, etc.). However, health risks for professional persons from improper handling or installation cannot be ruled out. This does not only apply to flammable substances but also to substances that are operated at very high pressure (CO_2) or are toxic (ammonia). The risks can be minimized by training and education, which is obligatory for persons in contact with dangerous substances.

Health and occupational risks are not considered high for the relevant sectors but are not quantified in this study.

More detailed analysis is required whether and how flammability risks, in particular those of hydrocarbons, can sufficiently be managed. This aspect grows in importance as hydrocarbons (A3) compete with other flammable substances (A2L), which the chemical industry offers as low-GWP alternatives to common HFCs.

Table VII-3: Option D-1 Voluntary agreements: Selected impacts in 2030

	Environmental impacts			Economic impacts			Social impacts		
Voluntary agreements	Number of replaced units in 2030	Reduction of direct HFC emissions 2030 (kt CO_2 eq)	Effect on indirect energy-rel. CO_2 emiss. kt CO_2	Marginal emiss. abatement cost €/t CO_2 eq	Direct net costs to sector M€/year	Direct net cost per operator € /year	Investment cost of equipment (=sales of equip. suppliers) w/o first fill M€/y	Loss (-) / Gains (+) from service Art 3+4 or new service for NH_3+CO_2 M€/y	Job creation (equipment + service)
Commercial hermetics	5,737,309	149	-79.0	-0.8	-0.12	-0.02	81.3	-14.3	++
Condensing units	3,020,046	3,927	-201.6	1.2	105.0	2.9	752.7	-185.9	+++
Centralized systems	144,901	14,741	-233.9	23.7	418.8	2,283	773.9	-86.3	+++
Fire protection HFC-23	24,455	961	n.a.	3.1	3.2	130	0.0	-2.2	-
XPS-134a	13 (production lines)	1,553	n.a.	1.0	1.2	98,000	2.5		+
Photovoltaic industry to replace SF_6 and NF_3	n.e.	80 (SF_6) 20 (NF_3)	n.a.	~ 0	~ 0	~ 0	~ 0		0
Semiconductor industry	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.		n.e.
HFC-23 by product emissions	1 destruction plant	370	n.e.	< 2	0.55	0.55	0.3		+
Total	**8,926,711***	**21,802***	**-514.5**	**16.8****	**528.6***	**-**	**1,610.7***	**-288.9**	**+++**

* Without semiconductor and photovoltaic industry. ** Without photovoltaic and semiconductor industry, and without HFC-23 by-product emissions.

VII.2 Option D-3 "Improve containment and recovery under the F-gas Regulation: Include transport refrigeration in trucks and trailers"

As shown in chapter 8.1 of the report, abatement costs for including rail vehicles and refrigerated vans in the scope of containment and recovery provisions are relatively high. Reasonable abatement costs are only achieved for refrigerated trucks and trailers, which confirms the findings of an earlier study for the EU Commission on this matter[148].

Table VII-4: Parameters for including transport refrigeration in trucks and trailers in containment and recovery provisions.

Improve containment and recovery: Transport ref.	**Containment (Article 3)**	**Recovery (Article 4)**	**Abatement cost**
	Emission reductions 2030 (kt CO_2 eq)	Emission reductions 2030 (kt CO_2 eq)	(€/t CO_2 eq)
Trucks & trailers	1,289	141	46

Environmental impacts

Direct emissions

The total reduction potential of direct global warming emissions of this option amounts to 1,430 kt CO_2 eq in 2030 compared to the WM scenario. New emissions of alternative refrigerants do not arise.

Indirect emissions related to energy

Specific indirect emissions from application of Articles 3 and 4 of the F-gas Regulation do not arise.

Toxicity of alternative substances

Not applicable.

Economic impacts

Marginal abatement costs of F-gas emissions

Marginal abatement costs of this option are comparably high at 45.8 €/t CO_2 eq but are below 50 €/t CO_2 eq which are considered a critical magnitude.

Direct net costs to industry sectors

Direct net costs to the transport refrigeration sector amount to 66.4 M€/year.

Direct costs per operator

Direct net costs per operator (one vehicle) will amount to ca. 105 €/year.

Administrative costs to EU businesses

No information available, so far.

[148] BIPRO 2008: Study on the potential application of Art 3 and 4(1) of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases to air conditioning and refrigeration systems contained in different transport modes. Final report, prepared for the European Commission, DG Environment.

Costs for public institutions

Administrative costs are related to the need for implementation of new legislation establishing certification requirements for personnel, as well as issuance of certificates and control. As the general systems for certification are already established under the F-gas Regulation, additional administrative costs for Member States are considered to be very low.

Third countries and international relations

The share of vehicles from Non-EU countries in refrigerated road transportation within EU-27 is negligible. Therefore, operators from third countries are not found to be advantaged compared to EU-based operators paying additional operational costs for containment and recovery.

Social impacts

Invest costs of equipment by operators. Gains of equipment suppliers

Not applicable for this option.

Business opportunities for service companies

This option will lead to an increase of service costs to operators of refrigerated trucks and trailers to 71.3 M€/year.

Employment

New requirements for servicing of refrigerated trucks and trailers are expected to lead to the creation of new jobs at service companies (medium impact).

Occupational health

No additional impacts on health and safety of personnel are expected.

Table VII-5: Option D-3 "Improve containment and recovery": Overview of impacts in 2030

	Environmental impacts			Economic impacts			Social impacts		
Improve containment and recovery	Number of replaced units in 2030	Reduction of direct HFC emissions 2030 (kt CO_2 eq)	Reduction of indirect energy-rel. CO_2 emiss. kt CO_2	Marginal emiss. abatement cost €/t CO_2 eq	Direct net costs to sector M€/year	Direct net cost per operator € /year	Investment cost of equipment (=sales of equip. suppliers) w/o first fill M€/y	Service cost for operators (= gains for service companies) by Art 3+4 M€/y	Job creation at service companies
Trucks and trailers	631,000	1,430	n.a.	45.8	66.4	105.2	n.a.	71.3	++

VII.3 Option D-4a "Ban the use of F-gases in open applications (SF_6)"

With regard to open applications, the use ban for SF_6 in magnesium die casting >850 kg/year should be extended to small facilities and recycling plants.

Table VII-6: Parameters for use bans in open applications (SF_6)

Ban the use of F-gases in open applications (SF_6)	Possible start	Exemptions	Emission reduction 2030 (kt CO_2 eq)	Abatement cost (€/t CO_2 eq)
SF_6 in Mg die casting and recycling of die casting alloys	2015	no	260 (250)	0.4

Environmental impacts

Direct emissions

The direct emission reduction potential of this option is comparably low and amounts to ca. 260 kt CO_2 eq in 2030. It is assumed that half of the SF_6 quantity used as cover gas in 19 small die casting and 1 recycling plant is replaced by HFC-134a and SO_2 each. This causes new emissions of ca. 6 t of HFC-134a and ca. 6 t of SO_2. The global warming emissions of HFC-134a (there is no GWP of SO_2) would amount to 8.5 kt CO_2 eq and would decrease the emission reduction from the SF_6 substitution by 3.2%. Remaining emission reduction potential is 250 kt CO_2 eq.

Indirect emissions related to energy

No additonal energy consumption is associated with the change in cover gas.

Ecotoxicity of alternative substances

Global warming emissions of the cover gas are eliminated completely when SO_2 is applied and are significantly reduced when HFC-134a is chosen as alternative. Both, SO_2 and HFC-134a cause emissions of acidic waste gas (SO_2, HF). On application > 650°C, HFC-134a is partly decomposed to acid HF. The use of 6 t of HFC-134a is estimated to result in waste gas emissions of ca. 2 t of HF. In relevant EU legislation (e.g. Directive 2000/76/EC) and national legislation of the Member States, the mass concentration limits for this waste gas are usually 50 times lower than for SO_2 as HF is an extremely potent acid. Thus, the acidification effect from the use of HFC-134a should not be considered less severe than that from the use of SO_2.

As these emissions range below the legal threshold for waste gas concentration limits, they are considered acceptable considering the high environmental benefit of the replacement of SF_6 for climate protection.

Economic impacts

Marginal abatement costs of F-gas emissions

Abatement costs of this option are low and amount to ca. 0.4 €/t CO_2 eq.

Direct net costs to industry sector

Direct net costs to the magnesium industry amount to 10,000 €/year. Annualised equipment investment cost (~ 100,000 €/year) and annual savings from the new cover gas (~ 90,000 €/year) almost balance out each other.

Direct costs per operator

Direct costs to individual operators are estimated to range at 500 €/year (without license fee for the use of HFC-134a). The financial load to operators is considered acceptable. The charge for medium-sized and large foundries ranges between 0.06% and 0.07% of the turnover from Mg casting parts. The annual charge for small foundries is 0.5% on average[149].

Administrative costs for EU businesses

No information available, so far.

Costs for public institutions

Administrative costs are related to the need for implementation of new legislation banning the use of F-gases in open applications, as well as for the monitoring whether the bans are implemented and for enforcement and control measures.

Third countries and international relations

It is unlikely that the slight increase of cost for the application of an alternative cover gas causes operators to relocate the production to countries outside the EU-27.

Social impacts

Investment costs of equipment. Sales of equipment suppliers

Annualised investment costs for equipment to be paid by the operators of foundries are comparably low and amount to ca. 0.1 M€/year.

Effects on service companies

There will be no additional service requirements from the conversion of the cover gas.

Employment

The increase in turnover at equipment suppliers is considered too low for the creation of new jobs. In the Mg industry itself, the very limited changes to production facilities and the production process are not expected to impact on employment.

Health and occupational risks

SF_6 in magnesium die casting and recycling of alloys would need to be substituted by alternative cover gases, such as SO_2 and HFC-134a.

As SO_2 is toxic, it must be ensured that workers are not directly exposed to the gas. This could happen in case of accidents (e.g. leakage of the gas piping) and during the daily cleaning process. While in the past the furnace was very leaky or even open and occupational exposure limits (maximum acceptable concentration values) were exceeded

[149] All data from Öko-Recherche 2009: Service contract to assess the feasibility of options to reduce emissions of SF_6 from the EU non-ferrous metal industry and analyse their potential impacts; Final Report, prepared for the European Commission.

frequently, a number of technical measures have significantly improved occupational health and safety[150] in recent years.

Unlike SO_2, HFC-134a is not toxic before decomposition. Therefore, accidental leakages of the gas piping system rarely increase risks for occupational health. During the daily cleaning process of the melt, however, the lid of the crucible is open which could cause a risk to the health of cleaning workers. The concentration of the by-product HF, generated during decomposition of HFC-134a, rises to up to 40 times the limit of the concentration tolerated (e.g. Germany: 0.83 mg/m^3 /1 ppmv). As a safety measure, it is recommended that the workers wear protective masks.

An overview of selected impacts of the option “Ban the use of SF_6 in open applications” is given in table VII-7.

[150] Bartos, Scott C.: Characterization of Emissions and Occupational Exposure Associated with Five Cover Gas Technologies for Magnesium Die Casting, U.S. Environmental Protection Agency Climate Protection Partnership Division, Washington DC August 2007. Bartos measured the air near the ingot loading area of the crucible in a modern cold-chambered die-casting plant in USA (Lunt Manufacturing). He found an average SO_2 value of 0.14 ppmv which was much below the permitted concentration of 2 ppmv.

Table VII-7: Option D-4a "Ban the use of F-gases in open applications (SF_6)": Overview of impacts in 2030

	Environmental impacts			Economic impacts			Social impacts		
Ban the use of F-gases in open applications (SF_6)	Number of replaced units in 2030	Reduction of direct emissions 2030 (kt CO_2 eq)	Effect on indirect energy-rel. CO_2 emiss. kt CO_2	Marginal emiss. abatement cost €/t CO_2 eq	Direct net costs to sector M€/year	Direct net cost per operator € /year	Investment cost of equipment (=sales of equip. suppliers) w/o first fill M€/y	Loss (-) / Gains (+) from service Art 3+4 or new service for NH_3+CO_2 M€/y	Job creation (equipment suppliers)
SF_6 in Mg die casting and recycling of die casting alloys	19 + 1	250	none	0.4	0.01	500*	0.1	n.a.	0

* if no license fee for HFC-134a is paid.

VII.4 Option D-4b "Ban the placing on the market of certain open applications containing HFCs"

Bans for the placing on the market (POM) of two open applications of HFCs have been selected to be feasible, in chapter 8 of the report. In one application sector, exemptions from the POM ban need to be defined (see table VII-8).

Table VII-8: Parameters for POM bans in open applications (HFCs)

Ban POM in open applications	Possible start	Exemptions	Emission reductions 2030 (kt CO_2 eq)	Abatement cost (€/t CO_2 eq)
Technical aerosols	2020	5%; need to be defined	3,637	10.0
XPS foam (134a)	2015	no	1,553	1.0
Total			**5,190**	**7.3**

Environmental impacts

Direct emissions

The total emission reduction potential of these bans amounts to 5,190 kt CO_2 eq in 2030 compared to the emissions under the WM scenario of the model AnaFgas. On the basis of the assumed alternative propellant gas in the aerosol sector and the specific penetration mix of blowing agents that replace HFC-134a in the XPS industry (85% organic solvents, 15% unsaturated HFC-1234ze), new emissions must be considered. They would comprise 2,600 t of unsaturated HFCs (1234ze), and 2,400 t of hydrocarbons/organic solvents. Their global warming potential is calculated at 23 kt CO_2 eq, which decrease the overall emission reduction potential by 0.4%, which is negligible.

Indirect emissions related to energy

Alternative technical solutions are only considered if they show at least equal energy performance as the reference F-gas technology (see chapter 6). The insulation performance of the blowing agent "organic solvent/CO_2" is poorer than that of HFC-134a (or HFC-1234ze). The disadvantage can be offset by thicker walls of the board, which requires more raw materials, and hence increases annual operating cost. Additional indirect CO_2 emissions from energy production do not arise (for details see EU sector sheet 23 in annex V).

Ecotoxicity

Within the option D-4b, hydrocarbons (ethanol) and unsaturated HFCs (HFC-1234ze) are likely to be used as alternative substances. When released to the atmosphere in large quantities, these substances (or their decomposition products) can damage the environment.

Emissions of volatile organic compounds like ethanol (2,400 t) can contribute to ground level ozone and photochemical smog, which might impact the air quality on regional scale.

Decomposition of emitted unsaturated HFCs (2,600 t) leads to formation of hydrofluoric acid (HF), and forms, like HFCs, ca. 10% trifluoroacetic acid (TFA). The release of HF and TFA can cause acidification of ecosystems.

The quantities of emissions of alternative substances are comparably small and are not assumed to damage the environment more than the HFCs they are likely to substitute.

Economic impacts

Marginal abatement costs of F-gas emissions

Marginal emission abatement costs amount to 10 €/t CO_2 eq in the aerosol sector and to 1 €/t CO_2 eq in the foam sector (former use of HFC-134a in XPS). This results in comparably low average abatement costs of 7.3 €/t CO_2 eq.

Direct net costs to industry sectors

Annualised net sector costs are calculated in comparison to the costs of HFC systems under the WM scenario (see EU sector sheets 22 and 23 in annex V).

Starting point of the cost calculation in the XPS sector is the number of converted production lines in 2030, which are estimated at 13 units in EU-27. The additional annualised cost of equipment, raw material and blowing agent for one production line (output 75,000 m^3 XPS product per year) is calculated at 98,000 €. Thus, the direct net cost to the sector is 1.2 M€/year.

In the sector of technical aerosols, additional investment costs for the application of unsaturated HFCs are not considered. According to information from industry, the existing filling equipment can continue to be used without substantial changes for the new propellant gas which is not flammable at room temperature. The additional annualised costs to the sector consist of additional expenses for the new propellant gas for 9 million aerosol cans. As the price difference between HFC-134a and HFC-1234ze is 14.30 €/ kg (EU sector sheet 22), the additional net cost to the sector amount to 36.3 M€/year.

Direct costs per operators (end-users)

As afore mentioned, in the XPS sector the additional net costs for one production line amount to 98,000 €/year. Under the assumption that one operator owns one production facility, the annualised direct costs per operator and the annualised costs of one production line are the same. Considering an annual output of a typical production line of ca. 75,000 cubic metres, and a wholesale price of € 300 per cubic metre of foam boards, the annual production is worth over 20 M€. Compared to this, the additional cost of 98,000 €/year from application of alternative blowing agents account for just 0.5%, which represent viable financial charge to individual operators.

It must be realised that the share of 0.5% only applies to the blowing agent penetration mix of 85% organic solvent and 15% unsaturated HFCs. If we consider only 15% of products (2 production lines) for which the use of unsaturated HFCs is absolutely necessary, the additional annual costs are not only 98,000 €/y but 2.7 M€/y (for each of the two production lines) as a result of the high expenses for blowing agent (see EU sector sheet 23). The share of the additional cost is no longer 0.5% but increases to 13% (if the price of the product remains the same as before).[151]

[151] From the perspective of the end-user of the product, costs are determined as follows: Additional cost per cubic meter of product is € 1.31, if the penetration mix for the blowing agents consists of 85% of organic solvent and 15% of unsaturated HFCs. If we consider only the 15% of products for which the use of unsaturated HFCs is necessary, the additional costs per cubic metre are € 36.60. Given a

In the aerosol sector, additional costs to fillers are 14.30 €/kg of propellant gas. The increase in absolute cost depends on the annual quantity for filling. Data on typical HFC quantities for industrial fillers of non-flammable technical aerosols are not available, so far. Therefore, we are not yet able to estimate the financial charge on operators from the use of unsaturated HFCs instead of HFC-134a, expressed as share in annual sales of technical aerosols.

Administrative costs for EU businesses

So far, no information available.

Costs for public institutions

Administrative costs are related to the need for implementation of new legislation banning the use of F-gases in the two sectors, as well as for the monitoring of implementation and for enforcement and control measures.

Third countries and international relations

In contrast to MDI, external trade of technical aersols is of minor importance. No further information available yet.

Social impacts

Investment costs of equipment. Sales of equipment suppliers

Annualised investment costs for equipment to be paid by the operators in the XPS sector amount to 2.5 M€/year. The sum corresponds to additional sales of equipment suppliers and includes 13 production lines with annualised capital investment cost of 195,000 €. Investment cost for new filling equipment in the aerosol sectors do not arise.

Effects on service companies

The XPS foam and the aerosol sector are not subject to Art 3 and 4 of the F-gas Regulation. Therefore, specific service activities from the F-gas Regulation will not be ceased.

Employment

The increase in turnover at equipment suppliers can lead to the creation of a small number of new jobs.

Health and occupational risks

According to the assumed penetration mix, in the XPS sector highly flammable hydrocarbons (organic solvents) account for 85% of the annual demand of the industry for alternative blowing agents (11 of 13 production lines). Health risks for professional persons can be minimized by training and education (obligatory for persons in contact with dangerous substances) and by adequate safety installations. These are common in existing European production facilities, the majority of which already rely on the use of HFC-152a or organic solvents, both of which are flammable substances.

It should be noted that the XPS products themselves do no not contain flammable gases because hydrocarbons/organic solvents are completely released to the atmosphere on manufacturing if they are used as blowing agents.

---

market price of € 500 for one cubic metre of XPS panels (blown with HFCs), the cost increase is more than 7%. The owner of a commercial building (residential buildings are hardly insulated with XPS), for which ca. 50 m^3 XPS are required (= 1,000 m^2 of panels with a thickness of 50 mm), has to pay € 1,830 more for the products blown with unsaturated HFCs than for XPS foam based on HFC-134a.

The unsaturated HFC-1234ze, which is considered a possible alternative propellant gas for technical aerosols and a possible alternative blowing agent for XPS foam, is not flammable at room temperature (<30°C). According to information from industry, additional safety installations are not necessary in the aerosol sector. In the XPS sector, however, the process temperature on foam blowing is significantly higher than 30°C so that adequate safety measures must be taken in the factory, comparable to those when hydrocarbons/organic solvents are used.

The cost of safety installations for production facilities with blowing agents of hydrocarbons or unsaturated HFCs are accounted for in the invest cost assessment for converted production lines in the EU sector sheets.

Health and occupational risks are not considered high for the two HFC application sectors but are not quantified in this study.

Table VII-9: Option D-4b "Ban the POM of certain open applications (HFC)": Overview of impacts in 2030

	Environmental impacts			Economic impacts			Social impacts		
Quantitative limits for the placing on the market of HFCs	Number of replaced units in 2030	Reduction of direct HFC emissions 2030 (kt CO_2 eq)	Effect on indirect energy-rel. CO_2 emiss. kt CO_2	Marginal emiss. abatement cost €/t CO_2 eq	Direct net costs to sector M€/year	Direct net cost per operator € /year	Investment cost of equipment (=sales of equip. suppliers) w/o first fill M€/y	Loss (-) / Gains (+) from service Art 3+4 or new service for NH_3+CO_2 M€/y	Job creation (equipment + service)
Aerosols	9,000,000 cans	3,637	0	10.0	36.3	*(€ 14.30 per kg)**	0.0	n. a.	0
XPS-134a	13 (prod. lines)	1,553	0	1.0	1.2	98,500	2.5	n. a.	+

* Data on absolute cost per operator are not yet available.

VII.5 Option D-5 "Ban the placing on the market of certain closed applications containing F-gases"

Bans for the POM of closed applications are considered for several sub-sectors where safe and cost-effective alternatives are estimated to be available in the suggested start year (table VII-10).

Table VII-10: Parameters for bans of POM of closed applications.

Ban the POM of certain closed applications containing F-gases	Possible Start (penetration mix 100%)	Exemptions	Direct emission reduction 2030 (kt CO_2 eq)	Abatement cost (€/ t CO_2 eq)
Commercial refrigeration				
Centralized systems (supermarkets)	2020		12,055	23.7
Condensing units	2020		2,849	1.2
Commercial hermetics	2020		147	-0.8
Industrial refrigeration				
Small industrial	2030	5% need to be defined	67	-0.9
Large industrial	2030	5% need to be defined	202	-21.6
Stationary air conditioning				
Moveable AC	2020		2,781	8.9
Single split AC	2020		22,970	19.0
Multi split AC	2020		2,172	13.1
Rooftop AC systems	2020		573	8.2
Chillers				
Displacement chillers	2020		1,989	5.9
Transport refrigeration				
Refrigerated trucks and trailers	2030		322	2.6
Fire protection				
Fire protection systems with HFC-23	2015		961	3.1
Total			**47,089**	**16.9**

Environmental impacts

Direct emissions

The total direct emission reduction potential of all bans of the POM of closed applications containing F-gases amounts to 47,089 kt CO_2 eq in 2030 compared to the emissions under the WM scenario. On the basis of the assumed penetration mixes for the different sectors, new emissions of alternative refrigerants and fire extinguishing agents would comprise 6,800 t of hydrocarbons, 5,000 t of CO_2 (refrigerant), 10,300 t of unsaturated HFCs, and 210 t of fluorinated ketones. Their global warming potential is calculated at 78 kt CO_2 eq which decrease the overall emission reduction potential by 0.16%, which is negligible.

Indirect emissions related to energy

Alternative technical solutions for refrigeration and air conditioning show at least equal energy efficiency as reference F-gas technologies (see chapter 6). Where an abatement technology does not show at least identical energy efficiency, due to lower thermodynamic performance of the refrigerant itself, additional technical measures are assumed to increase the energy efficiency to the level of the reference systems. This leads to higher investment costs, which are accounted for in the abatement cost assessment in the relevant EU sector sheets in annex V.

In stationary air conditioning the energy efficiency of the abatement technologies in the penetration mix is the same as that of the reference technology. In the sectors of refrigeration the efficiency is higher so that indirect emissions in this sector are lower compared to the HFC reference technologies.

With regard to energy related emissions, the total reduction potential of all bans of POM of closed applications amounts to 716 kt CO_2 eq in 2030. The overall emission reduction of 47,000 kt CO_2 eq (direct) is increased by further 1.5% (indirect).

Ecotoxicity

When released to the atmosphere in large quantities, certain substances (or their decomposition products) used in abatement technologies can damage the environment.

Hydrocarbon (HC-290, HC-600a) emissions (6,800 t) can lead to ground level ozone and formation of photochemical smog, which might impact the air quality on regional scale.
Ammonia (emissions of 890 t), which is toxic to humans[152], too, contributes to acidification of ground and aquatic systems.
Unsaturated HFCs (10,300 t) are likely to be used as substitutes for HFCs in refrigeration and air conditioning. Decomposition processes of these substances lead to hydrofluoric acid (HF), and form, like HFCs, ca. 10% trifluoroacetic acid (TFA). The release of HF and TFA can cause acidification of ecosystems, in particular aqueous ecosystems, as it impacts the ph values.

In the fire protection sector, the fluorinated ketone FK 5-1-12 might be used as substitute for HFC-23. Decomposition products formed through thermal degradation include hydrofluoric acid (HF) and trifluoroacetic acid (TFA; toxic), to comparable degree as the replaced HFCs.

---

[152] Ammonia is classified by ASHRAE not like hydrocarbons or fluorinated substances as a class A refrigerant (low degree of toxicity) but in group B as refrigerant with higher toxicity (B2).

The quantities of emissions of alternative substances are comparably small and are not assumed to damage the environment more than the HFCs they are likely to substitute.

Economic impacts

Marginal abatement costs of F-gas emissions

Marginal abatement costs widely vary between particular sub sectors and range between ca. -21.6 €/t CO_2 eq (large industrial refrigeration plants) and +23.7 €/t CO_2 eq (centralized commercial systems), with an average of + 16.9 €/t CO_2 eq for the twelve concerned sectors.

Direct net costs to industry sectors

Annualised net sector costs are calculated in comparison to the costs of HFC systems under the WM scenario, which are subject to Articles 3 and/or 4(1) of the F-gas Regulation (see EU sector sheets in annex V).

Basis of the cost calculation is the number of replaced units in the different sectors in 2030, which are estimated in the model AnaFgas. All operators of air conditioning, refrigeration and fire protection equipment need to pay investment costs for abatement technologies, which are higher than those for conventional HFC systems (see cost assessment in the relevant EU sector sheets). Only in a few sectors, lower operating costs for energy, for refrigerants and from discontinuation of the application of Articles 3 and 4 (1) of the F-gas Regulation offset higher investment cost, on annualised calculation basis. Amongst these sectors is industrial refrigeration and commercial hermetic equipment.

Direct net costs to industry total 1,055 M€ per year, and differ largely between the twelve sub sectors. Sector costs are highest for alternative split air conditioners (489 M€/year) and centralised commercial systems (318 M€/year), which together represent 82% of the overall cost to the 12 industry sectors. Third highest cost (82 M€/year) arise for commercial condensing units. Negative costs are assumed for industrial refrigeration and commercial hermetic systems.

Direct costs per operators (end-users)

It is assumed that the number of operators in a sector is the same as the number of units in a sector.

Annualized net costs per individual user widely range from negative cost of -€ 22,642 for large industrial refrigeration equipment (based on energy efficient ammonia in direct mode), to positive annualised net cost of +€ 2,283 commercial centralised systems (supermarkets)

In the sectors of small air conditioning systems the net costs per operator (end-user) are comparably low with +0.55 €/year (moveable systems) and +5.1 €/year (single split systems). These moderate costs are important because the combined emission reduction potential of the two sectors accounts for 55% of the emission reduction potential of the twelve affected sectors.

In sectors with direct cost per user > +15 €/year (supermarkets, fire protection, chillers, multi-split ac systems, refrigerated trucks) the owners are not individual households but commercial entities. For these users higher financial resources can be assumed than for private households/end-users. Therefore, the financial load to individual operators seems to be viable in the 12 sectors of concern.

Operators of industrial refrigeration equipment benefit to particularly high extent from application of alternative refrigerants (-€ 22,642 per plant). It must, however, be noted that the financial investment calculation of industrial operators is mostly based on higher discount rates and shorter depreciation periods than used in our cost assessment in the EU sector sheets (4%; 30 years).[153]

Administrative costs for EU businesses

No information available, so far.

Costs for public institutions

Administrative costs are related to the need for implementation of new legislation banning the use of F-gases in selected sectors, as well as for the monitoring whether the bans are implemented and for enforcement and control measures.

Third countries and international relations

In certain sectors of stationary air conditioning imports from third countries play an important role. Today, high shares of new moveable, single split and multi split AC equipment containing HFCs are imported, mainly from Japan and China (see annex III, 31). The current import quotas are estimated at 90%, 75%, and 78%, respectively. If these quotas remain unchanged until 2030, production of these types of systems in Asia would be influenced by this option to considerable extent.

Furthermore, quantities of HFCs imported from outside of EU-27 will need to decrease over time which will affect production facilities, mainly in USA and Asia, where HFC manufacture largely takes place today (chapter 3.1). It should, however, be realised that the Chemical industry can compensate loss in HFC sales by gains in sales of unsaturated HFCs.

Social impacts

Investment costs of equipment. Sales of equipment suppliers

Investment costs for new equipment to be paid by operators exclude the first charge of refrigerant or fire protection agent. On an annual basis, the cost of equipment alone range from 0 €/year (fire protection equipment) to 714 M€/year (centralized commercial systems). The total annualised equipment costs in the affected twelve sectors amount to 2,860 M€/year. This sum is equivalent to the additional annual sales of equipment suppliers. These will have receive additional earnings of 2,680 M€/year from manufacture, delivery and installation of systems of alternative technologies.

Effects on service companies

After replacement of HFCs in systems of refrigeration, stationary air conditioning, and fire protection >3 kg, servicing activities according to Articles 3 and 4(1) of the F-gas Regulation are no longer required. In the sectors of moveable and single split air conditioners, application of Article 4(1) is no longer necessary. Discontinuation of Articles 3 and 4(1) leads to a total loss in service turnover of -1,270 M€/year. This sum already includes earnings from new service and maintenance for ammonia and CO_2 systems of +78 M€/year. Service losses are particularly high for single split and multi-split air conditioning units (-711 M€/year; 56%).

[153] If the depreciation period would not be the real lifetime of 30 years but only 20 years (for some reasons), the additional net cost per plant (operator) would turn from negative to positive values.

In the sectors of industrial refrigeration and refrigerated trucks earnings can be expected, which are comparably small though.

Employment

The increase in turnover at equipment suppliers is expected to lead to the creation of new jobs. The job creation could be high at manufacturers/installers of commercial centralized systems and condensing units, and single split air conditioners. Providers of service and maintenance are the actors who are facing strongest reduction in activities and turnover, which leads to increased job risk.

It must, however, be considered that in Europe, service companies which have limited their business activities to leak checking and recovery rarely exist. The providers of service and maintenance are largely involved in installation of new equipment and its on-site erection. Vice versa, specialised large-scale manufacturers of refrigeration, air conditioning and fire protection equipment are rarely limited to production, but are also involved in service and maintenance of equipment, and in containment and recovery measures according to Articles 3 and 4 of the F-gas Regulation at their customers. It is therefore possible that both, equipment suppliers and service companies would benefit from the realisation of the option “bans of POM of certain closed systems containing F-gases”.

Health and occupational risks

Most substances used in abatement technologies are flammable. Common HC refrigerants such as R290 and R600a are classified by ASHRAE in the safety group A3 (high flammability) and show low flammability level (LFL) of ca. 2% concentration in a room. Unsaturated HFC refrigerants which are also likely to be used as substitutes for HFCs show higher LFL (> 5.5%) have recently been classified as “mildly flammable” (A2L), which is the new sub class of A2, for which the application is less restrictive than for A3 refrigerants. The new fire safety class A2L may also include HFC-32 and ammonia. The latter is still classified B2, indicating higher toxicity than usual for A class refrigerants (A1, A2, A3).

Health risks from flammable substances (hydrocarbons, unsaturated HFCs) for non-professionals are met by technical safety standards and safety installations (charge limits in occupied spaces, operation in indirect mode for higher charges, etc.). However, health risks for professional persons from improper handling or installation cannot be ruled out. This does not only apply to flammable substances but also to substances that are operated at very high pressure (CO_2) or are toxic (ammonia). The risks can be minimized by training and education, which is obligatory for persons in contact with dangerous substances.

Health and occupational risks are not considered high for the twelve involved application sectors, but are not quantified in this study.

More detailed analysis is required whether and how flammability risks, in particular those of hydrocarbons, can be managed sufficiently. This aspect grows in importance as hydrocarbons (A3) compete with other flammable substances (A2L) which the Chemical industry offers as low-GWP alternatives to common HFCs.

Table VII-11: Option D-5 "Ban the POM of certain closed applications containing F-gases": Overview of impacts in 2030

	Environmental impacts			**Economic impacts**			**Social impacts**		
Ban the POM of certain closed applications containing F-gases	Number of replaced units in 2030	Reduction of direct HFC emissions 2030 (kt CO_2 eq)	Reduction of indirect energy-rel. CO_2 emiss. kt CO_2	Marginal emiss. abatement cost €/t CO_2 eq	Direct net costs to sector M€/year	Direct net cost per operator € /year	Investment cost of equipment (=sales of equip. suppliers) w/o first fill M€/y	Loss (-) / Gains (+) from service Art 3+4 or new service for NH_3+CO_2 M€/y	Job creation (equipment + service)
Hermetic Commercial	5,307,011	147	73.1	-0.8	-4.64	-0.02	70.7	-13.3	++
Condensing units	2,421,320	2,849	162.3	1.2	82.44	2.9	602.2	-157.1	+++
Centralized systems	134,032	12,055	220.1	23.7	380.1	2,283	714.1	-80.0	+++
Industrial Ref small	462	67	5.8	-0.9	-0.07	-153	5.2	0.5	++
Industrial Ref large	225	202	51.7	-21.6	-5.10	-22,642	38.6	0.3	+++
Refrigerated Trucks	63,185	322	12.4	2.6	0.96	15.2	16.5	0.04	++
Moveable AC systems	34,283,827	2,781		8.9	18.76	0.55	74.4	-85.7	+
Split AC systems	96,697,511	22,970		19.0	488.72	5.1	630.4	-483.5	+++
Multi split AC systems	1,376,202	2,172		13.1	45.74	26.4	278.4	-228.4	+++
Rooftop AC systems	522,524	573		8.2	11.78	9.0	99.2	-85.3	++
Chillers	714,570	1,989	191.3	5.9	33.05	25.2	330.5	-134.1	+++
Fire protection 23	24,455	961		3.1	3.18	130.1	0	-2.2	0
Total	**141,545,325**	**47,089**	**716.6**	**16.9**	**1,055.0**	**-**	**2,860.2**	**-1,270.2**	**+++**

VII.6 Option D-6 “Set quantitative limits for the placing on the market of F-gases (HFCs)”

This option could implement a gradual HFC phase down at EU level to achieve significant F-gas emission reductions.

Compared to the other options included in the assessment of impacts, this option provides most flexibility to industry to adapt to a transition to low GWP options available.
Table VII-12 illustrates the minimum level of HFC supply of all sectors that could be achieved in EU-27 by technically feasible abatement options as outlined in annex VI and chapter 6 and calculated by the model AnaFgas.

Table VII-12: Parameters for quantitative limits for the placing on the market of HFCs in EU-27

Set quantitative limits for the placing on the market of F-gases	Additional supply reductions in 2030	Additional direct emission reductions in 2030	Emission abatement cost
	kt CO_2 eq	kt CO_2 eq	€/t CO_2 eq
	136,500	71,740	16.2

Environmental impacts

Direct emissions

The total direct emission reduction potential of the option D-6, quantitative limits to placing on the market of HFCs, amounts to 71,740 kt CO_2 eq in 2030 compared to emissions under the WM scenario. On the basis of the assumed penetration mixes for the 25 sectors, new emissions of alternative refrigerants and fire extinguishing agents would comprise 15,000 t of hydrocarbons (including ethanol-solvents), 5,900 t of CO_2 (refrigerant), 17,700 t of unsaturated HFCs, 2,600 t of ammonia, and 360 t of fluorinated ketones. Their global warming potential is calculated 140 kt CO_2 eq, which decrease the overall emission reduction potential by 0.2%, which is negligible.

Indirect emissions related to energy

The alternative technical solutions for refrigeration, air conditioning, and foam blowing show at least equal energy performance as the reference F-gas technologies (see chapter 6). Where an abatement solution does not show at least identical energy efficiency, due to lower thermodynamic performance of the refrigerant or due to poorer insulation performance of the blowing agent, additional technical measures can increase the energy efficiency to the level of the reference systems. This leads to an increase in investment costs, which is accounted for in the abatement cost assessment in the relevant EU sector sheets in annex V. Additional technical measures in the foam sectors are increased thickness of the insulation walls to compensate for higher thermal conductivity of the blowing agent which requires more raw material and increases operational costs.

In the sectors of mobile and stationary air conditioning and of foam, the energy efficiency of the abatement technologies in the penetration mix is the same as in the reference systems. In refrigeration the energy efficiency is higher for the abatement solutions represented in the assumed technology mix. As a result, indirect emissions in refrigeration (stationary and transport refrigeration) are lower compared to the HFC reference technologies.

With regard to energy related emissions, the total reduction potential of the limits for POM of HFCs amounts to 1,583 kt CO_2 eq in 2030. The overall emission reduction of 71.600 kt CO_2 eq (direct) is increased by further 2.2% (indirect).

Ecotoxicity

When released to the atmosphere in large quantities, certain substances (or their decomposition products) used in abatement technologies can damage the environment.

Hydrocarbon (HC-290, HC-600a, and ethanol) emissions (15,000 t) can lead to formation of ground level ozone and photochemical smog, which might impact the air quality on regional scale.

Ammonia (emissions of 2,600 t) contributes to acidification of ground and aquatic systems.
Unsaturated HFCs (17,700 t) are likely to be used as substitutes for HFCs in refrigeration and air conditioning, and additionally in foam blowing and technical aerosols. Decomposition processes of these substances lead to formation of hydrofluoric acid (HF), and form, like HFCs, ca. 10% trifluoroacetic acid (TFA). The release of HF and TFA can cause acidification of ecosystems, in particular aqueous ecosystems.

In the fire protection sector, the fluorinated ketone FK 5-1-12 (emissions of 360 t) might be used as substitute for HFC-227ea and HFC-23. Decomposition products formed through thermal degradation include hydrofluoric acid (HF) and trifluoroacetic acid (TFA; toxic), to comparable degree as the replaced HFCs.

The quantities of emissions of alternative substances are comparably small and are not assumed to damage the environment more than the HFCs they are likely to substitute.

Economic impacts

Marginal abatement costs of F-gas emissions

Marginal abatement costs widely vary between particular sectors and range between ca. -21.6 €/t CO_2 eq (large industrial refrigeration plants) and +48.5 €/t CO_2 eq (bus air conditioning), with an average of + 16.2 €/t CO_2 eq for the 25 concerned sectors.

Direct net costs to industry sectors

Annualised net sector costs are calculated in comparison to the costs of HFC systems under the WM scenario, most of which are subject to Articles 3 and/or 4(1) of the F-gas Regulation (see EU sector sheets in annex V).

Basis of the cost calculation is the number of replaced units in the different sectors in 2030, which are estimated in the model AnaFgas. All operators of air conditioning, refrigeration, fire protection, and foam blowing equipment need to pay investments cost for abatement technologies, which are higher than those for conventional HFC systems (see cost assessment in the relevant EU sector sheets)[154]. Only in a few sectors, lower operating costs for energy, for certain refrigerants and foam blowing agents, and from discontinuation of the measures set out by Articles 3 and 4 (1) of the F-gas Regulation offset higher annualised investment cost. This is the case in industrial refrigeration and commercial hermetic equipment, and in XPS industry which currently uses HFC-152a as blowing agent.

[154] In the aerosol sector, higher investment costs from application of unsaturated HFCs (1234ze) are not considered in the study because the existing filling equipment for HFC-134a can continue to be used. Additional costs in the sector relate to the costs of the alternative propellant gas only.

Direct net costs to industry total 1,500 M€/year, and differ largely between the 25 sub sectors. Annualised sector costs are by far highest for alternative split air conditioners (488 M€/year) and centralised commercial systems (419 M€/year). These two sectors together represent 60% of the overall cost to the 25 industry sectors. Third highest cost (228 M€/year) arise for mobile air conditioning of trucks. Negative costs are assumed for industrial refrigeration, for commercial hermetic systems, and for XPS manufacture where hydrocarbons replace HFC-152a blowing agents.

Direct costs per operators (end-users)

It is assumed that the number of operators in a sector is the same as the number of units in a sector.

Annualized net costs per individual user widely range from negative cost of -€ 56,400 for XPS with HFC-152a and -€ 22,642 for large industrial refrigeration equipment (based on energy efficient ammonia in direct mode) to positive annualised net cost of +€ 98,000 for XPS production with HFC-134a. Comparably high net costs per operator arise also for owners of ships (mobile air conditioning) and fishing vessels (transport refrigeration). Extremely high or low costs per operator occur in sectors with a small number of units which show extraordinary high one-time investment cost (e. g. large industrial plants: 9.0 M€; fishing vessels: 2.3 M€; manufacturing equipment of XPS foam: 1.6 M€).

In the sectors of air small air conditioning systems, the net cost per operator (end-user) are comparably low with +0.55 €/year (moveable systems) and +5.1 € /year (single split systems). These moderate costs are important because the combined emission reduction potential of the two sectors accounts for 35% of the emission reduction potential of all 25 sectors.

In sectors with high direct cost per user > 150 €/year (supermarkets, fishing vessels, ship and bus air conditioning, fire protection, industrial refrigeration, XPS-134a, other PU foam, etc.), the owners are not individual households but commercial entities. For these users higher financial resources can be assumed than for private end-users. Therefore, the financial charge to individual operators seems to be viable in the 25 involved sectors.

Operators of industrial refrigeration equipment benefit to particularly high extent from the application of alternative refrigerants (-€ 22,642 per plant). It must, however, be noted that the financial investment calculation of industrial operators is mostly based on higher discount rates and shorter depreciation periods than used in our cost assessment in the EU sector sheets (4%; 30 years).[155]

In the XPS sector, the additional manufacturing net costs of a new production line with alternative blowing agents to HFC-134a amount to 98,000 €/year. Under the assumption that one operator owns one production facility, the annualised direct costs per operator and the annualised costs of one production line are the same. Considering an annual output of a typical production line of ca. 75,000 cubic metres of foam, and a wholesale price of € 300 per cubic metre of foam panels, the annual production is worth over 20 M€. Compared to this

[155] If the applied depreciation period would not be the lifetime of 30 years but only 20 years, the additional net cost per plant (operator) would turn positive.

sum, the additional cost of 98,000 €/year represent just 0.5% of the annual sales, which is considered viable financial load to operators[156].

In the aerosol sector, additional costs to fillers are 14.30 €/kg of propellant gas. The increase in absolute cost depends on the annual quantity for filling. Data on typical HFC quantities used by industrial fillers of non-flammable aerosols are not available. Therefore, we are not yet able to estimate the financial load to individual operators from use of unsaturated HFCs instead of HFC-134a, expressed as share in annual sales of technical aerosols.

Administrative costs for EU businesses

So far, no information available.

Costs for public institutions

The option that could be implemented in a similar way as the ODS phase out, can build on know-how and structures for implementation established in all Member States due to the long term experience of implementing the Montreal Protocol and related European ODS policies. Information on the past and current costs for ODS phase-down and phase out could be used to estimate the administrative costs for this option.

The administrative costs of the option that introduces a trading scheme for allowances to place fluorinated gases on the market would require administrative acts for the issuance of allowances (either a process for "grandfathering" or an auctioning system), for the monitoring of the placing of the market and a registry or account database that registers the allowances submitted and the amounts placed on the market, as well as an administrative system for compliance. Different to the first option, most of these administrative costs would occur at EU level, while also revenues from auctioning of allowances would create revenues at that level. Another way of implementing this option could be the integration in a quota allocation and licensing scheme (see description of option D-6, chapter 8.1).

Third countries and international relations

In certain sectors of stationary air conditioning, imports from third countries play an important role. Today, high shares of new factory sealed, single split and multi split AC equipment containing HFCs are imported, mainly from Japan and China (see annex III, 31). The current import quotas are estimated at 90%, 75%, and 78%, respectively. If these quotas remain unchanged until 2030, production of these types of systems in Asia would be influenced by this option, to considerable extent.

Furthermore, quantities of HFCs imported from outside of EU-27 will need to decrease over time which will affect production facilities, mainly in USA and Asia, where HFC manufacture largely takes place today (chapter 3.1). It should, however, be realised that the Chemical industry can compensate loss in HFC sales by gains in sales of unsaturated HFCs.

---

[156] It must be stated that the share of 0.5% only applies to the blowing agent penetration mix of 85% of organic solvent and 15% of unsaturated HFCs. If we consider only the 15% of products (2 production lines) for which the use of unsaturated HFCs is necessary, the additional annual costs are not only 98,000 €/year but 2.7 M€/year (for these 2 lines) as a result of the high expenses for blowing agent (see EU sector sheet 23). The share of the additional cost is no longer 0.5% but increases to 13% (if the price of the concerned products will not be increased).

Social impacts

Investment costs of equipment. Sales of equipment suppliers

Investment costs for new equipment to be paid by operators in the different sectors exclude the first charge of refrigerant or fire protection agent. On an annual basis, the cost of equipment alone range from 0 €/year (fire protection) to 1,011 M€/year (in the sector of bus air conditioning). The total annualised equipment cost in the affected 25 sectors amount to 5,613 M€/year, which is twice as much as under option D-5, bans of POM of closed applications. This sum is equivalent to the additional annualised sales of equipment suppliers. These will receive additional earnings of 5,613 M€/year from manufacture, delivery and installation of systems of alternative technologies.

Effects on service companies

After replacement of HFCs in systems of refrigeration, stationary air conditioning, and fire protection equipment >3 kg, servicing activities according to Articles 3 and 4(1) of the F-gas Regulation are no longer required. In the sectors with charges <3 kg, i.e. domestic refrigeration, commercial hermetics, moveable air conditioners, single split air conditioners, and, partly, condensing units, application of Article 4(1) is no longer required. Discontinuation of Articles 3 and 4(1) leads to a net loss in service activities and turnover of -1,356 M€/year. This sum already includes earnings from new service and maintenance for ammonia and CO_2 systems of +114 M€/year. Losses are particularly high in four sectors, namely single split and multi-split air conditioning units, chillers, and condensing units (-1,070 M€/year; 79%). In transport refrigeration (vans, trucks, fishing vessels) earnings can be expected, which are, however, comparably small.

Employment

The increase in turnover at equipment suppliers is expected to lead to the creation of new jobs. The job creation could be high at manufacturers/installers of commercial refrigeration equipment (centralized systems and condensing units), manufacturers/installers of stationary air conditioning systems (single split and multi-split air conditioners and chillers), and manufacturers/installers of large industrial refrigeration plants. Particularly high will be the increase of sales at manufacturers and installers of mobile air conditioning systems for buses and trucks (31% of the total).

Providers of service and maintenance are the actors who are facing strongest decrease in turnover, which leads to increased job risk.

It must, however, be considered that in Europe, service companies which have limited their business activities to leak checking and recovery rarely exist. The providers of service and maintenance are largely involved in installation of new equipment and its on-site erection. Vice versa, specialised large-scale manufacturers of refrigeration and fire protection equipment are rarely limited to production, but are also involved in service and maintenance of equipment, and in containment and recovery measures according to Articles 3 and 4 of the F-gas Regulation at their customers. It is therefore possible that both equipment suppliers and service companies would benefit from the policy option D-6, quantitative limits of POM of F-gases.

Health and occupational risks

Most substances used in abatement technologies are flammable. Common HC refrigerants such as R290 and R600a are classified by ASHRAE in the safety group A3 (high flammability) and show low flammability level (LFL) of ca. 2% concentration in a room. Unsaturated HFC refrigerants which are also likely to be used as substitutes for HFCs show higher LFL (> 5.5%) have recently been classified as "mildly flammable" (A2L), which is the new sub class of A2, for which the application is less restrictive than for A3 refrigerants. The new fire safety class A2L may also include HFC-32 and ammonia. The latter is still classified B2, indicating higher toxicity than usual for A class refrigerants (A1, A2, A3).

The unsaturated HFC-1234ze which is considered not only a possible alternative refrigerant (for centrifugal chillers) and aerosol propellant but also an alternative blowing agent for XPS foam is not flammable at room temperature (<30°C). However, the process temperature on foam blowing is significantly higher than 30°C so that adequate safety measures must be taken in the factory, comparable to those when hydrocarbons/organic solvents are used.

It should be noted that the XPS products themselves do no not contain flammable gases because hydrocarbons/organic solvents are completely released to the atmosphere on manufacturing if they are used as blowing agents.

Health risks from flammable substances (hydrocarbons, unsaturated HFCs) for non-professionals are met by technical safety standards and safety installations (charge limits in occupied spaces, operation in indirect mode for higher charges, etc.). However, health risks for professional persons from improper handling or installation cannot be ruled out. This does not only apply to flammable substances but also to substances that are operated at very high pressure (CO_2) or are toxic (ammonia). The risks can be minimized by training and education, which is obligatory for persons in contact with dangerous substances.

Health and occupational risks are not considered high for the involved application sectors, but are not quantified in this study.

More detailed analysis is required whether and how flammability risks, in particular those of hydrocarbons, can be managed sufficiently. This aspect grows in importance as hydrocarbons (A3) compete with other flammable substances (A2L) which the Chemical industry offers as low-GWP alternatives to common HFCs.

Table VII-13: Option D-6 "Set quantitative limits for the placing on the market of F-gases (HFCs)": Overview of impacts

	Environmental impacts			Economic impacts			Social impacts		
Quantitative limits for the placing on the market of HFCs	Number of replaced units in 2030	Reduction of direct HFC emissions 2030 (kt CO_2 eq)	Reduction of indirect energy-rel. CO_2 emiss. kt CO_2	Marginal emiss. abatement cost €/t CO_2 eq	Direct net costs to sector M€/year	Direct net cost per operator € /year	Investment cost of equipment (=sales of equip. suppliers) w/o first fill M€/y	Loss (-) / Gains (+) from service Art 3+4 or new service for NH_3+CO_2 M€/y	Job creation (equipment + service)
Domestic Refrigeration	2,783,424	12	1.8	1.0	0.01	0.004	2.0	-0.3	+
Hermetic Commercial	5,737,309	149	79.0	-0.8	-0.12	-0.02	81.3	-14.3	++
Condensing units	3,020,046	3,927	201.6	1.2	105.0	2.9	752.7	-185.9	+++
Centralized systems	144,901	14,741	233.9	23.7	418.8	2,283	773.9	-86.3	+++
Industrial Ref small	5,968	871	75.3	-0.9	-0.92	-153	67.3	-6.5	++
Industrial Ref large	2,909	2,612	667.7	-21.6	-65.9	-22,642	498.7	-3.6	+++
Refrigerated Vans	601,764	421	7.1	45.1	20.9	31.8	17.8	+1.5	+
Refrigerated Trucks	532,335	2,990	100.5	2.6	16.8	15.2	141.7	+3.7	++
Fishing vessels	365	405	8.7	3.4	1.96	5,368	6.3	0	+
Cargo ship AC	3,715	320	0.7	16.7	5.60	1,504	4.1	+0.01	+
Passenger ship AC	469	125		35.0	2.90	6,190	0.7	0	0
Bus AC	609,411	1,616		48.5	107.1	158	1,011.4	-	+++
Truck AC	19,520,298	4,170		43.1	227.9	11.7	724.2	-	+++
Moveable AC systems	34,283,827	2,781		8.9	18.7	0.55	74.4	-85.7	+
Split AC systems	96,697,511	22,970		19.0	488.7	5.1	630.4	-483.5	+++
Multi split AC systems	1,570,583	2,827		13.1	53.5	26.4	316.6	-256.0	+++
Rooftop AC systems	522,524	573		8.2	11.8	9.0	99.2	-85.3	++
Chillers	771,866	2,512	207.0	5.9	36.3	25.2	357.0	-143.7	+++
Centrifugal chillers	3,799	82		11.1	1.51	318	3.0	-3.1	0
Fire protection 227ea	48,550	440		22.3	10.9	225	5.4	-4.4	+
Fire protection 23	24,455	961		3.1	3.18	130	0.0	-2.2	0
Aerosols	9,000,000 cans	3,637		10.0	36.3	4.0	0.0	-	+
XPS-152a	13 (prod. lines)	460		-1.6	-0.7	-56,400	2.5	-	+
XPS-134a	13 (prod. lines)	1,553		1.0	1.2	98,000	2.5	--	+
PU other	77 (prod. lines)	587		3.5	0.32	4,130	3.3		+
Total	**166,886,028***	**71,740**	**1,583**	**16.2**	**1,500.0**	**-**	**5,612.8**	**-1,355.7**	**+++**

* Without number of aerosol cans.

VII.7 Option D-8 “Destruction of HFC-23 emissions from halocarbon production”

The inadvertent formation of HFC-23 emissions within the manufacturing process of halocarbons cannot be addressed by bans, containment measures or limits for placing on the market, but destruction technology needs to be installed and operated properly by halocarbon production facilities and emissions need to be monitored.

Such measures could be achieved by a VA (see sub option within option “Voluntary agreements”). However, potential international agreements under the Montreal Protocol might require legal implementation of such measure.

Environmental impacts

Direct emissions

The one European plant without abatement technology annually causes emissions of ca. 26 metric tons of HFC-23. Installation of an incineration facility is assumed to reduce the emissions by 25 t to 1 t per year. Thus, the emission reduction potential of this option amounts to 370 kt CO_2 eq today and in 2030 compared to the WM scenario of the model AnaFgas.

Indirect emissions related to energy

So far, No information is available on possible additional energy consumption for the destruction/incineration plant. These data are site-specific.

Ecotoxicity

It is assumed that decomposition products in the waste gas are sufficiently abated.

Economic impacts

Marginal abatement costs of F-gas emissions

Abatement costs for HFC-23 emissions from halocarbon destruction are rather low at <2 €/t CO_2 eq.

Direct net costs to industry sectors

This option requires the operator of halocarbon production facilities to install destruction technology. Direct costs to industry are expected to range at ca. 0.55 M€/year. These costs are considered acceptable for Chemical companies.

Direct costs per operator

In this option, end users are in fact represented by the one operator of the halocarbon production facility. Therefore the costs per operator are also ca. 0.55 M€/year.

Administrative costs for EU businesses

No information available, so far.

Costs for public institutions

Administrative costs are related to the need for implementation of new legislation requiring the installation of destruction technology, as well as for the monitoring and for enforcement and control measures.

Third countries and international relations

No effect likely.

Social impacts

Investment costs for equipment. Earnings of equipment suppliers

Equipment investment costs are expected to be in the range of 0.3 M€/year, which is comparably low.

Effects on service

No information available.

Employment

The technical measures required in this option and the related need for investments is likely to result in low negative effects on employment at the one halocarbon production facility concerned. In contrast, business opportunities for manufacturers of destruction technology arise to limited extent, but are not estimated to lead to the creation of additional jobs. Positive and negative employment effects are likely to balance each other.

Occupational health

So far, no information is available.

Table VII-14: Option D-8 "Destruction of HFC-23 emissions from halocarbon production": Overview of impacts

	Environmental impacts			**Economic impacts**			**Social impacts**		
Mandatory destruction of HFC-23 emissions from halocarbon production	Number of replaced units in 2030	Reduction of direct HFC emissions 2030 (kt CO_2 eq)	Reduction of indirect energy-rel. CO_2 emiss. kt CO_2	Marginal emiss. abatement cost €/t CO_2 eq	Direct net costs to sector M€/year	Direct net cost per operator € /year	Investment cost of equipment (=sales of equip. suppliers) w/o first fill M€/y	Loss (-) / Gains (+) from service Art 3+4 or new service for NH_3+CO_2 M€/y	Job creation (equipment + service)
Destruction of HFC-23 emissions to the extent possible	1	370	n.e.	< 2	0.55	0.55	0.3	n.a.	0