UNITED NATIONS

EP

UNEP/OzL.Pro/Workshop.8/2/Add.1

Distr.: General
6 May 2015

Original: English

United Nations Environment Programme

Workshop on hydrofluorocarbon management: technical issues
Bangkok, 20 and 21 April 2015

Report of the workshop on hydrofluorocarbon management: technical issues

Addendum

Summaries by the session rapporteurs

I. Background

1. The present addendum compiles the reports written by the rapporteurs of sessions 1 to 5 of the workshop on technical issues related to hydrofluorocarbon (HFC) management, held in Bangkok on 20 and 21 April 2015. The session reports formed the basis of the summary by the rapporteurs of the key conclusions of the workshop (UNEP/OzL.Pro.WG.1/35/5), presented to the Open-ended Working Group at its thirty-fifth meeting, held in Bangkok from 22 to 24 April 2015, immediately following the workshop. The session rapporteurs were the following:

Session 1: Mr. Ullrich Hesse

Session 2: Mr. Richard Abrokwa-Ampadu

Session 3: Mr. Gursaran Mathur

Session 4: Mr. Enshan Sheng

Session 5: Mr. Chandra Bhushan

2. The final programme of the workshop is set out in the annex to the present addendum.

II. Session 1

Challenges and opportunities in addressing high-GWP HFCs in the refrigeration sector

A. Introduction

3. The session on refrigeration considered four main sectors, namely, commercial, industrial, transport refrigeration and domestic. In terms of total carbon dioxide (CO_2)-equivalent they are split as follows: commercial (73 per cent), industrial (20 per cent), transport refrigeration (5 per cent) and domestic (2 per cent). The need for cooling of food and beverages creates a major refrigeration requirement in these main sectors. Temperature levels for refrigerating food are: (a) medium temperature (0 to +8 °C) and (b) low temperature (-25 to -18°C). Industrial refrigeration includes many different applications which require different temperature levels.

4. Introductory presentations were given by Mr. Paulo Vodianitskaia and Mr. Reinhard Radermacher, who elaborated on the various lower-global-warming-potential (GWP) alternatives to

hydrofluorocarbons (HFCs) currently used in each of the different refrigeration subsectors. The presentations referred to efficiency, GWP and cooling capacity and included considerations on the sustainability of options and the need to consider energy related CO_2 emissions.

5. The presentations by eleven panellists included topics relating to the availability of components, low-GWP options for large commercial and industrial systems, options for small commercial and plug-in systems, and on-site built commercial systems. Cascade systems and the performance of low-GWP supermarket systems were discussed, as well as drop-in and retrofit options for existing systems. Low-GWP alternatives and standards for transport refrigeration were explained. The panellists were mainly drawn from industry or industry associations; two panellists were consultants. Almost half the panellists were from parties operating under paragraph 1 of Article 5 (Article 5 parties) (see annex for details of the panellists).

B. Overview of low-GWP technologies in the refrigeration sector

6. The refrigeration systems discussed in all the subsectors were of the vapour compression type. Key points made were as follows:

(a) **Domestic refrigeration** covers refrigerators, freezers and combinations of both. These are factory produced, fully hermetic systems with low charges; risks for leakages are minimal. For domestic systems, HC-600a is a very low-GWP option, which has been commercialized for more than 15 years. HC-600a refrigerators have proved to be a reliable and highly efficient option; flammability issues have been fully addressed. More than 500 million domestic refrigerators using hydrocarbons (HCs) are already operating globally. Certain countries, including the United States of America, are still using HFC-134a, mainly because of safety regulations;

(b) **Commercial refrigeration** can be split into three subsectors:

(i) **Small plug-in units** are technically comparable to domestic refrigerators. HCs such as HC-290 are in use as a low-GWP option. Refrigerant charge is often larger than in domestic refrigeration. Low-GWP HFCs and hydrofluoroolefins (HFOs) are also viable low-GWP options. Some plug-in units, such as bottle coolers and vending machines, use CO_2;

(ii) **Condensing units** are factory produced combinations of a condenser and compressor connected on-site by pipework leading through the building (e.g., supermarket) to one or a small number of evaporators in retail display cases. Higher flammability or toxic refrigerants are typically not considered appropriate inside a supermarket as it is an area with public access. Certain HFCs and HFOs are viable low-GWP options. Acceptance of lower flammability (2L) refrigerants is not yet clarified, although these low-GWP options may prove to be safe and efficient. CO_2 is a non-flammable option, but it should be mentioned that capital costs for small condensing units using CO_2 are currently quite high;

(iii) **Centralized systems** are installed in a separate machinery room typically with connecting pipework to an externally located condenser and with a widespread network of refrigerant pipework leading to evaporators in many different display cabinets and cold storage rooms. Flammable or toxic refrigerants are not an option inside a supermarket. Non-flammable lower-GWP HFCs represent an option. CO_2 is an option in both transcritical and cascade systems. Several thousand supermarkets are already using CO_2 systems. Flammable refrigerants such as HC-290 or ammonia can be used together with a secondary fluid system (such as glycol or pumped CO_2). Small plug-in HC-290 units cooled by a water circuit are also used in some types of supermarkets;

(c) **Industrial refrigeration** systems cover a wide range of capacities and temperatures. For most large industrial systems ammonia is already widely used and is a good low-GWP refrigerant. CO_2 is also being introduced for larger industrial systems. A significant proportion of industrial systems are too small for cost-effective use of ammonia. For small and medium-sized industrial systems, low-GWP options include lower-GWP HFCs, HFC/HFO blends, HFOs or CO_2. In some cases high-GWP HFCs will still be needed;

(d) **Transport refrigeration** subsectors are road transport, refrigerated containers and ships. They are often used in a wide range of ambient conditions. Low-GWP alternatives include CO_2 and HFC/HFO blends. Flammable refrigerants are being considered for refrigerated containers and road transport. On ships the options depend on the application; options are similar to industrial systems.

C. Summary of low-GWP options

7. As described in the fact sheets, the low-GWP options include CO_2, ammonia, low-GWP HFCs, HFOs and HFC/HFO blends:

(a) CO_2 is a commercially available option for industrial refrigeration and centralized commercial refrigeration. It is used in transcritical systems or in cascade systems. The efficiency of transcritical systems is very high in cool ambient conditions and new developments allow efficient operation in warm conditions. In the hottest ambient conditions it is more efficient to use a cascade system. Capital costs were originally higher than those of HFC systems but are coming down. CO_2 systems for smaller applications including road transport, refrigerated containers and condensing units are being developed but they are not yet fully proven in terms of either cost or energy efficiency;

(b) Ammonia is a well-established, energy-efficient option for industrial refrigeration. There is also experience with ammonia and secondary refrigerants in centralized commercial refrigeration systems. Development trends for ammonia are leading to the use of compact heat exchangers, semi-hermetic compressors and systems with a very low charge;

(c) HCs are an option for systems with low charge. In domestic refrigeration HCs are well established. In commercial centralized systems HCs are used in combination with secondary refrigerants or combined with CO_2 for low temperature cascade systems;

(d) Medium-GWP HFC blends (such as R-407F) can be used in place of very high-GWP HFCs (such as R-404A) in new systems and they can be retrofitted into existing systems. These alternatives often save energy, however, there are also known cases in which efficiency decreased. Avoiding the use of R-404A is an important strategic element, since it has a GWP that is around two times higher than other commonly used (high-GWP) HFCs;

(e) Moderate and low-GWP HFCs, HFC/HFO blends and HFOs have recently been introduced, but commercial experience is limited.

D. Discussion

8. The availability of low-GWP technologies varies in each refrigeration market subsector. Conclusions from the workshop discussions include:

(a) HCs are available for domestic and small, plug-in commercial systems. Evaluation of the safety of HCs in transport refrigeration is under way and market introduction could occur by around 2018;

(b) CO_2 for use in centralized supermarket systems or industrial systems is well established as either transcritical or cascade systems. Smaller CO_2 systems for condensing units and transport systems are under development;

(c) Ammonia is well established in industry with potential wider markets based on technical developments for risk reduction;

(d) Medium-GWP HFC options are currently available as R-404A alternatives;

(e) Low-GWP HFCs and HFC/HFO blends are expected to become commercially available between 2016 and 2020 in a range of applications such as condensing units and transport systems. Safe use of lower flammability (2L) refrigerants needs to be better understood.

9. Barriers that were mentioned during discussions include:

(a) Centralized systems in commercial refrigeration will have the largest impact on total CO_2-equivalent. For widespread use of low-GWP technologies such as CO_2 transcritical, CO_2 cascade, HCs or ammonia with a secondary fluid, the main barriers are capital investment, technician training, standards and safety codes;

(b) More widespread use of ammonia and lower flammability refrigerants for industrial systems require better training of designers, installers and maintenance technicians;

(c) Very low temperature (below -50^{o}C) applications currently use high-GWP HFCs (such as HFC-23) in cascade systems. Currently there are no low-GWP options for the majority of these systems. This is only a very small part of the refrigeration market.

E. Adaptations needed to make a technology shift viable

10. In order to make a technology shift viable, the following are required:

(a) Safety codes and standards need to be updated, especially for the use of flammable refrigerants;

(b) Issues for high ambient temperatures include:

(i) High discharge temperatures of low-GWP HFC and HFO options (may need technical modification like liquid injection);

(ii) CO_2 systems require enhancements to achieve competitive seasonal efficiency in hot climates;

(c) Training and education are needed:

(i) To design and maintain leak tight systems, as largest part of refrigerant use is for topping-up;

(ii) To build up knowledge on proper design of CO_2 systems and their safe and proper servicing;

(iii) Safe and proper design and maintenance of ammonia and HC, including the design of proper secondary fluid systems;

(d) Awareness-raising on the impact of HFC emissions and the importance of their reduction;

(e) Key considerations regarding manufacturers include the development of safety codes and standards and the training of design, manufacturing and servicing staff on CO_2 and ammonia technology.

F. Relevant barriers to and challenges in moving forward

11. The relevant barriers to and challenges in moving forward were identified as follows:

(a) Limits to the applicability of new technology include the limited availability of low-GWP HFCs and the charge limitation of HCs;

(b) Further research and development is needed for the reduction of refrigerant charge, the further verification of the efficiency of CO_2 systems in hot climates and the development of codes of good practice for CO_2 enhanced systems;

(c) Higher cost of CO_2 is a blocking point for CO_2 in transport applications. This is currently not the case for commercial refrigeration. For a rapid global introduction, the design of systems, safety and training in the servicing sector need to be enhanced. This also applies to flammable refrigerants and ammonia;

(d) Clear regulatory guidelines with phase-down scenarios are needed to initiate the commercialization of innovations based on experience from the European Union F-gas regulations.

G. Most rapidly implementable actions to stimulate early changes in reducing HFC consumption

12. The most rapidly implementable actions to stimulate early changes in reducing HFC consumption were said to include:

(a) Introduction of HCs in new small hermetic systems for commercial plug-ins once the impact of standards is clear;

(b) Avoidance of R-404A in all new systems; retrofit of larger commercial and industrial R-404A systems if possible (e.g., large turbos);

(c) Introduction of CO_2 and other low-GWP options in new centralized commercial systems;

(d) Introduction of ammonia, CO_2 and other low-GWP alternatives in new industrial systems wherever possible;

(e) Release of clear phase-down scenarios and timelines;

(f) Training to increase awareness on importance of leak tightness, leak tight design and refrigerant recovery.

III. Session 2

Challenges and opportunities in addressing high-GWP HFCs in the stationary air-conditioning and heat pump sector

A. Introduction

13. The technical issues were introduced by the two resource experts Mr. Daniel Colbourne and Mr. Roberto Peixoto as technology overview speakers. A panel of nine technology providers and implementers from companies and organizations in different countries, including China, Egypt, India, Lebanon, Norway, Saudi Arabia, Sweden and the United States of America contributed via presentations and discussions. A tenth panellist from Japan was unable to attend. The names and contributions of the panellists are available in the annex to the present addendum. The discussions during the session were structured so as to enable the overview speakers to make presentations on the status of the sector and subsectors while the panellists briefly elaborated on the issues identified and later assisted in the discussion. The structure of the session is provided in the annex to the present addendum.

14. Mr. Colbourne discussed the air-to-air sector (as described in fact sheets 7, 8 and 9). He described the market subsectors and presented the various low-GWP refrigerants that can be used. Mr. Peixoto dealt specifically with the alternatives available for chillers and heat pumps for heating (fact sheets 10 and 11). A special presentation on energy efficiency perspectives was made by Mr. Saurabh Kumar.

B. Overview of low-GWP technologies in the stationary air-conditioning and heat pump sector

15. It was stressed that the availability of low-GWP alternatives varied considerably across the different sectors and subsectors of the stationary air-conditioning market. In the discussions during the workshop, air conditioners and heat pumps were classified as follows:

(a) **Air-to-air air-conditioners (including reversible air-to-air heat pumps):**

- (i) Split type:
  - a. Non-ducted small single split (2 to 12 kW, 0.5 to 3 kg charge);
  - b. Non-ducted medium single split (10 to 30 kW, 3 to 10 kg charge);
  - c. Multiple split (20 to 150 kW; 10 to 100 kg charge):
    - i. Multi-split;
    - ii. Variable refrigerant flow (VRF);
  - d. Ducted split (10 to 200 kW; 5 to100kg charge):
    - i. Residential;
    - ii. Commercial;
- (ii) Factory sealed:
  - a. Packaged rooftop (20 to 200 kW; 5 to 30kg charge);
  - b. Small self-contained ((2 to 7 kW; 0.2 to 2 kg charge):
    - i. Portable;
    - ii. Window/ PTAC/ TTW;

(b) **Chillers:**

- (i) Positive displacement;
- (ii) Centrifugal;

(c) **Heating only heat pumps.**

1. Options mentioned for new equipment

16. A wide range of low-GWP alternatives are described in the fact sheets and were discussed during the workshop. Some of these are already becoming commercially established in certain parties not operating under paragraph 1 of Article 5 (non-Article 5 parties), while others are at an earlier stage

of development. There is currently less availability of lower-GWP alternatives in Article 5 parties, although this is likely to change significantly during the next few years as technologies used in non-Article 5 countries are made more widely available.

17. In terms of application to specific subsectors, the following options were discussed as among those available:

(a) Small factory-sealed air-conditioners, which include the use of the following refrigerants: HC-290, HFC-32, R-446A, R-447A;

(b) Non-ducted single split air-conditioners, which include the use of the following refrigerants: HC-290, HFC-32, R-444B, R-446A, R-447A;

(c) Ducted split air-conditioners, which include the use of HFC-32, R-444B, R-446A, R-447A, HC-290;

(d) Packaged rooftop ducted air-conditioners, which include the use of R-744, HC-290, HFC-32, R-444B, R-446A, R-447A;

(e) Multi-split air-conditioners, which include the use of HFC-32, R-444B, R-446A, R-447A, (HC-290);

(f) Chillers, which include the use of R-717, R-744, HC-290, HC-1270, HFO-1234ze, HFO-1233zd, HFO-1336mzz, HFC-32, R-444B, R-446A, R-447A;

(g) Heating only heat pumps, which include the use of R-744, HC-290, HC-1270, HC-600a, HFO-1234ze, HFO-1234yf, HFO-1233zd, HFO-1336mzz, HFC-32, R-444B, R-446A, R-447A.

2. Summary of status for lower and medium ambient temperatures

18. By 2020 it is likely that there will be widespread availability of lower-GWP alternatives for:

(a) Small self-contained air-conditioners;

(b) Small and medium-sized split and multi-split systems;

(c) Chillers.

19. The most problematic area is for larger air-to-air systems which require refrigerant charge in the 50 kg to 100 kg range. It is not yet clear whether lower flammability refrigerants can be used in such applications.

3. High ambient temperature considerations

20. Many countries with high ambient temperatures are still using HCFC-22 for air-conditioning equipment. For new equipment there is already a significant switch to high-GWP HFC alternatives. For air-to-air systems the switch is mainly to R-410A (GWP 2088). For chillers there has been a switch to HFC-134a (GWP 1430).

21. **Constraints on refrigerant selection.** At high ambient temperatures the heat load per unit of floor area is much higher than in milder climates. This means that systems with larger cooling capacity are required, leading to increased refrigerant charge for a given room size. This may limit the suitability of higher flammability refrigerants (such as HC-290) in small splits and of lower flammability (2L) refrigerants (such as HFC-32) in larger air-to-air systems.

22. **Importance of energy efficiency.** During discussions it was noted that in countries with high ambient temperature, achieving high energy efficiency is a priority over using lower-GWP alternatives. Good efficiency has a greater impact on CO_2 emission reductions and presents fewer challenges. Energy efficiency standards in high ambient temperature countries are often set at a high level. Achieving such standards may also require higher refrigerant charges (e.g., to allow the use of larger heat exchangers with small temperature differences). This adds further to the constraints in terms of using flammable refrigerants.

23. **Lower-GWP options, air-to-air.** For air-to-air equipment the lower GWP alternatives that are most likely to be suited to high ambient conditions are HFC-32 and newly developed blends with properties similar to R-410A (such as R-446A, R-447A). These have GWPs in the range 450 to 675, which is considerably lower than R-410A; they have lower flammability (2L). There is little data yet available on the performance of these systems at high ambient temperatures, but it is expected that they will have a better performance than R-410A. It is worth noting that HC-290 may only have limited applicability in high ambient temperatures due to charge restrictions and R-744 is not likely to deliver sufficiently high efficiency. For small and medium-sized split systems the lower flammability

refrigerants are likely to fall within current safety standards. The ability to use lower flammability refrigerants in larger air-to-air systems (e.g., VRF) is not yet clear. More work is required to understand the safety issues involved. It was suggested that a switch to water chillers could be made for larger systems, but some participants said that this would reduce efficiency. This issue also needs further clarification.

24. **Lower-GWP options, chillers.** There is a range of low-GWP alternatives for chillers as listed above. It was generally agreed that such chillers could be designed for good performance at high ambient temperatures.

25. **District cooling.** District cooling could provide a high efficiency solution that would avoid the need for installation of multiple pieces of small equipment, addressing some of the difficulties described above. While it was agreed that such systems might be applicable under certain circumstances (e.g., when a major property development was being planned), it was not likely to be a solution for the majority of small systems. It was also pointed out that in regions with a water shortage, district cooling may not be applicable.

26. It is important to note that there was a lack of consensus among participants about whether some of the solutions described above are applicable in high ambient temperatures. Some participants said that no solutions were available for such conditions, while others provided evidence that showed low-GWP options are available.

27. **Maintenance.** Improving the service practices for better containment of refrigerants is important and applicable with the established technology based on HFCs; this will guarantee a low climate impact since less refrigerant gas will be released to the atmosphere.

C. Relevant barriers and challenges

28. The following were identified as important aspects in relation to barriers and challenges:

(a) **Selection, design and installation of the new technology and equipment.** A review of all aspects of alternative technology is necessary to ensure high efficiency and safe operation. There could also be situations where not all components are available for all the new refrigerant options;

(b) **Restrictive safety standards and codes.** While it was agreed that the flammable alternatives, such as HC-290 in small air-to-air systems, would result in energy efficiency increases (of about 5–10 per cent in residential air-conditioners) severe codes and standards that restrict the charge of flammables could result in restricted cooling as well as heating capacity;

(c) **Disparate or lack of national legislation.** A lack of national legislation or regulation leaves a vacuum that restricts the promotion of new technologies or innovation. This was one issue that was key for industry representatives in the panel;

(d) **Focused training relating to changing technologies and public awareness.** Operatives and the whole chain of stakeholders need to have awareness of all aspects of the new low-GWP technologies, especially flammable technologies. There is a need to establish training programmes both in the manufacturing and service sectors, as well as carrying out awareness-raising programmes for the general public;

(e) **Harmonization of standards.** There is a need for international standards organizations to make efforts to revise standards in such a way that the approach towards the application of low-GWP HFC alternative technologies, especially in Article 5 parties, will be harmonized.

D. Most rapidly implementable actions to stimulate early changes in reducing HFC consumption

29. Based on the discussions that took place during the session, the following is a summary of actions that could be considered for rapid implementation in order to stimulate early changes in reducing HFC consumption in the stationary air-conditioning sector:

(a) Innovations and improvements in equipment design that could lead to improved energy efficiency as well as reduction in refrigerant use;

(b) Introduction of low-GWP alternatives for new equipment in subsectors and geographic regions for which such alternatives already exist or are close to market. By 2020 this could include small self-contained air-conditioners, small split systems and water chillers in all non-Article 5 parties and in many Article 5 regions;

(c) Urgent technical assessments and design and development work is required to support the uptake of low-GWP alternatives. In particular two critical areas need to be addressed:

(i) Use of flammable refrigerants: more clarity is required on the sizes and types of systems that can safely use (a) higher flammability alternatives such as HC-290; and (b) lower flammability alternatives such as HFC-32;

(ii) Use of low-GWP alternatives in high ambient temperature conditions: more clarity is required on the technical barriers to the use of low-GWP alternatives in high ambient temperature conditions, taking into account the special circumstances of high cooling demand and the need for high energy efficiency;

(d) Update of legislation and regulations in different countries to facilitate progress in the transfer of technologies, especially from technology providers in non-Article 5 countries to clients in Article 5 countries, where such legislation could currently have a negative impact on such transfers;

(e) Harmonization or review of standards and codes relating to the use of flammable refrigerants and technology to help remove barriers militating against the use of such HC-290 technology and facilitate the uptake of the HC technology in more general terms.

IV. Session 3

Challenges and opportunities in addressing high-GWP HFCs in mobile air-conditioning

A. Introduction

30. In non-article 5 countries, the majority of new cars started using HFC-134a in mobile air-conditioning (MAC) in the early 1990s. Currently HFC-134a is still the global standard refrigerant for small to medium-sized MAC systems. Due to its very high GWP, the automotive industry is looking for low-GWP refrigerants as alternatives.

31. An overview presentation on MAC, including for cars and larger vehicles, was made by Mr. Predrag Pega Hrnjak. The list of the four panellists for the session and their presentations to address specific issues related to low-GWP alternatives for MAC can be found in the final workshop programme set out in the annex to the present addendum.

B. Overview of technologies in the sector

32. Currently, all modern MAC systems in cars and other small vehicles use HFC-134a as the refrigerant. In recent years there has been a significant activity in the area of development of new low-GWP refrigerants (GWP<150) as alternatives to HFC-134a. This was stimulated by the European Union MAC Directive that bans the use of refrigerants with a GWP above 150.

33. From 2006, CO_2 (R-744, GWP = 1) was tested extensively and a number of performance enhancement technologies (e.g., internal heat exchangers, microchannel evaporators) were developed to improve its performance. In 2009 a new refrigerant, HFO-1234yf (GWP=4), was introduced. HFO-1234yf MAC systems employed the performance enhancement technologies that were developed for CO_2 for equal or better performance than the baseline system, HFC-134a. At the end of 2014, around three million cars on the road were using HFO-1234yf. Due to patent issues, this refrigerant is only manufactured by two refrigerant companies. The current cost of this refrigerant is 15 to 20 times that of HFC-134a. In the last 10 years, the application of the above technologies to HFC-134a system has resulted in a doubling of the system's energy efficiency. A few original equipment manufacturers and suppliers have investigated hydrocarbons (HC-290, HC-600a) for direct expansion and HFC-152a in secondary loop. These can provide good thermal performance, but car manufacturers are reluctant to use them due to flammability concerns.

34. A few other new refrigerant mixtures for MAC have been developed (e.g., R-445A, GWP=120). Some original equipment manufacturers and suppliers have conducted extensive testing with R-445A for performance, material compatibility, flammability and risk assessment. However, these systems have not yet been commercialized. For electric vehicles and hybrid vehicles heat pump systems are needed for passenger heating - both CO_2 and R-445A have shown good performance in heat pump mode.

35. At this time HFO-1234yf seems to be the leading low-GWP alternative and the automotive industry is expected to continue manufacturing vehicles with this refrigerant. The number of cars using HFO-1234yf – currently around 3 million – is expected to continue to rise until 2020 and beyond. Cost

is a key concern for this refrigerant at this time. However, the cost of HFO-1234yf should decrease with greater penetration in the MAC sector.

36. For MACs in large vehicles (e.g., buses, trains) the potential alternatives are not so clearly identified as those for small vehicles. Various options are being considered including R-744, HFO-1234yf and HFC-32.

C. Adaptations needed to make a technology shift viable

37. The adaptation of an alternate refrigerant for MAC systems is dependent on many variables, including safety, energy efficiency, design considerations, cost, applicability at high ambient temperatures and technology training for service. Safety is one of the most important parameters for adaptation of a refrigerant to meet regulations or codes.

38. The ideal choice of a refrigerant for MAC would be to have one solution that would be accepted by all car manufacturers on a global basis. Original equipment manufacturers and suppliers are working for a sustainable option that could one day be adopted on a global basis.

39. Countries or locations that have high yearly average ambient temperatures require the vehicle MAC systems to run year-round. Replacing the existing refrigerant (HFC-134a) with a low-GWP refrigerant will have a huge impact on the CO_2 emissions from leaked refrigerant. Hence, it is imperative that the car manufacturers and equipment suppliers make use of a refrigerant that has a low GWP.

40. Irrespective of the refrigerant selected for MAC systems, there will be a large cost associated with the conversion from the current refrigerant, HFC-134a. New components must be designed and produced; in the service sector new charging and evacuations equipment will have to be developed. A significant amount of finance will be required for technician training programmes and certification for garages and shops that service and repair MAC systems.

41. Original equipment manufacturers and suppliers will tend to select a low-GWP refrigerant that would require minimum design changes to the components and systems, which would significantly reduce the overall cost of the change and without which considerable amounts would be spent by the industry on retooling. The developing countries might resist this switchover due to the financial impact of producing vehicles with alternate MAC systems.

D. Relevant barriers to and challenges in moving forward

42. The application of the new technology could be very challenging as there could be multiple barriers, including: (a) challenges in design; (b) different power trains for different vehicles (e.g., electric and hybrid); (c) different refrigerants for straight cooling and for heat pump applications; (d) non-availability of a refrigerant on a global basis; (e) multiple choices of refrigerants; (f) assessing the patent cost of new refrigerants to original equipment manufacturers; (g) socioeconomic issues; and (h) training and certification of the technicians for system servicing and repairs.

43. For potential candidates for new refrigerants for MAC systems, more research and development work is required for validating R-445A as a refrigerant. Should CO_2 be selected as the candidate for large MAC systems, the durability of the system needs to be validated.

44. For large MAC systems using CO_2 as an alternate refrigerant, ejector systems should be used to enhance the performance of the system at high ambient temperatures.

E. Most rapidly implementable actions to stimulate early changes in reducing HFC consumption

45. MAC systems for the automotive sector (passenger cars and small vans) to a large extent have adopted HFO-1234yf as the refrigerant in Europe and the United States. It is expected that the number of vehicles with this refrigerant will continue to increase every year.

46. For large MAC system for buses, the development activity is slow and there are very few low-GWP alternatives yet on the market. However, some R-744 systems are available. Further development work is required in this market sector.

47. The MAC sector needs to ensure that it has the necessary standards and codes to address the design, safety, handling, servicing and end-of-life recovery of the low-GWP alternative refrigerants.

48. The time to implement low-GWP refrigerants for MAC systems is now. This sector represents 20 per cent of total GWP gas emissions. It is necessary to develop technologies that are environmentally benign, cost effective, sustainable and can be used around the globe.

V. Session 4

Challenges and opportunities in addressing high-GWP HFCs in the foam sector

A. Introduction

49. The fourth session covered the challenges and opportunities in addressing high-GWP HFCs in the foam sector. Mr. Igor Croiset gave an overview presentation entitled "HFCs elimination in foams for domestic and commercial appliances: challenges and opportunities". Mr. Paulo Altoe then gave an overview presentation entitled "Factors which influence the choice of alternatives". The five panellists, whose names and presentation titles can be found in the annex to the present addendum, gave their insights on specific topics.

B. Overview of technologies in the sector

50. The closed-cell foam sector currently uses a wide variety of blowing agents: flammables and non-flammables. Flammables are predominantly HCs (i.e., pentanes and isobutane) and oxygenated hydrocarbons (HCOs) such as methyl formate and methylal. Non-flammables are CO_2 and HFOs.

51. Where possible, large enterprises have already adopted HCs as the default blowing agent option due to its low incremental operational cost despite the high initial incremental capital cost. CO_2 is adopted as the blowing agent for some applications where thermal insulation requirement is not stringent.

52. Those HFCs used by small enterprises are the most difficult HFCs to phase out In such enterprises the key challenge is the cost increase that is involved. They cannot afford either the high incremental capital cost for HCs or the high incremental operational cost for HFCs/HFOs. Therefore, the default choice is usually CO_2 if thermal insulation can be compromised. When higher thermal insulation is a must, HFC/HFO co-blown with a high percentage of CO_2 is normally adopted.

53. Methyl formate and methylal are being used in both non-Article 5 and Article 5 parties, especially in integral skin applications, although stability and flammability are two key issues (yet) to be managed.

54. The main low-GWP blowing agents for XPS are CO_2, HCs or HFOs co-blown with CO_2. Alcohols and ethers are sometimes used at low levels as co-blowing agents for certain foam properties.

55. HFOs continue to be evaluated within the foam sector and are showing considerable promise, particularly as a result of their contributions to thermal efficiency even at relatively low levels within the formulations used at present. One manufacturer is already producing commercially at the pilot scale with others likely to follow within the next two years. However, system costs and geographic availability remain uncertain.

56. The most difficult segment is polyurethane spray-foam, for which the major challenge relates to the safe processing of these systems under in-situ conditions within a building. HFC is still the only option available so far, although CO_2 is possible for selected applications. The adoption of HFOs will be very difficult due to its current high costs.

C. Adaptations needed to make a technology shift viable

57. HC technology is a proven blowing technology, but the extension of its adoption is hindered by its flammability. Pre-blending of HCs has proven to be a viable option for small and medium-sized enterprises in certain countries.

58. High ambient temperatures can be an issue for HC premixes which have proven to be an option for some small and medium-sized enterprises. Reformulation of a polyol blend to improve its HC solubility can be the solution in certain cases. Additionally, proper training should be given to operators to store and handle HC premixes safely.

59. Methyl formate can be a good alternative for some selected applications, but its flammability and the corrosiveness of some blends containing methyl formate is expected to present significant challenges.

60. From a technical point of view, HFOs are effective blowing agents for all foaming applications, but the major hurdle is their very high cost. Additionally, some HFOs are known to give stability issues in blends. Reformulation is therefore needed to maximize the use of water/CO_2 to reduce operation cost, and, in the case of certain HFOs, to mitigate the blend stability issue.

D. Relevant barriers to and challenges in moving forward

61. For large enterprises, the transition to low-GWP options is relatively smooth since HC technology has predominantly been adopted due to its low operational costs despite the high one-off capital cost. However, significant challenges exist for small and medium-sized enterprises, namely:

(a) **Safety.** There is a significant concern when HCs and HCOs are used. Premixed blends can mitigate the majority of the risks. In case certain fire performance is needed, the polyurethane system sometimes needs reformulation to ensure certain fire resistance performance;

(b) **Energy efficiency.** If HC/HFO is not adopted, CO_2 can be an option. However, CO_2-blown foams have low thermal insulation. Co-blowing with HFOs can be one of the ways forward to address this – striking a good balance between cost and performance;

(c) **Cost.** When neither HCs nor CO_2 is an option, HFOs can be the choice. Unfortunately, the cost of HFOs is too high to use them on their own. In addition, the commercial availability issue is currently not very clear. To mitigate the cost increase, co-blowing with CO_2 can – or should – be adopted;

(d) **High ambient temperatures.** When HC premixes are used, there is a need to ensure proper storage, transport and handling of premix containers;

(e) **In-situ spraying.** This sector remains extremely hard to address. Although HFO/CO_2 co-blowing can be part of a solution, it does not fundamentally solve the problem. Unfortunately, the panel at the workshop did not have a clear vision for the way forward.

E. Most rapidly implementable actions to stimulate early changes in reducing HFC consumption

62. For large enterprises, HCs are a viable option to move forward. For medium-sized enterprises, HCs should be adopted wherever practical. For small enterprises, HFOs and HC premixes could be two options to choose from.

63. For applications where HFOs are the only choice, the industry needs more time to prove the HFO technology on a large scale (e.g., long-term stability). The commercial availability of HFOs remains unclear.

VI. Session 5

Overarching and cross-cutting issues on technical aspects of HFC management

A. Introduction

64. The fifth session provided an opportunity for participants to discuss many overarching and cross-cutting issues that had come up in the previous four sessions. The issues covered included:

(a) Availability of low-GWP alternatives and cost of conversion;

(b) Intellectual property rights;

(c) Energy efficiency;

(d) Issues related to high ambient temperatures;

(e) Flammability and safety standards;

(f) Leak reduction, recovery and reuse of high-GWP refrigerants;

(g) Training, tools and capacity-building required in the servicing sector for moving to low-GWP alternatives in Article 5 countries.

65. At the start of the session, two overview speakers presented the views of the industry associations – for fluorinated and natural refrigerants – on the availability of low-GWP alternatives to replace high-GWP HFCs.

66. In part 1 of the session, nine panellists broadly covered the issues of availability, costs, industry trends and intellectual property rights. One panellist, representing an industry association of an Article 5 country, talked about the challenges faced by companies in Article 5 parties in converting to low-GWP options. There were presentations from the panellists of industry representatives and experts on costs and the initiatives being taken by the industry on its own or in response to domestic

legislation in transitioning towards low-GWP alternatives. An expert on intellectual property rights gave his opinion on the impact of intellectual property rights in facilitating or restricting access to low-GWP technologies.

67. In part 2 of the session, eight panellists gave their views on issues related to high ambient temperatures, flammability and safety standards, leak reduction, recovery and reuse and training and capacity-building. Two industry representatives spoke about the options and challenges in moving to low-GWP alternatives in high ambient temperature regions. Two panellists from industries gave their opinion on the challenges faced by industries due to different safety and flammability standards in different countries. Another industry representative spoke about the importance of training and certification schemes to ensure the safe and environmentally friendly handling of low-GWP alternative refrigerants. The last three panellists put on the table the important issue of leak reduction, recovery and reuse of HFCs as well as the training and capacity-building required in the servicing sector in Article 5 countries.

68. The names of the panellists and the issues they addressed are included in the final programme of the workshop, as set out in the annex to the present addendum.

69. A specific presentation on energy efficiency had been given under session 2 with the understanding that it was a cross-cutting theme to be taken up further under session 5. Many speakers dwelled on the issue of energy efficiency.

B. Availability and costs

70. Both the overview speakers pointed out that there is a suite of technologies available today to replace high-GWP HFCs in most sectors. In many subsectors alternatives are increasingly becoming cost-effective and are already being used on a commercial scale in a number of geographic regions, including in Article 5 countries. There are multiple refrigerants—fluorinated and naturals—that can be used in applications like foam, refrigeration and air-conditioning; many more are being developed. The growing number of options will see competition among alternatives and the industry will choose the most appropriate option based on multiple factors such as cost, efficiency and safety.

71. Other speakers on the panel supported the views of the overview speakers on the availability of low-GWP alternatives. Specific presentations were made on the availability of, and costs of moving to, low-GWP alternatives in the mobile air-conditioning and foam sectors. It was shown that different alternatives have different trade-offs. Some are expensive, others have high flammability and some alternatives will require further research and development to prove viability in certain regions. From the discussions and presentations it can be concluded that no perfect refrigerant exists. The current refrigerants are not perfect; they are either ozone-depleting or have high-GWP or some other trade-offs. Trade-offs are inevitable for every refrigerant.

72. It was also clear from the presentations that different regions would have different timelines for the uptake of alternatives. For instance, it was pointed out that for the hot ambient temperature regions, low-GWP alternatives to HFCs are currently at the demonstration stage in larger split air-conditioning systems, and more time would be required to introduce these technologies into the open market. It was pointed out that a time lag is required to build capacity and develop the markets before any new alternative can be introduced from one region to another.

73. Issues of cost were also discussed. Generally, the costs of low-GWP alternatives are, at present, higher than the existing high-GWP HFCs. It was pointed out that operating costs are higher for patented chemicals like HFOs, whereas capital costs are higher for systems using flammable refrigerants like HCs. However, it was also pointed out that cost is a factor of scale and competition; as low-GWP alternatives are introduced in scale and there is competition among different alternatives, costs are bound to come down, as has happened in Europe. Examples were given to illustrate how, for many applications, costs are competitive with high-GWP HFCs in certain regions.

74. The availability and costs of low-GWP alternatives are also impacted by domestic legislation as well as by industry’s own initiatives in certain non-Article 5 countries. A presentation was made on the European Union’s F-gas regulations and how they would impact the availability and cost of low-GWP alternatives. It was pointed out that all imports to the European Union will have to meet the requirements of the F-gas regulations, which is likely to spur on the development of low-GWP alternatives in large exporting countries like China.

75. There was a debate (without any conclusion) on approaches to moving to the low-GWP alternatives. While one panellist from an Article 5 country emphasized the need for a one-time transition to low-GWP alternatives, another panellist pointed out the need for moving to commercialized alternatives even if they have relatively lower GWP (but not low) than the existing

high-GWP HFCs. There was also a debate on the definition of low-GWP refrigerants, which remained inconclusive.

76. From the deliberations, it was quite clear that the prospect of introducing low-GWP alternatives in the near-term would be strongly influenced by the volume of demand, which in turn would depend on countries legislating regulatory requirements for moving to low-GWP alternatives. Drawing upon the history of the Montreal Protocol, one of the panellists made the observation that when the Protocol was negotiated, there were far less alternatives available than at present. Once the Montreal Protocol provided regulatory certainty, it speeded up the availability of alternatives. This was also the message offered by many other panellists at the session: policy and regulatory certainty is important to spur development and commercialization of low-GWP technologies.

C. Intellectual property rights

77. The issue of intellectual property rights came up time and time again during the two days of the workshop. Many participants from Article 5 countries were concerned about the impact that intellectual property rights would have on costs and technology transfer. One of the questions that was considered during the session was whether patents would adversely affect the transition to low-GWP alternatives and hinder technology transfer to Article 5 countries.

78. The lone speaker on the issue started off by stating that in the past intellectual property rights had not been a major issue in terms of a transition to new substances under the Montreal Protocol. This was because some technologies had multiple suppliers, some key refrigerants were not patented and the Multilateral Fund for the Implementation of the Montreal Protocol paid for the incremental costs and the costs of technology transfer to Article 5 countries. However, patents could become an important issue in an HFC phase-down regime because the patents of the new fluorinated refrigerants were only registered a few years ago and will, therefore, remain active in the near-term. As patent holders want to maximize the profits from their inventions, they will put a premium on alternatives, thereby increasing costs. The second major issue concerning patents is patent thickets: “A dense web of overlapping intellectual property rights that a company must hack its way through in order to actually commercialize new technology”.[1] As the technological, commercial and regulatory background becomes more complex, as could be the case during HFC phase down, there is more potential for patent thickets to develop. However, some reasons for optimism were also pointed out:

(a) Some key substances are not patented, like natural refrigerants;

(b) Even if patents or patent thickets block the commercialization or use of some technologies, new inventions always overcome them;

(c) We can expect competing technologies, driven in part by new markets and regulatory signals, which may drive down prices of patented technologies;

(d) Patents aren’t permanent – they expire in time;

(e) Unless there is an extraordinary change, the Multilateral Fund will still be mandated to fund technology transfer, including for licenses to use patented technology.

79. The discussion that followed was centred on how the Multilateral Fund will facilitate technology transfer; what will it pay for and how the cost of transition will be shared. The message that emerged was that more understanding is required on this issue. However, it also emerged that new approaches may be required to facilitate technology transfer, especially in sectors where there are limited alternatives.

D. Energy efficiency

80. Energy efficiency emerged as one of the most important talking points at the workshop. The importance of improving the energy efficiency of the refrigeration and air-conditioning sector alongside the HFC phase-down was pointed out as a conjoined agenda throughout the workshop.

81. The general sense at the workshop was that the energy efficiency of low-GWP alternatives is similar to or better than high-GWP HFCs. However, it was pointed out that a strategy is required to ensure that the phase down results in significant improvements in energy efficiency as well. Investment in energy efficiency to maximize the climate benefits of moving away from high-GWP gases received strong approval at the workshop. Similarly, it was mentioned that massive investments

[1] Shapiro, Carl (2001). "Navigating the patent thicket: cross licenses, patent pools, and standard-setting" (PDF). In Jaffe, Adam B. et al. Innovation Policy and the Economy I. Cambridge: MIT Press. pp. 119–150. ISBN 0-262-60041-2.

are being made in energy efficiency improvements in the refrigeration and air-conditioning sector, but without any attempt to reduce GWP of refrigerants. There is a need to incorporate HFC phase down in these projects as well.

82. At the workshop, there was a growing recognition that tools like life cycle climate performance must be used in selecting low-GWP technologies. It was emphasized that the energy use of the alternatives must be rigorously evaluated before deciding on their appropriateness.

E. High ambient temperatures

83. The concerns of countries with high ambient temperatures regarding unavailability of proven technologies were discussed in many sessions. It emerged that in the refrigeration, MAC and foam sectors, high ambient temperatures are not an impediment to the use of currently available low-GWP alternatives. This, however, is not the case with the air-conditioning sector. High ambient temperature countries use larger air-conditioning systems owing to the larger differences between the inside and outside temperature. The larger system size creates challenges in the uptake of technologies using flammable refrigerants.

84. In order to discuss the above-mentioned issues, two industry representatives from countries with high ambient temperatures (from the Middle East and North Africa region) presented their views on the alternatives and challenges in phasing down high-GWP refrigerants in the air-conditioning sector. One representative spoke about the challenges in moving to low-GWP refrigerants, while the other spoke about the potential of not-in-kind technologies.

85. It was pointed out that design for high ambient temperatures needs special care to avoid excessive condensing temperatures and getting close to the critical temperature of refrigerants. Other issues like safety, refrigerant charge quantity, and improving the energy efficiency for both partial and full loads, have to be taken into consideration. The main challenge is to balance energy efficiency and maximum refrigerant charge limits for safety.

86. Special care needs to be taken in selecting and designing heat exchangers and compressors. In heat exchangers, the use of smaller tube diameters or the microchannel type of heat exchangers was recommended. It was pointed out that for small and medium-size units, compressor manufacturers are offering scroll, reciprocating and screw compressors with low-GWP refrigerants like HC-290, HFC-32 and HFC-1234yf, with energy efficiency levels that can meet or exceed the new minimum energy performance standards in the Gulf Cooperation Council region. These compressors are classified as equipment and protective systems intended for use in potentially explosive atmospheres (*Appareils destinés à être utilisés en Atmosphères Explosives* (ATEX)) certified for flammable refrigerants. Multiple compressors are becoming an option for air-conditioning manufacturers in countries with high ambient temperatures.

87. Test data (conditions based on Saudi Arabian Standards Organization (SASO) standard 2681) was also presented to show the suitability of different alternatives in high ambient temperatures. It was pointed out that both from the capacity and coefficient of performance point of view, HC-290 offers the best performance. R-410A was found to have a significant drop in capacity and coefficient of performance at higher temperatures.

88. One panellist recommended that financial support and time is required to adopt low-GWP alternatives in air-conditioning equipment in high ambient temperature conditions, as more research in design, component selection and safety issues is required. Demonstration will also be important to gain confidence in these technologies.

89. The potential of not-in-kind technologies, such as solar thermal driven absorption chillers, in hot ambient temperature regions was also discussed. It was pointed out that hot ambient temperature countries usually have some of the best optimal solar conditions (high average solar radiation 5–7 kWh/m^2), suitable for solar-based heating and cooling technologies. There is also a match between load profile and optimal solar radiation conditions. A case study of four solar thermal-driven absorption chiller projects retrofitted into existing buildings in Jordan to establish a basis for the sustainable air-conditioning industry in the Middle East and North Africa region was discussed. It was pointed out that the technology has been successfully tested but the costs are very high. Compared to a conventional electric chiller, the solar absorption chiller is four times more expensive in capital cost and the payback period varies between 7 and 15 years. Further learning and innovation through research and development and demonstration projects is required and economies of scale can bring down the costs.

90. The discussions at the session point to the fact that both time and support is required to adopt low-GWP alternatives in larger air-conditioning systems in high ambient temperature countries.

Support is required for research and development in system design, component selection and certification. Demonstration and training is required to increase acceptability.

F. Flammability and safety standards

91. Low-GWP refrigerants are mildly or highly flammable. This has led to safety-related concerns about low-GWP alternatives. At the session, two panellists talked about the flammability and safety standards for using low-GWP alternatives. It was pointed out that many of the safety standards were developed keeping in mind the widespread use of non-flammable technologies. They are therefore restrictive. There is a need to revisit, possibly revise and update, the charge size standards for low-GWP (and flammable) refrigerants and also to set compulsory proper operating conditions and safety measures. The use of risk assessment methodology instead of using only safety standards to decide on the use of flammable low-GWP alternatives was also suggested.

92. The other issue in the safety standards was the prevalence of different safety and flammability standards and codes in different countries which is disrupting the market development of low-GWP alternatives. The harmonization of safety and flammability standards and codes is important to give a clear indication to the industries and give them access to newer markets.

G. Leak reduction, recovery and reuse

93. Another issue that was addressed in the session related to leak reduction from existing equipment and the reclamation and recovery of high-GWP refrigerants. This was found to be the most significant issue for the low-volume-consuming countries. The need for strengthening the servicing sector to reduce leakage rates and to institutionalize recycling and reclamation programmes addressing refrigerant recovery during service and at end of life was recommended. In order to achieve this, support would be required from the Multilateral Fund as refrigerant recovery and recycling is quite expensive.

94. Apart from end-of-life measures, at the manufacturing stage, testing for leakages and ensuring better quality control for leak reduction was also emphasized. It was also suggested that domestic legislation on preventing venting, leakage reduction, recovery, reuse and destruction of high-GWP refrigerants should be promoted.

H. Training, tools and capacity-building

95. Training and capacity-building were identified as important issues in all sessions. It was pointed out by many panellists that the complexities involved in handling flammable low-GWP alternatives are greater than for the refrigerants currently used. Trained technicians would be required for handling and servicing flammable refrigerants and implementing safety standards, for recovery and recycling of high-GWP refrigerants and for retrofitting or conversion of high-GWP systems to low-GWP refrigerants.

96. In Article 5 countries, where the servicing sector is largely informal, there is a need to formalize and organize the sector to handle low-GWP alternatives. For this, training and certification of technicians is of fundamental importance. It was also pointed out that the tools required in the servicing sector to handle low-GWP alternatives would be different and had to be provided. Article 5 countries would also need support to develop infrastructure, for instance for the reclaiming, recycling and destruction facilities.

I. The way forward

97. Some key recommendations that emerged from the session were:

(a) Give legislative and regulatory certainty, thereby giving industry a clear signal to move to low-GWP alternatives;

(b) Provide clarity to Article 5 countries on what the Multilateral Fund would pay for and how it would facilitate fair and favourable technology transfer;

(c) Provide support for research, development and demonstration for using low-GWP alternatives in the air-conditioning sector in high ambient temperature regions;

(d) Invest in energy efficiency as part of the package to maximize the climate benefits of moving away from high-GWP HFCs. Use tools like life cycle climate performance in the selection of alternatives;

(e) Revisit and revise safety standards for flammable refrigerants, and harmonize safety standards and codes;

(f) Provide comprehensive training and certification programmes and capacity-building of technicians in Article 5 countries for handling low-GWP alternatives during various stages of the life cycle of the equipment and the refrigerant;

(g) Provide support to Article 5 countries in training and capacity-building as well as for developing infrastructure for refrigerant recovery, reuse and destruction facilities.

Annex

Final programme of the workshop

Day 1: Monday, 20 April 2015

10–11 a.m.	Opening of the workshop
10–10.10 a.m.	Welcome and introduction to the workshop objectives and format by the Executive Secretary, Ozone Secretariat
10.10–10.30 a.m.	Short overview of (a) current atmospheric HFC abundances in the atmosphere and projected concentrations and (b) current and extrapolated future HFC demand by sectors and potential impacts of mitigation measures Mr. A.R. Ravishankara, Co-Chair, Scientific Assessment Panel, and Ms. Bella Maranion, Co-Chair, Technology and Economic Assessment Panel
10.30–11 a.m.	Introductory session and overview of the sectors and subsectors to be discussed Mr. Sukumar Devotta, Mr. Ray Gluckman and Mr. Lambert Kuijpers

11 a.m.–2 p.m. **Session 1. Challenges and opportunities in addressing high-GWP HFCs in the refrigeration sector**

Facilitator: Mr. Peter Adler *Rapporteur*: Mr. Ullrich Hesse	
Subsectors/systems • Domestic refrigeration (refrigerators and freezers) • Commercial refrigeration (small stand-alone equipment, condensing units, large central pack systems) • Industrial refrigeration (small/medium-sized and large systems) • Transport refrigeration (road vehicle, intermodal containers, ships)	**Presentation on the sector's status** *Overview speakers (resource experts)* • Mr. Reinhard Radermacher • Mr. Paulo Vodianitskaia
Issues to be addressed	**Panellists: Technology providers/implementers**
• Availability of components and the implications thereof for system design when using low-GWP chemicals and blends in the refrigeration sector	• Mr. Torben Funder-Kristensen (Danfoss, Denmark)
• Low-GWP technology options for medium-sized and larger industrial systems under various ambient conditions	• Mr. Jonathan Ayotte (Carnot Refrigeration, Canada)
• Low-GWP technology options for industrial and large commercial and community applications	• Mr. Eric Delforge (Mayekawa Europe, France)
• Alternative options for plug-in cabinets, including for high ambient temperature regions, vending machines	• Mr. Roy Singh (Arctic King Appliances, South Africa)
• Low-GWP options for small commercial equipment	• Mr. Bruno Pussoli (Metalfrio, Brazil)
• Low-GWP alternatives for on-site-built commercial refrigeration equipment (including condensing unit systems); cost implications and performance in high ambient temperatures	• Mr. Christian Heerup (Danish Technological Institute, Denmark)
• Options (drop-in, retrofit, etc.) for existing commercial systems/equipment (including condensing units); servicing issues	• Mr. Zhang Zhaohui (CRAA, China)
• Low-GWP options for cascade systems for medium-sized and larger commercial refrigeration equipment	• Mr. Paul de Larminat (Johnson Controls, France)
• Technological transition and barriers in Article 5 parties for commercial refrigeration: end users' perspective	• Mr. Fernando Galante (EPTA, Argentina)
• Performance of low-GWP supermarket systems in various climate zones, including in high ambient temperatures	• Mr. Juergen Goeller (Carrier Transicold, Germany)
• Low-GWP alternatives and standards for transport refrigeration, including intermodal refrigerated containers, road vehicles and refrigeration on board vessels	• Mr. Holger Koenig (consultant, Germany)

2–3 p.m. **Lunch**

3–6 p.m. **Session 2. Challenges and opportunities in addressing high-GWP HFCs in the stationary air-conditioning and heat pump sector**

Facilitator: Mr. Saleem Ali *Rapporteur*: Mr. Richard Abrokwa-Ampadu	
Subsectors/systems • Small self-contained air-conditioning (portable systems, window units, through the wall, packaged terminal) • Small split air-conditioning systems (single split systems) • Larger split and other types of air-to-air systems (larger single splits and multi-splits, VRF/VRF systems, ducted systems and packaged rooftop systems) • Chiller systems (chillers with positive displacement compressors, chillers with centrifugal compressors) • Heating-only heat pumps (space heating, water heating, domestic tumble driers, large space heating systems, industrial process heating)	**Presentation on the sector's status** *Overview speakers (resource experts)* • Mr. Daniel Colbourne • Mr. Roberto Peixoto • Mr. Saurabh Kumar (*the energy efficiency perspective*)
Issues to be addressed	**Panellists: Technology providers/implementers**
• Availability and implications for system design and characteristics of low-GWP chemicals and blends in the air-conditioning (AC) sector	• Mr. Mike Thompson (Ingersoll Rand/Trane, United States)
• Alternatives to high-GWP HFCs for air-conditioning	• Mr. Jitendra Bhambure (Blue Star, India)
• Possibilities for applying various low-GWP options in single split air-conditioning units (including under high-ambient temperature conditions)	• Mr. Li Tingxun (Midea and Sun Yat-sen University, China)
• Current and near future availability of low-GWP refrigerants and barriers to their large-scale application in air-conditioning	• Ms. Wang Lei (China Household Electric Appliances Association, China)
• Suitable alternatives at high ambient temperatures for medium-sized air-conditioning equipment	• Mr. Bassam Elassaad (consultant, Lebanon)
• Alternatives for air-conditioning units in high ambient temperatures, with emphasis on energy efficiency	• Mr. Maher H. Mousa (Saudi Arabia HVAC industry consultant, UTC Building and Industrial Systems, Saudi Arabia)
• Use of non-HFC refrigerants in small and medium-sized air-conditioning and heat pump units	• Mr. Petter Neksa (SINTEF Energy, Norway)
• Large air-conditioning units using a variety of low-GWP options	• Mr. Alaa Olama (consultant, Egypt)
• District cooling and heating systems using low-GWP refrigerants and other sources as drivers	• Mr. Pär Dalin (Devcco, Sweden)

6–6.30 p.m. **Coffee break**

6.30–7.30 p.m. **Session 3. Challenges and opportunities in addressing high-GWP HFCs in mobile air-conditioning**

Facilitator: Mr. Saleem Ali
Rapporteur: Mr. Gursaran Mathur

Subsectors	**Presentation on the sector's status**
• Mobile air conditioning (MAC) (cars and larger vehicles)	*Overview speaker (resource expert)* • Mr. Predrag Pega Hrnjak
Issues to be addressed	**Panellists**
• Environmental impact of MAC in high ambient temperatures	• Mr. Pradit Mahasaksiri (Siam Denso, Thailand)
• Low-GWP systems, including HFO and CO_2 systems, perceived barriers, costs, safety issues and performance in high ambient temperatures	• Mr. Enrique Peral-Antunez (Renault, France)
• Introduction of low-GWP alternatives to HFC-134a in Article 5 MAC production: cost and safety issues	• Mr. Chen Jianping (Shanghai Jiao Tong University, China)
• Options for existing systems/equipment (drop-in, retrofit)	• Mr. Sangeet Kapoor (Tata Motors, Indi

Day 2: Tuesday, 21 April 2015

10–11.30 a.m. **Session 4. Challenges and opportunities in addressing high-GWP HFCs in the foam sector**

Facilitator: Mr. Saleem Ali
Rapporteur: Mr. Enshan Sheng

Subsectors	**Presentation on the sector's status**
• Closed-cell rigid foams used for thermal insulation: extruded polystyrene boards, polyurethane and phenolic boards and panels, polyurethane appliance insulation, polyurethane spray foam, polyurethane in situ/block foam	*Overview speakers (resource experts)* • Mr. Paulo Altoe • Mr. Igor Croiset
Issues to be addressed	**Panellists (technology providers/implementers)**
• Developments in the phase-in of low-GWP chemicals in various polyurethane sectors	• Ms. Kultida Charoensawad (Polyurethane Group, Federation of Thai Industries, Thailand)
• Alternatives currently offered in the extruded polystyrene industry, compromises on physical properties, cost constraints on process development	• Mr. Ashok Chotani (Isofoam, Kuwait)
• Safe and commercially viable low-GWP alternatives for micro, small and medium-sized enterprises in Article 5 and non-Article 5 parties	• Mr. Samir Arora (Industrial Foams, India)
• System houses and development of low-GWP technologies	• Mr. Stefano Varga (Cannon Afros, Italy)
• Use of fourth generation blowing agent to replace high-GWP HFCs	• Ms. Achara Bowornprasitkul (BASF, United States)

11.30 a.m.–1.30 p.m. and 3–5 p.m.	**Session 5. Overarching and cross-cutting issues on technical aspects of HFC management (parts 1 and 2)**
11.30–11.45 a.m.	**Introductory remarks on overarching and cross-cutting issues** Mr. Mack McFarland (Global Fluorochemical Producers' Forum) Mr. Marc Chasserot (Shecco)
11.45 a.m.–1.30 p.m.	**Session 5, part 1. Costs of conversion, intellectual property rights, accessibility to low-GWP alternatives and timeline of availability for new technologies**

Facilitator: Mr. Peter Adler

Rapporteurs: Mr. Chandra Bhushan

Issues to be addressed	**Panellists**
• For systems and sectors that currently use high-GWP chemicals, what are the challenges faced by companies in Article 5 parties in converting to low-GWP options? • What are the costs of non-HFC technologies for mobile air-conditioning and what is the expected cost depreciation for those technologies? • Can low-GWP fluorocarbons be cost-effective alternatives to high-GWP HFCs used in foam blowing? • Impact of intellectual property rights on technology transfer and development • How will the EU F-gas legislation (and others) affect the market for HFC-related technologies around the world, including cost and availability of low-GWP options?	• Mr. Ravinder Mehta (RAMA, India) • Mr. Predrag Pega Hrnjak (University of Illinois at Urbana Champaign, USA) • Mr. Miquel Quintero (consultant, Colombia) • Mr. Alistair McGlone (consultant, United Kingdom) • Ms. Andrea Voigt (EPEE, Europe)
• Examples of low-GWP alternatives that industries are scheduling to phase in with specific timelines and cost estimates in the refrigeration and air-conditioning sectors • Case study examples of using low-GWP substances and industries' response to policies	• Mr. Rajan Rajendran (Emerson, Australia) • Mr. Kevin Fay (Alliance for Responsible Atmospheric Policy, United States)

1.30–3 p.m.	**Lunch**
2–3 p.m.	**Side event: HFCs in aerosols: metered dose inhalers and non-medical aerosols** (Speaker: Ms. Helen Tope, discussion moderated by Mr. Ashley Woodcock)

3–5 p.m. **Session 5, part 2. Energy efficiency, safety, industry's response to low-GWP policies**

Facilitator: Mr. Peter Adler
Rapporteur: Mr. Chandra Bhushan

Issues to be addressed	**Panellists**
• Overall issues in adequate design for high ambient temperature operation • What are the costs of replacing conventional cooling units with non-conventional low-GWP options, including retro-fitting, with reference to projects in high ambient temperatures? • Status of safety standards, current and near future developments	• Mr. Samir Hamed (Petra Engineering Industries Company, Jordan) • Mr. Hisham Mikhi (Millennium Energy Industries, Jordan) • Mr. Paul Fu (Underwriters Laboratories, China)
• Challenges regarding flammability concerns and related safety standards, possibilities for compact systems limiting charge sizes	• Mr. Asbjorn Vonsild (Danfoss)
• Training and certification schemes to ensure the safe and environmentally friendly handling of low-GWP alternative refrigerants	• Mr. Marco Buoni (AREA, ATF, Galileo)
• Contribution of Article 5 party servicing organizations to the reduction of high-GWP emissions and low-GWP safety concerns	• Mr. Manuel Azucena (RACTAP, Philippines)
• HFC management through leak reduction and recovery and next actions for stepping forward	• Mr. Tetsuji Okada (JRAIA, Japan)
• Potential of leak reduction and recovery for refrigerant consumption reduction	• Mr. Julio Esteban (Smart Refrigerants, Panama)

5–6.30 p.m. **Session 6. Key conclusions relevant to policymaking on technical management of HFCs**

Facilitator: Mr. Peter Adler
Rapporteurs: Ms. Karin Shepardson and Mr. Stephan Sicars

Rapporteurs of sessions 1–5 to present the conclusions of the sessions

Sessions 1, 2 and 5 (7 minutes per speaker); sessions 3 and 4 (5 minutes per speaker)

Key issues for drawing up conclusions

- Specific challenges in phasing out HCFCs and phasing down HFCs in Article 5 parties, including with regard to high ambient temperatures (for specific sectors)
- Applications for which high-GWP HFCs are difficult to replace
- Applications for which high-GWP HFCs are easy to replace
- Timelines for the availability of alternative technologies

6.30 p.m. **Closure of the workshop**