



Distr.: General
13 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**

I. Opening of the workshop

1. In accordance with paragraph 2 of decision XXVI/9 of the Twenty-Sixth Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer, the Ozone Secretariat convened a workshop to continue discussions on hydrofluorocarbon (HFC) management issues.
2. The workshop was held at the United Nations Conference Centre in Bangkok on 20 and 21 April 2015. The workshop was opened at 10 a.m. on Monday, 20 April 2015, by Ms. Tina Birmpili, Executive Secretary of the Ozone Secretariat, who outlined its objective and structure.
3. The objective of the workshop was to provide a forum for the discussion of technical issues related to the management of HFCs, with the aim of (a) clarifying the status of equipment, products and related technologies in industry sectors that used HFCs as alternatives to ozone-depleting substances, (b) focusing on the availability at present and in the near future of low-global-warming-potential (low-GWP) alternatives to HFCs, and (c) exploring what was needed to improve HFC management practices. A discussion of all issues relating to HFC management, technical and otherwise, would take place during the thirty-fifth meeting of the Open-ended Working Group to the Montreal Protocol, to be held from 22 to 24 April 2015, immediately after the workshop.
4. The workshop, which the Secretariat had devised taking into account the views of all stakeholders, would feature six sessions. Each of the first four sessions would focus on a specific industry sector and its subsectors; the fifth would feature discussion of overarching and cross-cutting issues and the sixth would provide an opportunity for the participants to draw conclusions from the workshop. With the help of experts and review by members of the Technology and Economic Assessment Panel and its technical options committees, the Secretariat had prepared 15 fact sheets for the industry sectors to be discussed providing neutral information on the status of the market for low-GWP alternatives. The fact sheets are available on the Ozone Secretariat website (http://conf.montreal-protocol.org/meeting/workshops/hfc_management-02/presession/default.aspx).
5. Each of sessions 1–4 would feature overview speakers, panellists, a facilitator and a rapporteur. Session 5 would feature panellists, a facilitator and a rapporteur. For each session the overview speakers would present key facts, drawing on the relevant fact sheets, and would act as resource experts for the discussion that would take place during the session. The panellists, who had been drawn from “technology providers” and “implementers of technologies” from parties operating under paragraph 1 of Article 5 (Article 5 parties) and parties not operating under that paragraph (non-Article 5 parties), would then make short presentations, following which the workshop participants, panellists and overview speakers would hold an open discussion. The rapporteurs for session 1–5 would summarize the key issues addressed

during the sessions and present them during session 6, at which an effort would be made to distil any additional key conclusions, addressing in particular specific challenges and opportunities with regard to limiting high-GWP HFC use while phasing out HCFCs in industries and enterprises in Article 5 parties, including the challenges caused by high ambient temperatures; applications for which high-GWP HFCs were difficult to replace; applications for which high-GWP HFCs were easy to replace; and timelines for the availability of alternative technologies. The rapporteurs for the sixth session would also briefly summarize the discussions at the end of the workshop and would report to the Open-ended Working Group at its thirty-fifth meeting on the key conclusions reached during the workshop.

6. The workshop, she said, was yet another example under the Montreal Protocol of how trust could be built on sound processes, and it was her hope that the information to be presented on low-GWP alternatives to HFCs would isolate and crisply define the issues that needed to be further addressed in subsequent discussions and generate possible options for bridging different perspectives in finding a way forward.

7. Following the Executive Secretary's introduction, a number of presentations were made to set the stage for the sessions to follow. Mr. A.R. Ravishankara, Co-Chair of the Scientific Assessment Panel, and Ms. Bella Maranion, Co-Chair of the Technology and Economic Assessment Panel, presented an overview of current and projected atmospheric HFC abundances, current and future HFC demand by sector and potential impacts of mitigation measures. Mr. Sukumar Devotta, Mr. Ray Gluckman and Mr. Lambert Kuijpers, as independent experts, then provided an overview of the sectors and subsectors to be discussed during the workshop.

8. In his presentation Mr. Ravishankara recalled that the success of the Montreal Protocol in alleviating ozone layer depletion lay in its promotion of alternatives to ozone-depleting substances. In accordance with that approach HFCs, which previously had been almost non-existent, had been introduced as alternatives to hydrochlorofluorocarbons (HCFCs). Principally as a result of their use as alternatives to HCFCs, the production and consumption of HFCs were increasing rapidly in all sectors where HCFCs had been used, as were emissions of HFCs and their abundance in the atmosphere. Projections of future consumption and emissions, which closely tracked actual consumption and emissions to date, thus inspiring confidence in their reliability, predicted rapid increases in the near future, and accurate information on the use of HFCs in various sectors was increasingly available. HFCs were powerful greenhouse gases and could make a significant contribution to global warming, offsetting the gains made through reductions in carbon dioxide (CO₂) emissions and undermining the benefits of maintaining CO₂ at 450 parts per trillion (ppt). Such a result was not inevitable, however, because many alternatives could be used in place of HFCs, which could limit their contribution to global warming to less than 1 per cent.

9. Ms. Maranion then outlined trends in the demand for HFCs in various sectors in both Article 5 parties and non-Article 5 parties, outlining information in the report on alternatives to ozone-depleting substances prepared by the Technology and Economic Assessment Panel in response to decision XXV/5. Markets for HFCs continued to develop in both Article 5 and non-Article 5 parties. Demand in the former increased by about 30 per cent per year from 2006 to 2011 and was expected to rise by 5–7 per cent annually after 2016, while demand in the latter grew by 10–12 per cent annually from 2001 to 2011 and was expected to drop to 1–3 per cent after 2014. The European Union's fluorinated gas regulations could be expected to affect demand in both groups, as might regulations in Japan, the United States of America and elsewhere. The greatest demand for HFCs came from the refrigeration and air-conditioning sector, which used 85 per cent, while foams accounted for another 7 per cent and all other sectors combined the remaining 7 per cent. Total demand in 2014 was approximately 700,000 tonnes, and demand in the dominant refrigeration and air-conditioning sector was expected to increase, under a business as usual scenario, by 50 per cent overall – and by a factor of three in article 5 parties – between 2015 and 2030. The increasing availability of high-performance low-GWP alternatives would provide opportunities but no simple solutions, she said, and the impacts of various mitigation scenarios would be examined in the Technology and Economic Assessment Panel's report being prepared in accordance with decision XXVI/9.

10. Introducing the next presentation, Mr. Kuijpers observed that if current HFC demand trends continued to 2050, or even to 2030, the result would be an enormous increase in HFC banks and a concomitant increase in emissions and global warming. The decision XXV/5 report provided details on HFC demand by sector and subsector. It also showed that mitigation efforts focused on the use of low-GWP alternatives in key sectors, while presenting challenges, could have a dramatic beneficial climate impact beginning as early as the 2020–2030 period. The current workshop, he said, came at a

crucial time and would deal directly with what was currently possible and what might in the future be possible for each sector and subsector.

11. Mr. Gluckman, alluding to fact sheet 2, then continued the presentation, providing an overview of which HFCs were used in which sectors and subsectors and the relative importance of each. The importance of the sectors in relation to global warming, he explained, was a function of the volume and GWP of the chemicals used in each sector, because different gases were used in different sectors and their global warming impact varied considerably. Viewed from that perspective, the refrigeration, air-conditioning and heat pump sector was clearly a crucial sector, constituting 86 per cent of CO₂-equivalent consumption, with aerosols at 4 per cent, foams at 7 per cent and fire protection at 3 per cent. As important as distinguishing between sectors, however, was distinguishing between subsectors within each sector, because again the volume and GWP of the chemicals used in each varied widely, as did factors such as leakage rates.

12. Concluding the presentation, Mr. Devotta spoke about options for reducing HFC consumption, consisting largely of four approaches: use of lower-GWP alternatives in new equipment; use of lower-GWP alternatives in existing equipment; leak prevention; and the use of reclaimed HFCs. The first approach was key to achieving medium-term and long-term emissions reductions; in general it required the use of very-low-GWP alternatives but in some sectors and subsectors moderate-GWP alternatives would be required as short-term transitional substances, and an important limiting factor was that some alternatives presented considerable challenges such as increased flammability. The second approach presented an opportunity for short-term reductions, as well as from 5 to 10 per cent energy savings, primarily in large equipment in use in supermarkets and industrial settings using very-high-GWP R404A. The third approach was premised on the fact that 60 per cent of current consumption was for replacing leaked gases and studies showing that leaks could easily be reduced by 50 per cent. The fourth approach reduced demand for virgin HFCs, thus directly reducing the amount produced and consumed, but it required that end-of-life HFCs be captured before venting to the atmosphere and that it be purified to its virgin state.

13. In conclusion, Mr. Kuijpers stressed that the key market for addressing HFC consumption was the refrigeration, air-conditioning and heat pump sector. The foams and aerosols sectors were also important, but relatively small. Various very-low-GWP and moderate-GWP alternatives were available in a number of sectors and subsectors, and in considering them various factors had to be taken into account, including commercial availability, energy efficiency, cost, safety and performance in high ambient temperatures.

II. Session 1

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

14. The first session of the workshop, on the challenges and opportunities in addressing high-GWP HFCs in the refrigeration sector, was facilitated by Mr. Peter Adler, principal and founder of the ACCORD 3.0 Network, with Mr. Ullrich Hesse, Dresden University of Technology, Germany, serving as rapporteur in an independent capacity. In opening the session, Mr. Adler said that its purpose was to provide clarity on the available data and technical challenges in the refrigeration sector, as well as on the markets that were most and least capable of making speedy progress in adopting new technologies. Since no single solution was applicable to every context, he said, the discussion would cover each of the four subsectors in turn: commercial, industrial, transport and domestic.

15. Presentations on the overall status of the refrigeration sector were delivered by two overview speakers: Mr. Paulo Vodianitskaia, consultant, Brazil, and Mr. Reinhard Radermacher, Centre for Environmental Energy Engineering, United States of America, both as independent experts.

16. Mr. Vodianitskaia, in his presentation, said that the focus of environmental indicators, after shifting from the ozone-depletion potential of chlorofluorocarbons (CFCs) in 1987 to the GWP of HFCs today, now needed to encompass a much wider range of indicators, with a particular emphasis on the sustainable extraction and use of materials from renewable sources. While sufficient options were already available in the domestic subsector, where most appliances used natural refrigerants such as isobutane, it was crucial for the other three subsectors to move from R-404A through intermediate blends to new blends with a reducible GWP, as well as to hydrofluoroolefins (HFOs) or unsaturated HFCs for commercial applications and to hydrocarbons and ammonia for industrial systems. Key issues to be addressed, he said,

included the lack of a single global safety standard; the high temperature discharge of some alternatives; and the critical question of energy efficiency.

17. In his presentation, Mr. Radermacher characterized the various existing refrigerants in terms of GWP, energy efficiency, flammability and displacement volume, and highlighted some of the better low-GWP options: CO₂ in cooler climates, propane and isobutane but for their flammability, and HFC-32, ammonia and R-404A for mass-produced small systems. He stressed the importance of energy efficiency: in very tight systems, energy efficiency was the biggest contributor to global warming regardless of the refrigerant, and it even played an important role in systems with considerable leaks and a high-GWP refrigerant. Energy efficiency was therefore just as important as refrigerant choice if not more so, and technology choices should take this into account. As a final note, he cautioned that testing had shown that some refrigerants considered non-flammable were in fact quite flammable in the presence of compressor oil.

18. There followed a series of brief presentations by a panel of 11 experts in the field: Mr. Torben Funder-Kristensen, Danfoss, Denmark; Mr. Jonathan Ayotte, Carnot Refrigeration, Canada; Mr. Eric Delforge, Mayekawa Europe, France; Mr. Roy Singh, Arctic King Appliances, South Africa; Mr. Bruno Pussoli, Metalfrío, Brazil; Mr. Christian Heerup, Danish Technological Institute, Denmark; Mr. Zhang Zhaohui, China Refrigeration and Air-conditioning Industry Association, China; Mr. Paul de Larminat, Johnson Controls, France; Mr. Fernando Galante, EPTA, Argentina; Mr. Juergen Goeller, Carrier Transicold and Refrigeration Systems, Germany; and Mr. Holger Koenig, independent consultant, Germany.

19. Mr. Funder-Kristensen, in his presentation on components for refrigeration systems using low-GWP chemicals and blends, said that the main challenge at present concerned the safety issues hindering the use of hydrocarbons; that the speed of innovation could exceed expectations once the intended refrigerant had been identified; and that investment decisions for future development relied on legislative certainty and the introduction of standards.

20. Mr. Ayotte, in his presentation on technology options for medium and large-scale industrial systems under various ambient conditions, drew attention to the range of transcritical, direct expansion, cascade and other systems that used natural refrigerants, such as CO₂, ammonia and propane, and which had attained high levels of efficiency and performance in all climate zones.

21. Mr. Delforge, in his presentation on low-GWP technology options for industrial and large-scale commercial and community applications, said that the use of natural refrigerants was set to become general practice in those sectors; that ammonia, in particular, which was safe and widely available, not only met current requirements for sustainability and accountability but also outperformed most low-GWP refrigerants in terms of overall efficiency; and that the key enabling factors included the development of smart equipment by increasing numbers of manufacturers, the use of natural water bodies and heat pumps, and suitable training for operators and maintenance staff.

22. Mr. Singh, in his presentation on alternative options for plug-in cabinets, such as vending machines, drew attention to the technical requirements for converting small-scale appliances to hydrocarbon use and highlighted the main challenges in his region, such as the inadequate training of users, compounded by a lack of collaboration with peers; the prohibitive cost of safety and ventilation features; the lack of affordable leakage testing, which was crucial in view of the compact design of the equipment; and the unavailability of spare parts.

23. Mr. Pussoli, in his presentation on low-GWP options for small-scale commercial equipment, outlined his company's efforts to convert its technologies to propane or CO₂ use and highlighted the challenges that it faced in complying with government regulations while promoting energy efficiency and seeking to reduce costs.

24. Mr. Heerup addressed the topic of low-GWP alternatives for on-site-built commercial refrigeration equipment (including condensing unit systems), and their cost implications and performance in high ambient temperatures. He explained that the development of condensing units was being driven by the supermarket sector in Europe and Japan. Solutions were available using natural refrigerants; a first generation European-manufactured CO₂ condensing unit had performed well in testing. He anticipated that further developments, driven by competition, would lead to smaller units with good efficiency in high ambient temperatures, and higher production would bring down costs.

25. In his presentation, Mr. Zhang addressed options for existing commercial systems and equipment and servicing issues. Options for existing commercial systems were drop-ins, retrofits and replacement, with drop-ins being the least expensive alternative and replacement being the most expensive. He noted that while filling of new equipment accounted for the bulk of consumption, most emissions occurred during operation, servicing and end of life. Consequently, in parallel with the adoption of ozone-friendly alternatives and technologies, responsible use of refrigerants should be promoted through awareness-raising initiatives, training of technicians in refrigerant recovery, reuse and destruction, and regulation of end-of-life disposal. He stressed that education and training of technicians would be a very daunting task.
26. Mr. de Larminat spoke about low-GWP options for cascade systems in relation to medium-sized and larger commercial refrigeration equipment. Rather than potential retrofits of such equipment and the use of lower-GWP blends, he proposed a complete change to a cascade system, which allowed the use of a combination of existing alternatives to achieve optimal results for a given application. For instance, CO₂ could be used for the low stage, the higher stage could provide heat rejection to the atmosphere, and straightforward existing solutions for the medium stage included standard air-conditioning chillers for indirect refrigeration in higher temperatures and direct expansion CO₂ for lower temperatures.
27. Mr. Galante spoke about technological transition and barriers to adoption in Article 5 countries for commercial refrigeration from the end-user's perspective. He contended that cost was the most important barrier for end-users of centralized systems, although not for end-users of stand-alone equipment. For centralized systems, because low-GWP alternatives were not efficient in high ambient temperatures, there was no payback on the additional investment required to convert. Other barriers were technical servicing capabilities, safety, availability of components and final disposal in the case of retrofits.
28. In his presentation, Mr. Goeller described the performance of low-GWP supermarket systems in various climate zones in Europe. He noted that there were options for reducing the impact of direct emissions, but that energy efficiency had to be considered as well. His company had achieved huge improvements in energy efficiency with transcritical systems using standard CO₂ technology in moderate and cooler climates, and was making progress in adapting such systems for use in warmer climates. Overall, he held out strong hopes for energy-efficient CO₂ applications in warm climates.
29. The last panellist to speak, Mr. Koenig, addressed low-GWP alternatives and standards for transport refrigeration, including trucks, trailers and refrigerated containers. Refrigeration applications in transport typically operated in ambient temperatures of -30 to -50 degrees Celsius. One big challenge was the substantial investment needed for conversion; for refrigerated containers, for instance, spare parts needed to be available around the globe. Technological options were available using various alternatives, including hydrocarbons and CO₂, although market penetration was currently somewhat limited. Training, education and a good understanding of the safety considerations were needed, as well as clear guidelines from policymakers.
30. In the ensuing discussion, questions were put to the panellists on each of the four subsectors in turn, beginning with commercial refrigeration. Most revolved around issues related to the use of natural refrigerants in high ambient temperatures, with a particular emphasis on CO₂, ammonia and propane. Several panellists stressed that more research was needed to develop the required technologies, with one pointing out that they would eventually allow for the safer use of natural refrigerants with greater levels of safety and equal energy efficiency to HFCs, and another two suggesting that high ambient temperatures could be harnessed as a heat source. Another panellist said that while propane and isobutane were already used in small-scale, plug-in appliances, which required enhanced safety features owing to frequent leakage, CO₂ use was limited in his region because performance levels remained unacceptable, adding that there was a growing trend towards the use of hydrocarbons. On the subject of viable options for condensing unit systems, one panellist drew attention to the trend toward CO₂ technology, which seemed set to continue, adding that hydrocarbons alone were unlikely to suffice for charges in excess of 1 kilogramme. Another said that users in regions where such technologies were unaffordable could consider cascade systems with glycol, which could already replace some direct expansion systems, and that while CO₂ might be a market leader in the near future, many other competing technologies were likely to emerge. A third recalled that a CO₂ and HFC-134a cascade system could lead to significant improvements, with at least 98 per cent savings in direct emissions. One panellist said that more time was needed to develop the new components required for cascade systems in high ambient temperatures, and another said that the future development of complex technologies called for innovation, energy efficiency and, above all, investment. As to the definition of the term "natural refrigerants", one panellist said that it

referred to products or compounds already available in the atmosphere in far larger quantities than could be produced synthetically and whose emissions would have no unexpected side effects.

31. On the cost differences between using A-3 and A-2L refrigerants as alternatives in small-scale, plug-in cabinets, one panellist said that experience to date with smaller-charge hydrocarbon systems, for example, had shown the cost of using A-2L to be roughly the same as that of using HFCs and that a larger charge with HFO-based systems might be considered acceptable in view of the minimal cost of security equipment. Another panellist said that although CO₂ cascade systems were very large, their use would result in significantly greater energy efficiency. One panellist said that the testing of such systems in moderate climates had shown the cost differential to have decreased dramatically owing to economies of scale, and that while adaptation to higher ambient temperatures would call for additional investment, the overall cost-efficiency would lead to relatively quick returns. Another said that installation costs would be much lower, and a third said that such installations would also reduce the costs linked to leakage. On the question of leakages, one panellist said that it was a matter of maintenance and compliance with prevailing regulations, noting that some users ignored the issue as their priority was to keep their systems operating.

32. One participant called on the Secretariat to update the fact sheets used to prepare the presentations, as relatively little of the information had come from Article 5 party experts and the sheets gave the misleading impression that many options were already available. The overview speaker of the session, Mr. Vodianitskaia, said in response that the fact sheets actually presented a good number of low-GWP options that were available to Article 5 and non-Article 5 parties alike.

33. The facilitator and a number of participants posed a number of questions on industrial applications. Questions referred to, inter alia, the conversion of ice-making systems using HCFC-22 to natural or other refrigerants readily available on a sustainable basis; how quickly the industrial sector could change over to alternatives in small and medium distributed systems; applications for which certain refrigerants must continue to be used in limited amounts; the feasibility of using solar-powered absorption refrigeration in cascade systems with CO₂ for industrial refrigeration; and how natural refrigerants compared to synthetic refrigerants in terms of energy efficiency.

34. With regard to the conversion of HCFC-22 ice-making systems, one panellist suggested that while the obvious alternative refrigerant would be ammonia, conversion was very complicated as the HCFC-22 system used copper heat exchangers that were not compatible with ammonia. One participant added that depending on the specifics of the ice-making system and giving due consideration to safety issues, propane might be an alternative, as it had been used before in developing countries for chiller conversions. Another indicated that many case studies showed that converting from HCFC-22 to ammonia generated such high energy efficiency gains that the payback period was very short.

35. In terms of the timing of industrial sector conversion in small and medium distribution systems, it was noted that industrial refrigeration was typically already based on natural refrigerants, mainly ammonia. HCFCs such as HCFC-22 were occasionally used in very low temperature applications, and such systems were very complicated to convert. In principle, however, the right refrigerants were almost always used in new plants, with the choice of refrigerant depending on the region of the world, as well as commercial and environmental considerations. It was further noted that the larger the capital cost, the lower the speed of change.

36. Regarding the need for the continued use of certain refrigerants in limited amounts to maintain efficiency, such as in applications for which flammability can be a serious problem, panellists indicated that while ammonia was a good choice for temperatures above -30 degrees Celsius and CO₂ was gaining a large market share for temperatures between -30 and -55 degrees Celsius, below that there were few alternatives to HFC-23 that did not compromise efficiency.

37. Addressing the feasibility of using solar-powered absorption refrigeration, a panellist agreed that it was possible to reach low temperatures using solar energy with an ammonia absorption system. While this was feasible from an energy efficiency perspective, it was difficult from a cost perspective as absorption systems always had at least twice as many heat exchangers as vapour compression systems.

38. Responding to a question about the energy efficiency of natural refrigerants compared to synthetic refrigerants, a panellist noted that tests in Europe had shown that CO₂ was more energy efficient in cooler climates than standard HFC systems. Another panellist cautioned that the matter was not clear cut, as efficiency depended on temperature and other conditions. As an example, he offered the generally

accepted idea that ammonia provided better efficiency than HFC-134a, which he said did not necessarily hold true for water chillers.

39. One participant commented on the use of ammonia in industrial refrigeration, saying that the trend was to reduce the size of industrial ammonia systems and to have custom-built, almost unitary systems with significantly lower charges. In supermarkets and other industrial applications, there were ammonia systems with ultralow charges of less than 20g per kilo, which meant that ammonia chillers could be used in urban areas. A panellist confirmed that his company had had such systems on the market for the last two years, and energy efficiency was very good.

40. A number of questions were then posed on transport applications, referring to, inter alia, how CO₂-based transport refrigeration equipment and refrigerated containers performed in high ambient temperatures, and whether the required system components were already available; the cost of CO₂ systems compared with existing HFC systems; the premium paid for safety measures when using flammable refrigerants; and how quickly the sector would swing away from the current HFC systems.

41. Regarding the question of performance and availability of CO₂-based transport refrigeration equipment, one of the panellists said that CO₂ refrigerated container systems were available and performed well in terms of efficiency on global shipping routes, which tended to be in very warm climates. A participant cautioned, however, that it was important to understand the operation profile of such applications, especially with respect to refrigerated containers. Studies had shown that it was difficult for CO₂ to compete with existing technologies in the refrigerated container market, which was very competitive, with very low equipment prices.

42. On the subject of the additional cost of alternatives to existing HFC systems, panellists responded that CO₂ systems for refrigerated containers were about 20 per cent more expensive than traditional HFC-134a systems, and the additional cost for safety was an extra 2–5 per cent, depending on the refrigerant used. Additional costs would fall once the technology achieved better penetration and production levels increased.

43. On the question of the timing of the swing away from HFCs, a panellist indicated that, assuming that manufacturers could successfully respond to industry interest in the safe design and safe operation of the new systems, there were plans to introduce new hydrocarbon- and HFC-32-based systems in the next three to five years. Change would come sooner rather than later, as this market was very competitive.

44. The questions posed in the area of domestic applications related to the slow pace of changeover to hydrocarbon systems in developing countries and barriers to the uptake of low-GWP refrigerants in the domestic sector.

45. On the topic of the adoption of hydrocarbon systems, panellists noted that such systems were well accepted in Europe but had indeed only recently started gaining acceptance in the United States. The slow pace of change could be explained in part by the cost of the safety equipment required to ensure safety during manufacturing, and design changes required to ensure safety for the consumer, but the pace was now accelerating.

46. Turning to the question of the uptake of low-GWP refrigerants in the domestic sector, panellists pointed to technical capabilities as a significant barrier, especially in after-sales service, as well as capital investment.

47. Finally, a number of cross-cutting questions were posed to the panellists, referring to, inter alia, ways of saving energy when using refrigeration or air-conditioning equipment, aside from using an energy-efficient refrigerant; the timeline required to bring CO₂ to a global market, particularly with regard to training; the reason for higher leakage rates in commercial systems compared to other systems, and what steps, if any, could be taken to reduce leakage rates; and finally, the most important barriers to the adoption of HFC alternatives.

48. Addressing the question of ways to save energy when using refrigeration and air-conditioning equipment, panellists concurred that heat recovery was a key aspect across all sectors, with one panellist stressing that cold storage should be run on a double business model of producing both heat and refrigeration. Other suggestions for generating energy savings were to design smart buildings for system optimization, and to simply close refrigeration cabinets in supermarkets.

49. On the question of the timeline required to bring CO₂ to the global market, panellists responded that the fastest deployment occurred when blue-chip companies introduced high standards from

non-Article 5 countries into Article 5 countries, which automatically resulted in the training of local support staff. If industry was convinced that a technology was worthy of being deployed, then it moved ahead regardless of whether there was a political timeline. Nevertheless, the development of efficient CO₂ systems for supermarkets had taken about 10 years. One panellist said that the time to market for transcritical systems would be longer than for subcritical cascade systems, which were simpler, but another said that the experience in Denmark showed that transcritical systems were closer to standard HFC systems, so training was in fact easier.

50. On the question of higher leakage rates in commercial systems and how to reduce them, one panellist noted that if refrigerants were relatively cheap and technicians were not well educated, there would be more leaks. Leakage rates in Denmark had dropped from about 30 per cent to about 10 per cent following the imposition of a tax that made leaks expensive. Leaks could be reduced, but it was easier to use a refrigerant that did not harm the environment, such as CO₂. Another panellist added that the source of high leakage rates in conventional HFC systems was the many connections; in chillers, in which the refrigerant charge was contained and much smaller and there were fewer connections, leakage rates were lower, at around 2 to 4 per cent.

51. Finally, with respect to the main barriers to the adoption of HFC alternatives, panellists pointed to the need to develop or update safety codes and standards, technician training and education, and investment capital.

52. Mr. Vodianitskaia, in his closing comments, noted that most of the questions and comments at the present session had concerned the steps to be taken to induce the switch to low-GWP alternatives in Article 5 and non-Article 5 parties, as well as the importance of raising awareness as to the importance of the changeover and establishing clear rules and standards, which called for the participation not only of Governments but also of industry and standardization bodies.

53. Mr. Radermacher, in his closing comments, concurred with Mr. Vodianitskaia's assessment, adding that solutions were already available but had to be tailored to specific circumstances and that communication was key to ensuring the critical involvement of a wide range of different stakeholders.

54. Summing up, Mr. Adler expressed appreciation for the dynamic discussion, saying that it had taken the technical debate on a highly complex topic to a higher level.

III. Session 2

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

55. The second session of the workshop, on challenges and opportunities in addressing high-GWP HFCs in the stationary air-conditioning and heat pump sector, was facilitated by Mr. Saleem Ali, Director of the Centre for Social Responsibility in Mining and Professor of Sustainable Science, Politics and International Studies, University of Queensland, Brisbane, Australia. Introductory overview presentations were made by Mr. Daniel Colbourne, independent consultant; Mr. Roberto Peixoto, Maua Institute of Technology, Brazil, and Mr. Saurabh Kumar, Energy Efficiency Services Limited, India, participating in their personal capacities. Additional introductory remarks were made by a panel of technology providers and implementers in the sector: Mr. Mike Thompson, Ingersoll Rand/Trane, United States; Mr. Jitendra Bhambure, Blue Star Limited, India; Mr. Li Tingxun, Midea and Sun Yat-sen University, China; Ms. Wang Lei, China Household Electric Appliances Association, China; Mr. Bassam Elassaad, independent consultant, Lebanon; Mr. Maher H. Mousa, industry consultant, UTC Building and Industrial Systems, Saudi Arabia; Mr. Petter Neksa, SINTEF Energy Research, Norway; Mr. Alaa Olama, independent consultant, Egypt; and Mr. Pär Dalin, Devcco, Sweden. The discussion that followed included questions from the floor and responses from the panel.

56. Commencing the overview of stationary air-conditioners and heat pumps, Mr. Colbourne outlined the different types of appliance that operated within a very varied sector. For new equipment, a range of refrigerants were available, from high-GWP substances (including HFC-134a, R-407c and R-410A) to low-GWP alternatives. He outlined the main characteristics of the various appliances in the sector, including small factory-sealed air-conditioners, non-ducted single split air-conditioners, ducted split air-conditioners, packaged "rooftop" ducted air-conditioners and multi-split systems, along with the ozone-depletion potential of the main refrigerants used for each type of appliance and the alternative

low-GWP options that could potentially be used. Continuing the presentation, Mr. Peixoto delivered similar information on chillers and heating-only heat pumps. He then compared the capacity and coefficient of performance for a range of refrigerants compared to R-22. For drop-in or retrofit, performance was always worse than R-22, and GWP was nearly always higher; and conversion to low-GWP flammable refrigerants was potentially hazardous. The main hurdles that needed to be overcome in identifying and using alternatives were complications involved in selection, design and installation; lack of knowledge on such issues as flammability and pressure; obstructive safety standards; and disparate national regulations and codes.

57. Mr. Kumar gave a presentation on using innovative business models to scale up energy-efficient investments, using India as an example. Noting the rapid growth in the use of HFCs in the heating, ventilation and air-conditioning sector, he said that alternative technologies existed but their market potential was constrained by low demand, driven in part by concerns about cost and safety. However, hydrocarbon-based, energy-efficient technology for air-conditioning was commercially available in India, and options were being explored to develop replicable and scalable business models to aggregate demand and drive down costs through economies of scale, making energy-efficient alternatives more affordable. The method had already proved successful in a drive to replace incandescent light bulbs with LED bulbs in Andhra Pradesh.

58. Mr. Thompson said that it was an exciting time in the air-conditioning sector, as the next generation of innovative technologies was being developed. His own company had committed to phasing out high-GWP refrigerants, and he was confident that solutions could be found to the problems faced in the various subsectors. In the area of centrifugal chillers, for example, a number of Article 5 parties had expressed concern about the transition to the use of R-410A as a refrigerant, but drop-in replacements were being developed with improved energy efficiency and less flammability.

59. Mr. Bhambure gave a presentation on alternatives to high-GWP HFCs for air-conditioning. While the task of identifying alternatives was made more difficult by the lack of a clear, standard definition of what was meant by “low-GWP”, a number of alternatives were emerging in the sector, including HFC-32 and HC-290, with other options in the development stage, including R-446A and R-447A. Criteria used to evaluate alternatives included GWP, environmental impact, flammability, maturity, efficiency, cost and use in high ambient temperature conditions. Currently, however, no long-term feasible option was available, based on the evaluation criteria, and further studies were urgently needed on promising alternatives.

60. Mr. Li gave a presentation on the use of HC-290 as a refrigerant. The substance, he said, had 5 to 10 per cent higher efficiency than R-22, and it functioned well at high ambient temperatures. Safety issues regarding flammability had been overstated; it was difficult to ignite the HC-290 indoor air-conditioning unit, and smoke presented more danger than fire.

61. Ms. Wang gave a presentation on the use of HFCs in the Chinese household electrical appliances sector. The use of HFCs had largely been avoided in the refrigeration subsector, where natural hydrocarbon refrigerants were dominant, but their use was increasing in the air-conditioning subsector with the phase-out of HCFCs. Ozone-protective and climate-friendly natural propane refrigerants, including HC-290, had been selected for adoption in the air-conditioning subsector, although restrictions on the charge size due to safety concerns meant that heating capacity and energy efficiency did not reach their full potential. Those restrictions, she concluded, were too stringent, and HC290 could be used safely at higher charges.

62. Mr. Elassaad, in his presentation, gave an overview of suitable alternatives at high ambient temperatures for small and middle-sized air-conditioning equipment. Challenges related to operation at high ambient temperatures included reduced performance, decreased efficiency and quicker wearing out of components, leading to shorter product life. For local equipment manufacturers in countries with high ambient temperatures attempting to move directly from HCFCs to low-GWP alternatives, issues of pressure and flammability presented a double challenge. Local research was needed to assess available technologies, review relevant energy efficiency standards and codes, undertake an economic comparison of alternatives, and promote technology transfer. In conclusion, he gave a summary of research projects currently being implemented in the Middle East.

63. Mr. Mousa gave a presentation on the current status of alternative refrigerants in the air-conditioning and refrigeration sector for Article 5 countries with high ambient temperatures. The

landscape, he said, was not clear – there were a number of technical issues and challenges, many related to the fact that most low-GWP alternatives were flammable and operated at high pressure, generating safety concerns. In response, new building standards and codes were required, as well as training to improve service practices. He concluded that feasible high ambient temperature solutions were still not available, and that HFCs were the only current viable solution. Cost versus value added should be considered in any HFC management initiatives, and any HFC phase-down should incorporate a technology review in later years to determine the technological state of readiness, including for high ambient temperature alternatives.

64. Mr. Neksa, in his presentation on the use of non-HFC refrigerants in small and medium-sized air-conditioning and heat pump systems, gave an overview of the history of the use of various refrigerants. That, he said, had come full cycle, from the use of natural refrigerants before 1930, to an increasing use of synthetic fluids with eventual regulation of ozone-depleting substances under the Montreal Protocol, and a reversion in recent times to environmentally benign natural refrigerants. All refrigerants could achieve acceptable efficiencies and cost, even in hot climates. Both hydrocarbons and CO₂ offered potential, although a number of challenges needed to be overcome related to charge, flammability, pressure, technical aspects and components, and the regulatory environment.

65. Mr. Olama commenced his presentation on low-GWP alternatives for large air-conditioning units with a summary of the low-GWP alternatives to currently used HFCs. Currently, the only non-flammable option for split systems and variable refrigerant flow (VRF) systems was R-410A, although the use of non-flammable alternatives to HFCs generally involved greater capital costs and reduced efficiency. Low-GWP options could be assessed according to various criteria, for example safety and practicality, commercial availability, cost, energy efficiency and applicability in high ambient temperatures. He drew conclusions as follows: a number of low-GWP refrigerants were available for large air-conditioning units, although they were not yet commercially available for high ambient temperature countries; charge limitations applied for all flammable options in those countries; the economics of lower-GWP options had not yet been assessed; and non-fluorinated solutions needed to be seriously examined as an option for high ambient temperature countries.

66. Mr. Dalin gave a presentation on district cooling systems, which had significant advantages for large-scale applications, including capacity reduction in a centralized system; financially optimized production mix; suitability for low-GWP alternatives; secure operational systems with minor leakage; and financial feasibility for a significant share of the air-conditioning market. In Stockholm, for example, the district cooling network was providing cooling solutions to approximately 600 buildings in 2010. In conclusion, he said that the phase-out of HFCs presented a great opportunity for the introduction of district cooling systems.

67. Following the presentations, the facilitator and a number of participants posed questions to the panellists.

68. In response to questions raised regarding potential trade-offs between efforts to increase energy efficiency and efforts to increase the use of low-GWP alternatives, several panellists underscored that energy efficiency almost always increased as the size of the air-conditioning system increased. One panellist said that based on history, one should expect to see continued and significant improvements in energy efficiency in systems using low-GWP alternatives. Another noted that many countries already possessed energy efficiency standards that all new low-GWP systems would have to meet. Several noted that the biggest current limitation regarding energy efficiency concerned systems that used flammable or slightly flammable alternatives, with some stating that these limitations were or could be addressed through higher charging allowances that could likely become available because of design changes, production improvements, improved training of inspectors and service technicians, and updated building and safety codes.

69. One participant said that several fact sheets prepared for the workshop showed that significant compromises still existed between energy efficiency and the use of low-GWP alternatives. Greater efficiency required larger charging systems, which posed problems for flammable alternatives. The goal of increasing energy efficiency would yield important climate benefits but also necessitate the continued use of HFCs in some applications in some regions. Another said that more information was needed regarding how all low-GWP alternatives behaved in a variety of potential large volume systems or systems that would use emerging technologies. One noted the absence of sufficient published data that could be used to

compare the cooling capacity and cost of production of low-GWP hydrocarbons against those of other low-GWP alternatives.

70. A number of questions and comments from participants touched on issues relevant to the potential use of low-GWP alternatives in countries with high ambient temperatures, including the challenges faced due to, inter alia, the need for significant additional, reliable, cost-effective and energy efficient air-conditioning capacity in these countries; potential problems associated with flammable low-GWP alternatives; water and electricity shortages; and a gap between pronouncements concerning the potential effectiveness and efficiency of low-GWP alternatives and the amount of proven, commercially available equipment. One panellist responded to a specific question about the apparent contradiction between several statements in the presentations regarding the effectiveness of HC-290 in high ambient temperature countries and recent sales activity in the region by noting that this was due to a marketing decision by the major manufacturer concerned in response to perceived commercial preferences within the region.

71. During discussion of air-to-air air-conditioning systems, a number of general issues arose regarding the availability and appropriateness of potential low-GWP alternatives. One participant asked what the realistic chances of finding new low-GWP alternatives were given that between 65 and 80 refrigerants had already been identified. One panellist responded that new formulas and mixtures were constantly evaluated and options could arise that offered greater energy efficiency and other advantages, particular given that the use of flammable substances was increasingly accepted. Another noted that the development process should not start with reference to alternative substances but rather focus on which existing or potential substances, including those currently in use on a wide basis, could best meet the priority needs of parties, including effectiveness, broad availability, energy efficiency and safeguarding the stratospheric ozone.

72. One participant asked if test results and deployable equipment actually existed for all the low-GWP alternatives discussed in the relevant documents and presentations and, if so, whether they addressed all the concerns expressed by parties at previous meetings regarding when potential alternatives would become acceptable. Another emphasized that all alternatives had potential positive and negative implications across a range of factors and asked if it was possible to list the trade-offs for each specific alternative. During the resulting discussion, several panellists said that the many alternatives were available and proven but that, as a practical matter, not every potential equipment component or design configuration had yet been tested, although many had been proven and deployed, as shown in the fact sheets and presentations. Thus, a critical issue was accelerating progress in the design, engineering, testing and deployment of additional equipment and processes. Several issues were cited as opportunities for increasing the relevant market demand and moving this process forward, including, inter alia: market certainty resulting from additional regulatory controls on HFCs; advances in government regulation so that it accurately reflected important developments that had already occurred; harmonization of safety and building codes within and across countries and regions; enhanced training and reliability of inspection and service personnel; and greater awareness of the availability, effectiveness and efficiency of available alternative substances and equipment. One panellist said that the goal of reducing high-GWP emissions could be addressed through better manufacturing and servicing standards for equipment that used HFCs.

73. Regarding the use of specific alternatives for large air-to-air cooling systems, one participant asked whether there was potential to shift part of the air-to-air market to central systems with chillers given that the use of low-GWP refrigerants, in particular hydrocarbons (HC-290) and ammonia (R-717), was easier, safer and more energy efficient in large chillers, including under high ambient temperatures. Another asked if district air-conditioning systems would be a feasible low-GWP option for high ambient temperature countries. In response, one panellist noted that district cooling projects already existed in some high ambient temperature countries, especially Gulf States, and that many of the relevant issues were being considered as part of a study under way in Egypt. However, several constraints were likely to restrict district systems from meeting much more than 25 per cent of overall cooling needs in the Middle East, including shortages of electric power, water scarcity, preferred building types and development densities. Another participant underscored that water scarcity and other issues in the high ambient temperature countries, especially those in the Middle East, hindered the broad use of large central systems with chillers. It might also be inadvisable to promote one technology over another rather than offering consumers a range of choices. One participant said that it was technically possible to shift to central systems in many countries but that it would be necessary to adjust real estate codes and engage developers.

74. One participant asked whether there were potential approaches besides limiting the charge size of low-GWP systems that utilized flammable refrigerants, especially given the fact that many homes, businesses and modes of transport employed flammable substances on a daily basis, including natural gas

and gasoline. One participant said that while changing from a non-flammable to a flammable substance required taking safety into account, it was demonstratively true that some charge size restrictions for certain equipment were significantly outdated in their current form. In addition, many parameters besides flammability should be taken into account when evaluating refrigerants. Another participant noted that different legal systems assigned different levels and types of responsibility for risks that had an impact human life, which could in turn have an impact the deployment of certain low-GWP alternatives.

75. Regarding questions about specific alternatives to variant refrigerant flow systems, one panellist noted that CO₂-based units had already been deployed in some countries with cold climates. Another noted that certain regulatory standards already permitted the use of flammable refrigerants in medium-sized systems.

76. In response to a specific question, one panellist said that the performance comparisons carried out on HC-290 had been done on compressors appropriately designed to use the chemical or mixture in question and that all other aspects of the tests, including the efficiency of each compressor, were identical. Regarding the assessment of risks in using HC-290 in different types of systems, for example in self-contained small refrigerators versus larger and more complex air-conditioning systems, he said that the existing standards within and across many countries did not appear to be based on uniform technological or safety standards, comparability studies or the goal of reducing high-GWP emissions.

77. Several participants enquired about potential safety concerns associated with the use of flammable refrigerants in small split systems. A number of panellists noted that research studies, commercial developments and regulatory analysis were under way on that issue. One panellist said that further regulation would help increase this activity significantly. In response to questions about available technology in the sector addressing all the concerns expressed by Article 5 parties regarding potential alternatives, one panellist said many deployable options did exist, and more were coming, but that any alternative, including the continued use of HFCs, would result in trade-offs. Another panellist said that no alternative was currently available that met all criteria in high ambient temperature countries and that significant aspects of the high-GWP problem could be addressed by improvements in the manufacturing, inspection and servicing of equipment so that HFCs were not emitted from small split systems.

78. Returning to issues raised by questions specifically related to chillers, several panellists noted that low-GWP chillers could replace many air-to-air systems, including in both commercial and residential settings, and that proven technologies were already on the market. Important differences existed, however, regarding the needs, preferences and geographic locations of end-users, which meant that chillers would not be a universal solution. Regarding specific trade-offs among various options, one panellist said that chillers were more energy efficient on a ton-to-ton basis, but variant refrigerant flow systems were still more efficient than small chillers. It was also important to include calculations regarding the cost of purchasing and serving equipment, energy and water in a particular setting when evaluating alternatives.

79. One panellist said that it was important to be specific when discussing alternatives in order to understand exactly when particular solutions would and would not apply. In this regard, it was important not to mix the significant issues discussed in fact sheets that examined small, enclosed air-conditioning systems, small split systems and large air-to-air systems with the discussion of very large chilled water systems.

80. In response to a question regarding the availability of small and medium-sized chillers that used flammable refrigerants, one participant said that several options had been available on market and in use for around fifteen years. Such chillers were usually situated outside or in an equipment room and employed factory-sealed systems. Some 15-20 companies already produced low-GWP chillers with several different alternative chemicals and blends, including flammable refrigerants, as units that used CO₂, ammonia, or water. In response to another question, one panellist said that replacing multi-split systems with small to medium-sized chillers was an option in high ambient temperature environments and that location outside buildings would allow for a bigger charge of flammable refrigerants that would increase efficiency, but that obstacles existed to such use, including a lack of familiarity with chillers in some areas and misconceptions about the potential for water leakage.

81. In response to questions concerning heating only heat pumps, one panellist noted that while some countries employed subsidies to encourage the uptake of systems using low-GWP alternatives, refrigerants, medium- and large-scale systems were being produced and deployed in Europe without subsidies. If demand was sufficient, it would be possible to produce and use these systems without subsidies. Another panellist noted that the method used to heat the water in such systems could have an

impact on their operating cost and environmental effects. The facilitator noted the importance of differentiating between different categories of heating only heat pumps, such as domestic space heating, domestic hot water and district heating. One panellist said that low-GWP options existed in all categories. For example, district heating systems had been built in Norway using low-GWP or no-GWP systems. Efficiency was always greater with large capacity systems, however. Another panellist noted that countries with high ambient temperature and low water availability faced challenges in employing such systems, although these could be addressed.

82. The panellists responded to the points raised in the discussion, focusing on the key questions for the air-conditioning and heat pump sector. Among the priorities identified were the issues of flammability of alternatives; cost of alternatives; the need for training and proper service provision; and the strictness of regulatory codes. One panellist said that manufacturers would be unwilling to invest unless there was certainty on the regulatory environment. Another panellist said that time was a factor: a one-step transition was needed from ozone-depleting substances to energy-efficient systems that were available and commercially viable. Also, solutions should not be mixed, with the best alternatives being identified and applied for each use. Several panellists stressed the urgency of finding long-term solutions for the pressing needs of high ambient temperature countries. One panellist said that energy efficiency was of paramount importance; investment in low-GWP alternatives would be counterproductive if they were less efficient and required the expenditure of more energy in the operation of the appliances. An integrated, life cycle approach was therefore needed. Finally, one panellist highlighted the importance of a level playing field with regard to building directives and other factors, so that options such as district cooling were allowed to achieve their full potential.

83. The overview speakers also commented on the issues raised. Mr. Peixoto said that standards constituted one of the main challenges, and careful risk analysis was required to identify the degree of risk that was acceptable to society. It was impossible to have ideal refrigerants that took account of all constraints, so while defining the regulatory framework was challenging, it was of prime importance. Again, achieving energy efficiency for high ambient temperature conditions was a priority; the scenario was complex, but would become clearer in the near future.

84. Mr. Colbourne said that positive points could be drawn from the session. It was clear that a suite of alternatives was available or under development for all sectors, that considerable research and development was being undertaken, and that there was clarity on what needed to be done to provide products for the market. If the demand was for products with low GWP or medium GWP, then the engineers would find a way to achieve that for any particular system or appliance. It was essential, however, to have a driver or stimulus, whether legislative or demand-driven, for such a process of development. The move towards large-scale commercial refrigeration using low-GWP alternatives had been driven by large operators such as supermarket chains, but similar forces were not operating in other subsectors, such as air-to-air air-conditioners. With regard to safety issues, flammability presented an engineering challenge, particularly given the restrictive safety standards. For chillers and heat pumps, that was not a problem as they were sealed and located outside, but manufacturers and installers still needed to understand the flammability issues and routinely apply a risk assessment. He also stressed that in many countries there were minimum efficiency rules, so end users were free to choose whatever alternative they required providing the equipment achieved those standards. With regard to cost, the message was clear that once a sufficiently large market was achieved, and experience gained in producing new types of equipment, then cost parity would follow. Finally, he said that capacity-building in the service sector was of crucial importance in preparing technicians for new types of refrigerants, including flammable substances. That challenge applied to both Article 5 countries and non-Article 5 countries.

IV. Session 3

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

85. The third session of the workshop, on challenges and opportunities in addressing high-GWP HFCs in mobile air-conditioning, was facilitated by Mr. Saleem Ali, with Mr. Gursaran Mathur, CalsonicKansei, North America, serving as rapporteur in an independent capacity. An overview presentation was given by Mr. Predrag Pega Hrnjak, University of Illinois, United States, as an independent expert. Presentations were also given by Mr. Pradit Mahasaksiri, Siam Denso Manufacturing, Thailand; Mr. Enrique

Peral-Antunez, Renault, France, Mr. Chen Jianping, Shanghai Jiao Tong University, China, and Mr. Sangeet Kapoor, Tata Motors, India.

86. Mr. Hrnjak explained that mobile air-conditioning was a unique sector, with a global industry and a historic dominance of just one refrigerant, the high-GWP HFC-134a. Pressure for the adoption of low-GWP alternatives had started with the adoption of European Union legislation in 2006, and this had had a knock-on effect on American and Asian manufacturers exporting to European markets. A number of alternatives to HFC-134a were available. Historically, competition from CO₂ systems had helped to improve the performance of HFC-134a systems as well. The development of HFO-1234yf had seemed to provide a superior alternative, although doubts about its flammability had led to a renewed interest in CO₂, and some manufacturers were turning to R-445A, a blend of HFCs and CO₂. It was not yet clear which alternative to HFC-134a would succeed; HFO-1234yf was currently the main replacement substance in the European Union, but CO₂ performed better at lower temperatures and in more compact systems and electric vehicles, whereas R-445A was superior in heat pumps.

87. Mr. Mahasaksiri gave an overview of developments in the Association of Southeast Asian Nations (ASEAN) region which were having a significant impact on mobile air-conditioning because of a rapid increase in car sales and typically high temperatures across the region, with an average temperature of 27.6°C. Emissions of CO₂ from mobile air-conditioning were much higher per car in countries such as Indonesia and Thailand than in Japan because of the higher temperature in those countries and the greater use of air-conditioning, and also the higher mileage driven and the higher levels of particulate pollution, which tended to reduce performance. Surveys also showed that leakage rates were higher at higher temperatures. Until lower-GWP refrigerants could be adopted, it would therefore be important to reduce leakage rates and improve the quality of servicing and refrigerant recovery.

88. Mr. Antunez said that in calculating the climate impact of mobile air-conditioning, indirect emissions (from the energy consumption of the systems, and the production and transport of the refrigerants, etc..) were also important; life cycle climate performance provided a better way of measuring this than GWP. The ideal situation for the car industry was one unique refrigerant, used globally by all manufacturers. So far, the only option available for mass production was HFO-1234yf, but the fact that only two providers had commercialized it, and it was only available at high cost, was pushing the industry to look for alternatives. CO₂ was expensive because it required a significantly different system. R-445A, which performed well against other refrigerants, and was considered to be non-flammable under European Union standards, appeared to be the best compromise between cost, performance, efficiency and safety across a range of climatic conditions.

89. Mr. Chen gave an overview of the situation in China, where the adoption of the F-Gas Regulation in the European Union had stimulated discussion about suitable replacements for HFC-134a. HFO-1234yf was regarded as acceptable, although it was less efficient. CO₂ prototypes were being tested, but were more costly and less efficient in hot conditions. R-445A was being tested and its performance appeared to be acceptable, although special servicing equipment was needed. HFC-152a and a blend of propane and isobutane both had better performance than HFC-134a, and in fact hydrocarbons had been used in the servicing market for over 10 years, with lower costs and higher efficiency; there was a question mark, however, over the safety of using them in the more than 1 million Chinese taxis fuelled by compressed natural gas. He agreed that for mobile air-conditioning, life cycle climate performance was a better indicator of impact than GWP; energy consumption was related not only to the climate but also to traffic conditions.

90. Mr. Kapoor said that none of the potential replacements for HFC-134a – HFO-1234yf, HFC-152a and CO₂ – could be considered to be drop-in alternatives; equivalent performance, durability and safety standards could only be achieved with significant re-engineering. The use of secondary-loop systems presented a great opportunity, being safer (helping to offset the flammability risks of using HFC-152a and HFO-1234yf), requiring lower volumes of refrigerant and a lower frequency of servicing (both helping to offset higher initial costs) and being suitable for all climates, although they required the installation of additional components. They offered significant potential for improving overall energy efficiency and thereby reducing climate impacts. Funding for demonstration projects was needed.

91. Responding to questions, one panellist expressed the view that HFO-1234yf and R-445A could both be used as drop-in replacements. Some companies were trying to develop CO₂ systems further, but the performance of HFO-1234yf systems was much better than it had been a few years ago. He considered it 70 to 80 per cent likely that one refrigerant would emerge as the global solution, largely because the car

industry operated globally and would strongly prefer not to have to use different refrigerants for different markets.

92. Another panellist, however, observed that while European Union legislation had led to the use of HFO-1234yf within the region, it was not widely used elsewhere, so European Union manufacturers were still using HFC-134a for exports. Although it would be more complicated to add in yet another refrigerant, it would not be impossible; however, it would be preferable for cars to use essentially the same components, rather than very different systems, as was needed for CO₂.

93. On the relative performance of substances for use in heat pumps, evaluations had shown that CO₂ was much better than R-445A, but that R-445A was sufficiently better than HFO-1234yf to enable its use. Another panellist observed that CO₂ did not work well in high ambient temperatures, so R-445A was a good compromise solution.

94. On refrigerant costs, panellists said that HFO-1234yf was about 15 to 20 times more expensive than HFC-134a in Europe and about 10 times more expensive in India. As production volumes rose, however, it could be expected that the price would fall.

95. Responding to a question about patent protection for HFO-1234yf, panellists commented that the patent was granted in 2003, so would expire in 2023. The problem with the availability of the refrigerant was not so much the patent as the fact that there were currently only two providers.

96. On the flammability of refrigerants, an industry-wide risk assessment conducted over three years had reached the conclusion that the level of risk was very low, lower than other risks which were considered to be acceptable. The assessment had been repeated after Daimler had claimed that HFO-1234yf was more flammable than had originally been thought, but had reached the same conclusions. If the fluid was released after a collision, it decomposed very quickly, and it had far less impact on the climate than HFC-134a. In response to a further question, it was explained that the flammability of the refrigerant varied with the temperature at which the test was carried out. Tests for the European Union registration, evaluation, authorization and restriction of chemicals (REACH) standard were carried out at room temperature, at which R-445A was not flammable; the A-2L test, however, tested for flammability at 60°C, at which it was flammable.

97. In response to a question about what happened when mobile air-conditioning systems were refilled during servicing with different refrigerants than those they were designed for, panellists observed that while manufacturers had tried to make this difficult by using charging ports and connections, it was not impossible, and had been done. In general, as long as the oil content was compatible, HFO-1234yf systems could perform as well or even better when refilled with HFC-134a or R-445A. Similarly, hydrocarbons could be used, and this had been observed in China – again, the system could work as well or better.

98. On the costs associated with the new refrigerants, it was observed that servicing companies would need to install new equipment, including recovery systems, which would be costly.

99. Responding to a question of the market penetration of HFO-1234yf, it was estimated that, globally, about 3 million cars currently used it. This was a very small proportion of the global total, though the number was growing rapidly.

100. Summarizing the discussion, Mr. Hrnjak concluded that while the mobile air-conditioning sector had started the transition away from high-GWP HFCs earlier than other sectors, a number of possible alternatives were available. He considered it likely that the industry would eventually converge on one solution which would be applicable globally, in Article 5 and non-Article 5 countries, and he expressed the hope that regulations being introduced by Governments would facilitate this development.

V. Session 4

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

101. The fourth session of the workshop, on the challenges and opportunities in addressing high-GWP HFCs in the foam sector, was facilitated by Mr. Saleem Ali, with Mr. Enshan Sheng, Huntsman Asia Pacific Technology Centre, China, serving as rapporteur in his personal capacity. In opening the session, Mr. Ali said that the discussion would deal on the one hand with the extruded polystyrene subsector, mainly laminated boards and panels, where most of the issues related to risk management at the production

and

in-situ levels and, on the other hand, the wider range of polyurethane products and applications. Particular emphasis should, he said, be placed on small and medium-sized enterprises given that while the foam sector accounted for a relatively small percentage of the HFC-related contribution to climate change, the fact that it involved large numbers of those enterprises meant that it was an area of great importance to the Article 5 parties striving for development.

102. Presentations on the overall status of the foam sector were given by two overview speakers: Mr. Igor Croiset, GIZ Proklima, Germany, and Mr. Paulo Altoe, Dow Chemical, Brazil.

103. In his presentation, Mr. Croiset drew attention to the selection criteria that small and medium-sized enterprises must consider when switching to a new low-GWP foam system, the insulation requirements and basic good practices needed to improve cooling power and energy efficiency, and the alternatives available for the main applications in the industrial or construction, transport, commercial and domestic refrigeration subsectors. Mr. Altoe, in his presentation, highlighted the challenges in eliminating HFC-based foams from commercial and domestic applications, including the relationship between thermal conductivity and energy efficiency, safety issues, the limited availability of tried and tested HFO-based alternatives and the returns on investment for small and medium-sized enterprises, backed by the results of comparative studies of, inter alia, HFO-blown foams and other blowing agents, and high water-content and fully water-blown systems.

104. There followed a series of presentations by five experts in the field: Ms. Kultida Charoensawad, Polyurethane Group, Federation of Thai Industries, Thailand; Mr. Ashok Chotani, Isofoam Insulating Materials Plants, Kuwait; Mr. Samir Arora, Industrial Foams Pvt., India; Mr. Stefano Verga, Cannon Afros, Italy; and Ms. Achara Bowornprasitkul, BASF, United States.

105. Ms. Charoensawad gave a presentation outlining the opportunities and challenges faced by small and medium-sized enterprises in Thailand in introducing low-GWP chemicals into various areas of the polyurethane industry, including the safety, cost and availability of effective alternatives.

106. Mr. Chotani gave a presentation on current alternatives in the extruded polystyrene industry in the Middle East and North Africa region, highlighting, inter alia, the necessary trade-offs with regard to physical properties, the cost constraints on process development and the problems posed by the lack of a regional approach and clear regulations for the selection and use of low-GWP blowing agents.

107. Mr. Arora, in his presentation, stressed that a proliferation of micro, small and medium-sized enterprises in Article 5 countries were still using HCFCs as blowing agents; that none of the potential low-GWP alternatives, such as HFOs, were commercially viable for those companies; and that there was an urgent need to implement demonstration projects to determine their safety.

108. Mr. Verga, in his presentation on system houses and the development of low-GWP technologies, drew attention to the findings of his company's testing of water, HFOs, pre-blended pentanes and other alternatives to HFCs in retro-fitted machinery, with a particular focus on dosing, safety and cost.

109. Ms. Bowornprasitkul, in her presentation, provided an overview of the properties and development of new generation blowing agents, the efforts of the United States Environmental Protection Agency to regulate HFCs and the progress made by major American companies to phase in low-GWP chemicals in the commercial refrigeration subsector.

110. Responding to questions, Mr. Chotani stressed that the authorities in his region had to come up with codes and local standards to determine whether the new hydrocarbon and water-based blowing agents that manufacturers were being pressured into using were acceptable, and that the flame-retardant alternatives to hexabromocyclododecane currently being tested should become available by 2016.

111. On the question of the current availability of new generation blowing agents, Ms. Bowornprasitkul said that several large American producers were already marketing a number of those products. Mr. Croiset, however, pointed out that HFOs could not yet be used in Europe as alternatives for refrigerated trucks and containers as they had yet to complete the six-year testing period required under the Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be used for such Carriage. As to the question of the possible risks that existing alternatives might pose to the environment and the health of workers in small and medium-sized enterprises, he recommended that the users pay heed to the safety instructions and take the proper steps to protect their staff.

112. Responding to a question on the use of pentane, Mr. Verga said that since the risk of explosions associated with pure pentane was 60 times greater than with pre-blended pentane, the latter was the safer option for small and medium-sized companies operating in areas without a local system house or lacking suitably trained staff. On the matter of the availability and safe storage of pre-blended materials, especially in high ambient temperatures, he said that system houses could supply small quantities in special drums that allowed them to remain stable for up to five months, adding that hydrocarbon pre-blended polyols in particular evaporated 60 times faster than pure pentane. In response to one representative's comment about his country's attempts to maintain pre-blended pentane in polyol repeatedly leading to phase separation, Mr. Verga, supported by Mr. Croiset, suggested that it might have been a result of the mixing method or choice of polyol rather than owing to high ambient temperatures. Mr. Croiset, warning of the dangers of opening drums transported in intermediate bulk containers and/or stored in extreme heat without pre-cooling, added that all chemicals must be kept at the correct temperature to avoid separation.

113. Asked by the facilitator if super-critical CO₂ might be a suitable option for site-produced polyurethane spray foams, Mr. Croiset said that it depended on whether the foams were for indoor use or to protect roofing from direct sunlight, for which trials of the water-blown option had produced good results. Mr. Altoe, on the other hand, said that the mechanical performance of water-blown foams might be limited in colder countries and that it might take time to replace the existing large cylinder systems with a CO₂/HFO blend. One representative pointed out that the uncontrolled use of spray foams in many developing countries, where no distinction was made between indoor and outdoor uses, gave rise to a significant risk of flammability.

114. In their closing comments, Mr. Croiset noted that small and medium-sized enterprises in the foam sector in Article 5 parties continued to face major difficulties in the absence of alternatives to HFCs capable of providing equal thermal conductivity without causing the degradation of technologies, and Mr. Altoe said that while it was not yet possible for those companies to switch to HFOs owing to their high cost, the outstanding foaming properties and safety of those substances made them a particularly bright prospect for the future. In the meantime, he said, medium-sized enterprises could consider using combinations of water and more affordable hydrocarbons, together with small quantities of HFOs.

VI. Session 5

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

115. The fifth session of the workshop, on overarching and cross-cutting issues on technical aspects of HFC management, was facilitated by Mr. Peter Adler, while Mr. Chandra Bhushan, Centre for Science and Environment, India, in his personal capacity, served as rapporteur. Initial presentations were made by Mr. Mack McFarland, Global Fluorochemical Producers' Forum, United States, and Mr. Marc Chasserot, Shecco, Belgium, followed by additional presentations and discussion focused on four topics and a summary discussion.

116. Mr. McFarland said that his trade association, which included corporations based in Europe, India, Japan and the United States, supported the phase-down of high-GWP HFCs especially in emissive application. He emphasized that multiple low- or no-GWP alternatives were currently available from multiple suppliers around the world and that even more would reach the market in the near future. These included both fluorinated and non-fluorinated substances, with no or low flammability and favourable toxicity. Equipment manufacturers and end uses should consider many factors when choosing which alternative to employ in particular applications, including system performance and capacity, energy-efficiency, flammability, local regulations, and purchasing and operating costs. He outlined specific low-GWP solutions currently available for major application sectors – automotive air conditioning, residential and light commercial air conditioning, commercial chillers, domestic refrigeration, commercial refrigeration, insulating foam, aerosols, and solvents, and noted that 90–99 per cent reductions in GWP were possible in some applications with the use of certain HFOs and hydrocarbon.

117. Mr. Chasserot detailed significant market developments regarding natural refrigerants, noting that end users and manufacturers in many different sectors now have many proven options. For example, an estimated 5,000 retail food stores worldwide already used transcritical CO₂ systems for refrigeration and this number was increasing rapidly. Japan was now the world leader in the use of CO₂ for heat pumps,

with more than 4.7 million already in operation, and in retail food stores, with more than 25 different store brands currently using CO₂ systems. In North America, CO₂ and hydrocarbon systems were gaining momentum in all aspects of the food retail and food service sectors, with more than 120 stores already using CO₂ transcritical systems. Coca-Cola had installed more than 1.4 million HFC-free units worldwide, including nearly 700,000 in the Africa, Asia, Latin America, and Pacific regions. China had emerged as a growing market for national refrigerants, including those already in use in bottle coolers, vending machines, heat pumps, retail store refrigeration, and industrial refrigeration.

A. Costs of conversion, intellectual property rights, accessibility of low-GWP alternatives and timeline of availability for new technologies

118. Brief presentations were made by Mr. Ravinder Mehta, Refrigeration and Air-conditioning Manufacturers Association, India; Mr. Predrag Pega Hrnjak, University of Illinois, United States; Mr. Miguel Quintero, independent consultant, Colombia; and Mr. Alistair McGlone, independent consultant, United Kingdom of Great Britain and Northern Ireland. Following these presentations, Mr. McFarland and Mr. Chasserot joined the presenters as panellists to respond to an initial set of questions from the facilitator and participants.

119. Mr. Mehta outlined the challenges faced by companies in Article 5 parties when seeking to convert to low-GWP options. These industries were already engaged in phasing-out HCFCs while also seeking to meet the large and growing demand for refrigeration and air-conditioning. High-GWP HFCs and HFC blends had been adopted in many instances as alternatives to HCFCs by developed countries, due to the non-availability of safe and proven low-GWP alternatives, and this process was being replicated in developing countries. Developing countries faced difficulties due to a lack of clarity regarding alternative technologies to HCFCs, especially in the air-conditioning sector. Industry would be unable to afford multiple conversions and faced significant uncertainty about time frame, availability, and costs of low-GWP alternatives. Increasingly stringent energy efficiency requirements or norms created another set of obstacles, as did the lack of clarity regarding the definition of “low GWP.” Significant challenges existed with regard to the use of flammable refrigerants, with many actors preferring to wait for safe non-flammable alternatives due to concerns with regard to market acceptability, government regulations, product safety, liability, servicing, transportation and storage, and the lack of relevant, global harmonized standards, regulations and codes. Consideration should be given to extending the HCFC phase-out schedule to ensure the availability of safe, economically viable, matured low-GWP technologies and avoid the need for multiple conversions; to implementing demonstration projects in Article 5 countries; to expediting the evaluation of low-GWP refrigerants for use in high ambient temperature countries; to ensuring that solutions were available for all sectors and product lines; to making refrigerants available without industrial process refrigeration restriction and at reasonable prices; and to resolving liability issues with regard to flammable refrigerants.

120. Mr. Hrnjak said that evaluations of cost comparisons needed to examine the total cost of ownership, including system and refrigerant purchases, servicing and other issues. The increasing array of HCFC alternatives, which included low-GWP and high-GWP products and both synthetic and natural refrigerants, meant that chemical and mechanical engineers would continue to compete with regard to the effectiveness, efficiency, reliability and environmental impact of their systems. The large playing field of competitors had positive benefits. Many countries needed to update various regulations to reflect the design and operational improvements in hydrocarbons and ammonia-based systems in order to enhance the uptake of low-GWP alternatives.

121. Mr. Quintero discussed approaches to understanding financial issues associated with converting from high-GWP HFCs to low-GWP fluorocarbons and other alternatives in the foam blowing sector. Understanding these costs was critical for the development and implementation of policies supporting such conversion. He outlined capital and operational cost considerations of the most prominent conversion options, including three that employed flammable alternatives – hydrocarbons, methylal, and methyl format, and four that did not – CO₂ (water), Formacel 1100, Solstice Liquid Blowing Agent and Forane 1233zd. In general, the non-flammable alternatives had the lowest capital costs and the flammable alternatives the lowest operating costs. He broke down specific factors within the operating costs, noting that pentane had the lowest incremental operating costs overall and that CO₂ (water) had the lowest among the non-flammable alternatives.

122. Mr. McGlone outlined the rights and obligations conferred by patents and the impacts that intellectual property rights generally had on technology development and transfer. He said that in general

terms, patent systems provided incentives for corporations and inventors to seek new technological solutions and to enter new markets because they protected valuable intellectual property. In the history of the Montreal Protocol, such protections had not produced significant impediment to the development and deployment of the needed alternatives and would be unlikely to do so in the future. A new regulatory regime would signal the market to continue to produce alternatives to both ozone-depleting and high-GWP substances. Increased competition would be likely to drive down the costs of buying or licensing patented substances. Patents were also not permanent and some alternatives, such as CO₂ and water, were not patented. It was likely that any HFC regulation established under the Protocol would include a mandate for the Multilateral Fund for the Implementation of the Montreal Protocol to assist eligible parties in accessing the needed substances and equipment.

123. During the ensuing discussion, one participant asked if the information presented regarding potential reductions in GWP emissions and replacement costs took into account the amount of energy used in the different systems, given that the CO₂ emissions from energy production represented a much larger contributor to climate change than HFCs. One panellist replied that equipment manufacturers understood the competitive importance of energy efficiency. Many countries also had energy efficiency regulations. Thus, the products available or being developed would be likely to match or exceed the efficiency of those that they replaced. Another panellist said that it could be possible to produce and use systems with higher energy efficiency at less overall cost owing to advances in design, manufacturing, materials used in their construction, compressor efficiency and other factors.

124. In response to questions regarding the potential impact of patent rights on the price of low-GWP alternatives, one panellist said that past experience in this sector indicated that patent holders would have difficulty charging excessive prices for low-GWP alternatives. Competition already existed and this would increase if additional national or international regulations were enacted. Excessive pricing itself would also produce incentives for competitors to enter the market and patents also would expire. Finally, parties could decide to instruct the Multilateral Fund to assist parties in meeting the incremental costs of using the relevant substances or equipment. Another panellist said that refrigerant fluids were generally a minor part of the overall cost of obtaining and operating the relevant systems and that history indicated that the costs of both fluids and equipment would be likely to decline over time.

Domestic legislation, industry initiatives, cost and availability of low-GWP alternatives

125. Brief presentations were made by Ms. Andrea Voigt, European Partnership for Energy and the Environment, Belgium; Mr. Rajan Rajendran, Emerson Climate Technologies, Australia; and Mr. Kevin Fay, Alliance for Responsible Atmospheric Policy, United States. Following these presentations, Mr. McFarland, Mr. Chasserot, Mr. Mehta, Mr. Hrnjak, Mr. Quintero and Mr. McGlone joined the presenters as panellists to respond to questions from the facilitator and participants.

126. Ms. Voigt outlined the new F-gas regulations in the European Union and their potential impact on the market for HFC-related technologies. The new regulations were largely not refrigerant-specific but based on their CO₂-equivalent GWP. They were designed to be technology-neutral, accelerate movement towards lower-GWP refrigerants, encourage the containment and end-of-life recovery of HFCs, promote recycling, foster additional innovation and competitiveness and achieve important environmental objectives. In general, European industry welcomed the new rules as they provided regulatory certainty in support of additional investment in low-GWP products and services and because the phase-down allowed for significant flexibility and freedom of refrigerant choice for end users. An industry analysis had found the cost of the regulations to be reasonable, at approximately 25 euros per tonne of avoided CO₂-equivalent emissions. At the same time, industry would like to see a greater focus on energy efficiency, including more attention to life cycle climate performance assessments. Several important barriers to the uptake of lower-GWP refrigerants also needed urgent attention, including the updating of standards and building codes and the training of service personnel.

127. Mr. Rajendran outlined a list of specific, low-GWP alternatives that industries were currently using in the domestic, commercial and industrial refrigeration and air-conditioning sectors, including both synthetic and natural refrigerants. Significant reductions in GWP emissions were being implemented by a broad variety of companies. While many options were currently available for all applications, not every product was appropriate for use in every application in every region. Costs were expected to fall as volume increased, and cost declines would accelerate further if national or international HFC regulations created greater certainty in the market and safety and other regulatory standards were updated to reflect

technological improvements. It was important to consider the HFC issue as a process of continuing transition to lower-GWP alternatives rather than a single conversion to a particular low-GWP alternative.

128. Mr. Fay recalled that the Montreal Protocol had helped to create one of the most successful, important and rapid technology transitions in history. In fact, the market certainty and incentives created by the treaty had eventually caused industry to petition for the faster phase-out of CFCs. Like CFCs once were, high-GWP HFCs were now transitional compounds that must be replaced. It was not necessary, however, for policymakers to decide which alternatives would be used in all potential applications in the future. Many options already existed and more would be created and improved upon provided that the correct market signals were established by policymakers. As had occurred previously in the context of the Montreal Protocol, a clear, long-term policy directive would drive innovation and cost reductions.

129. In response to several questions that addressed patents, panellists noted that hundreds of patents for HFC substitute fluids, blends and related equipment and processes had been issued around the world during the previous two decades, including in China, Europe, India, Japan and the United States. No single register existed regarding which companies in which countries held particular patents although at least one project was under way to list as many as possible. Patents had been part of the marketplace for hundreds of years and had not been an obstacle to technology transitions in the past. It was not possible, however, to predict the prices that patent holders would charge over time for access to particular products or licences. In the past, market competition and volume increases tended to bring prices down. Within the context of the operation of the Montreal Protocol, the Multilateral Fund had also provided resources to assist developing countries meet the agreed-upon incremental costs of implementing the agreement, which included accessing the necessary technology. However, no policy decision had yet been made by parties regarding a phase-down of HFCs or making specific funding available to assist in such a phase-down.

130. One panellist said that an attempt by the Multilateral Fund to purchase patents would be likely to result in the Fund paying too much and a better option would be to create market signals to reduce prices. Another emphasized that the expanding use of natural refrigerants offered opportunities to bypass some of the concerns regarding patents or potential monopoly pricing.

131. One participant reported that when companies in an Article 5 country had approached companies in developed countries regarding particular low-GWP technologies, they were refused access or such technologies were offered at an exorbitant cost, and asked whether the Multilateral Fund would be able to facilitate technology transfer at fair or favourable rates as envisaged in the Montreal Protocol. In response, one panellist said that the Technology and Economic Assessment Panel and the Fund had positive 25-year track records of evaluating cost-efficient alternative technology and assisting developing countries in accessing them. Asked what would happen to developing countries if the market did not respond effectively to new HFC regulations and failed to bring the necessary products to particular regions or to reduce prices to levels appropriate in developing countries, two panellists said such a result was unlikely and that the absence of a policy signal would result in the process taking far longer. Many technologies already existed and were being introduced in many countries and regions, but a strong policy signal would further drive the market, especially on a global basis.

132. One participant asked whether, given the large number of options for transitioning to low-GWP alternatives in different sectors, databases or other resources existed that would allow end-users and others to compare the cost and other attributes of the alternatives, for example their energy efficiency, and to learn about the experiences of others. In response, several panellists said that different elements of such information was available from a variety of sources, including, individual companies, industry associations, conference proceedings, reports of the Technology and Economic Assessment Panel, and the fact sheets prepared for the workshop, among others, and they offered to assist parties in obtaining the information they required.

133. Asked to clarify statements regarding the price, flammability and toxicity of specific HFC replacements, one panellist said that manufacturers could provide appropriate pricing information but he could provide a list of which fluids were not flammable or had low flammability, although some of that information was also set out in the fact sheets and reports of the Technology and Economic Assessment Panel. References to the favourable toxicity of certain compounds meant that they were listed in the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) category A and were thus comparable to the low-toxicity or no-toxicity of currently used substances. Responding to a question regarding contributions to climate change, one panellist said that it was his understanding that

HFC emissions were currently responsible for about 1 per cent of total radiative forcing, but that there was potential for a very significant growth in future.

134. Asked about the specific challenges faced by India with regard to adopting low-GWP alternatives, one panellist underscored the absence of a sufficient, stable workforce of service technicians. Whereas only about 250,000 service technicians worked in air-conditioning trades in India, at least 500,000 were needed to service even the current market demand. In addition, only about one-half of the current technicians were available year-round due to low wages and other factors, and the need for qualified personnel was expected to grow significantly. Technicians also needed far better training, especially if a diverse array of low-GWP alternatives, including flammable products, were deployed. Asked if domestic companies in India and the Middle East should adopt products that used F gases or go straight to HFOs or other very-low GWP options, one panellist said both were viable options and the choice depended on circumstances specific to the sector. In his view, global technological diffusion was occurring at a much faster rate today than it had twenty years previously and this provided end users in developing countries with many options, including leapfrogging to HFOs or other recently developed alternatives.

135. Responding to questions regarding the development, content and impact of F-gas regulations in the European Union, one panellist said that the cost estimates in her presentation were based on studies commissioned by European industry. The regulations had been developed in accordance with normal procedures and industry stakeholders had participated in the policy discussions. The first set of F-gas regulations had reduced HFC emissions compared with business-as-usual scenarios, created market incentives and led to the increased training of technicians to reduce leaks and other emissions. The new, second set of regulations had been designed to activate even larger reductions, by means of a phase-down in the production and use of high-GWP products, and would have an impact on both imports and exports. She outlined key elements of the new rules and said that European manufacturers were satisfied with that clear signal to the marketplace.

136. Another panellist noted that hundreds of companies in Europe manufactured equipment or components of systems that employed natural refrigerants and that the regulations were a boost to them. A large and increasing number of customers in Europe and in other regions were choosing to employ a long-term outlook and transition directly to natural refrigerants. Several panellists noted that end users in other regions also had multiple options in most sectors. One stated that the global market was much further along in the development and commercial deployment of alternatives to high-GWP HFCs than it had been when the Montreal Protocol first controlled CFCs or mandated the phase-out of HCFCs.

B. Energy efficiency, safety and industry's response to low-GWP policies

137. The second part of the fifth session of the workshop was on energy efficiency, safety and industry's response to low-GWP policies, with three main topics under discussion: high ambient temperature solutions, flammability and safety standards, and leak reduction. The session was facilitated by Mr. Peter Adler. Presentations were made by the following panellists: Mr. Samir Hamed, Petra Engineering Industries Company, Jordan; Mr. Hisham Mikhi, Millennium Energy Industries, Jordan; Mr. Paul Fu, Underwriters Laboratories, China; Mr. Asbjørn Vonsild, Danfoss Automatic Controls, Denmark; Mr. Marco Buoni, Air Conditioning and Refrigeration European Association, Italy; Mr. Manuel Azucena, Refrigeration and Air Conditioning Technicians for Development of the Philippines; Mr. Tetsuji Okada, Japan Refrigeration and Air Conditioning Industry Association, Japan; and Mr. Julio Esteban, Smart Refrigerants, Panama.

138. Mr. Hamed gave a presentation on overall issues related to design for high ambient temperature conditions. He said that a number of issues needed to be given careful consideration when designing for high ambient temperatures, including safety standards, refrigerant charge quantity, energy efficiency and the regulatory environment. Care needed to be taken to avoid excessive condensing temperatures. The main challenge for high ambient temperature conditions was the balance between energy efficiency and maximum refrigerant charge limits for safety. Financial support was necessary from United Nations entities and other organizations to promote the adoption of low-GWP refrigerants. Options such as HC-290 and HFC-32 were available, but more research was needed on the safety implications of those options. The transition would require special care with regard to design, selection of components and training of service technicians.

139. Mr. Mikhi gave a presentation on the costs of replacing conventional cooling units with non-conventional low-GWP options, including retrofitting, with reference to projects in high ambient

temperature locations. Solar-driven absorption chillers offered the potential to introduce a low-GWP, energy-efficient alternative to the electricity-driven appliances that currently dominated the market. The absorption chiller used a natural substance, water, as the refrigerant, with lithium bromide as the absorbent. The main barrier to the adoption of the alternative was currently the capital cost, which was around four times more than for a conventional unit. A pilot project was currently under way in Jordan, funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety in partnership with the Jordan Ministry of Environment and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. The project aimed to study factors affecting the cost and output of the absorption chiller system and establish if it could offer a sustainable air-conditioning option in the high ambient temperature conditions of the Middle East and North Africa.

140. Mr. Fu, in his presentation, provided an overview of the standards applied for various refrigerants by the United States Environmental Protection Agency, based on independent standards testing by the Underwriters Laboratories. The Underwriters Laboratories joint task group on flammable refrigerants had established three working groups to develop requirements for flammable refrigerants applicable to air-conditioning equipment and refrigeration equipment, and to address requirements for the testing and evaluation of flammable refrigerants (including the new 2L types). He summarized the work being undertaken by the three working groups and the standards being developed. Finally, he presented the standards applicable to equipment using CO₂.

141. Mr. Vonsild gave a presentation on the challenges arising from flammability concerns and related safety standards, and options for limiting the refrigerant charge. He presented information on the safety class of various refrigerants, the role of safety standards and policy options, charge limits for refrigeration and chillers and options for limiting charge, and competence standards. He drew the following conclusions: safety standards were important for low-GWP options; how to integrate safety standards into legislation was an important policy decision; the refrigerant options for a given application were limited depending on the charge needed, the location and the occupancy classification; several options were available to reduce the charge of a system, with each option offering both advantages and disadvantages; and competences were another important aspect of safety and were also subject to standards.

142. Mr. Buoni gave a presentation on training and certification schemes to ensure the safe and environmentally friendly handling of low-GWP alternative refrigerants. He said that as HFCs were replaced by low-GWP refrigerants there was a need to ensure that technicians were adequately trained to install and service the new equipment and deal with new substances. Training, assessment and certification were important elements of that process, which was both legislation driven, as new rules and regulations were introduced in the areas of environment and safety, and customer driven, as clients demanded adequate safety standards for new equipment. The Air Conditioning and Refrigeration European Association had recommended minimum competence requirements for service technicians for specific refrigerants, and had developed a “blended learning” programme for alternative refrigerants, which offered e-learning as well as classroom practice. The Association was working with the European Union, the UNEP OzonAction programme and others in the area of training.

143. Mr. Azucena gave a presentation on the contribution of servicing associations in Article 5 countries to the reduction of high-GWP emissions and low-GWP safety concerns. He stressed that the human element played a critical role in safe use of refrigerants; for example, one of the primary causes of ozone depletion was venting of refrigerants by technicians. His organization, Refrigeration and Air Conditioning Technicians for Development of the Philippines, aimed to improve the standards of operation in the industry, consistent with the code of practice for refrigeration and air-conditioning. He outlined the critical competences that had been developed in the areas of refrigerant recovery and recycling, retrofitting, conversion of CFC-based and HCFC-based equipment, and safe handling of flammable refrigerants. In conclusion, he gave a summary of the activities of the Technical Education and Skills Development Authority of the Philippines in developing relevant courses to train the body of technicians required.

144. Mr. Okada gave a presentation on HFC management by leakage reduction and recovery. He gave a summary of refrigerant stocks and emissions in Japan, and outlined the national legislative environment for dealing with such matters, including the Act on Rational Use and Proper Management of Fluorocarbons. The act addressed issues throughout the life of fluorocarbons, including manufacture of HFCs and equipment containing HFCs, the use and service of equipment, and recovery or destruction. He said that harmonization was important within a life cycle approach to HFC use and management.

145. Mr. Esteban gave a presentation on the importance of leak reduction and refrigerant recovery. Leak tightness in compliance with regulations was of prime importance, and actions should be taken to ensure that deliberate or inadvertent leakage was avoided during service and maintenance. Leaks should be avoided due to their environmental impact, negative effect on running and servicing costs, and the health and safety hazards that could result. He summarized the various methods that were available to detect leaks. Once a leak had been identified, it was necessary to remove the refrigerant in order to effect a repair, and again various technical options were available to carry out that task. Recycling and reclamation were essential in order to reap environmental and cost benefits.

146. The panellists gave concluding thoughts on the matters under discussion. One panellist said, with regard to high ambient temperature solutions, that manufacturers could develop products but not take the sole lead – the cycle needed to be completed by other entities in order to produce a positive market environment with supportive legislation, demand creation, training and certification. Another panellist said that demand for air-conditioning would continue to increase due to lifestyle changes, and there was an urgent need to find energy-efficient alternatives. Another panellist said that safety standards were well formulated throughout most of the world, although he noted the concern over charge limits for certain applications; a risk assessment was important if those limits were to be relaxed. Other panellists highlighted the importance of training and certification of technicians and service engineers, and increased consumer awareness, in an environment of rapid technological change. Finally, one panellist stressed the importance of reclamation and recycling as technologies were updated and systems were renovated or replaced.

VI. Session 6

Key conclusions relevant to policymaking on technical management of HFCs

147. During the sixth session of the workshop, on key conclusions relevant to policymaking on technical management of HFCs, the rapporteurs for sessions 1–5 presented summaries of their sessions, written versions of which are presented in document UNEP/OzL.Pro/Workshop.8/2/Add.1. In addition, Ms. Karin Shepardson and Mr. Stephan Sicars, the workshop rapporteurs, presented an oral summary of the workshop. A written version of their summary (UNEP/OzL.Pro/WG.1/35/5), which was presented to the Open-ended Working Group at its thirty-fifth meeting, is available on the Ozone Secretariat website (<http://conf.montreal-protocol.org/meeting/oewg/oewg-35/default.aspx>).

VII. Closure of the workshop

148. Following the customary exchange of courtesies, the workshop was declared closed at 6.20 p.m. on Tuesday, 21 April 2015.
