Sustainable Technologies for Stationary Air Conditioning Workshop

February 1, 2017

Las Vegas, Nevada, USA

Summary Report

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Acronyms and Abbreviations

AC	Air conditioning
AHR Expo	International Air-Conditioning, Heating, Refrigerating Exposition
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
AHRTI	Air-Conditioning, Heating, and Refrigeration Technology Institute
AREP	Alternatives Refrigerants Evaluation Program
A2	ASHRAE Standard 34 refrigerant designation for lower toxicity and lower flammability
A2L	ASHRAE Standard 34 refrigerant designation for lower toxicity and mild flammability
A3	ASHRAE Standard 34 refrigerant designation for lower toxicity and high flammability
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CCAC	Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants
COP	Coefficient of performance
CO_2	Carbon dioxide
DOE	U.S. Department of Energy
DX	Direct expansion
EGYPRA	Egyptian Project for Refrigerant Alternatives
EPEE	European Partnership for Energy and the Environment
EPA	U.S. Environmental Protection Agency
EU	European Union
F-gas	Fluorinated gas
GHG	Greenhouse gas
GWP	Global warming potential
HAT	High ambient temperature
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
HPMP	HCFC Phase-out Management Plan
HVACR	Heating, ventilation, air conditioning, refrigeration
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
NH_3	Ammonia
ODP	Ozone depletion potential
ODS	Ozone-depleting substance
ORNL	Oak Ridge National Laboratory

PRAHA	Promoting Low-GWP Refrigerants for Air-Conditioning Sectors in High Ambient Temperature Countries
SNAP	Significant New Alternatives Policy
TEAP	Technology and Economic Assessment Panel
TU Berlin	Technical University Berlin
UL	Underwriters Laboratories
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
VRF	Variable refrigerant flow
2L	ASHRAE Standard 34 refrigerant designation for mild flammability

Introduction

Background

The heating, ventilation, air conditioning, and refrigeration (HVACR) sector is the largest field of application for hydrofluorocarbons (HFCs). The use of HFCs has been increasing due to the need to replace ozone-depleting substances (ODS) being phased-out by the Montreal Protocol and in response to economic growth and global demand for new HVACR equipment. Within the HVACR sector, the growth of HFC use in stationary air conditioning (AC) applications is particularly significant and projected to continue to grow in both developed and developing countries.

In October 2016, Parties to the Montreal Protocol negotiated the Kigali Agreement, an amendment that commits countries to reduce the global production and consumption of HFCs by more than 80 percent by 2047. As such, there is a need for the HVACR industry to introduce safe, cost-effective, and environmentally-sound alternative technologies to enable Parties to comply with any phasedown of HFCs while also meeting increasing demand for stationary AC.

Key challenges in developing environmentally-sound solutions include flammability and energy efficiency. Across the stationary AC subsector, many alternative substances are flammable, so safety issues play a significant role in their application. Energy efficiency performance of AC systems is also a critical consideration when transitioning from HFCs to lower-global warming potential (GWP) alternatives, given that energy consumption represents the major share of greenhouse gas (GHG) emissions caused by such systems.

Workshop Objectives and Format

The *Sustainable Technologies for Stationary Air Conditioning Workshop* was held on February 1, 2017 in Las Vegas, Nevada on the margins of the International Air-Conditioning, Heating, Refrigerating Exposition (AHR Expo) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Winter Conference. The workshop was sponsored by the Alliance for Responsible Atmospheric Policy, the U.S. Environmental Protection Agency (U.S. EPA), the German Environment Agency (Umweltbundesamt), and the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) with support from the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) and Environment and Climate Change Canada.

Building on a series of conferences addressing alternatives to high-GWP HFCs and hydrochlorofluorocarbons (HCFCs) in different sectors, the workshop aimed to familiarize participants with climate-friendly and cost-effective technologies that have proven their applicability in a range of stationary AC applications. The workshop also sought to address issues related to the introduction and use of alternatives in both developed and developing country markets.

The workshop was divided into four sessions based on application fields; see Appendix A for the workshop agenda. Session I provided an overview of general AC aspects and included four presentations. Session II featured 11 speakers divided into two panels, the first discussing low-GWP alternatives for residential and light commercial applications and the second discussing large buildings and commercial AC. Session III covered AC in special applications and featured three speakers. Session IV discussed challenges to the adoption of alternatives and featured five speakers. During Sessions I, III, and IV, speakers had 15-30 minutes to present their topic, followed by a brief question and answer session. Session II consisted of shorter, 5-10 minute presentations, followed by a longer question and answer session.

Workshop Participants

Workshop participants included AHR Expo visitors, National Ozone and Climate Protection Officers and other government representatives, and representatives from international organizations, industry, and environmental organizations.

Organization of Summary Report

The remainder of this report provides a summary of the presentations made throughout the workshop, as well as the discussions held around the presentations. The report begins with opening remarks and moves through each Session in chronological order. The workshop summary is followed by two appendices that include the workshop agenda and concept note.

Opening Remarks

Mr. Phillipe Chemouny of Environment and Climate Change Canada and Mr. Kevin Fay of the Alliance for Responsible Atmospheric Policy welcomed participants to the *Sustainable Technologies in Stationary Air Conditioning Workshop*, acknowledging and thanking other workshop co-sponsors and organizers: CCAC, AHRI and the governments of Germany and the United States. Mr. Fay thanked the AHR Expo for providing the space for the workshop this year.

Mr. Chemouny noted that as the fifth in a series of workshops, the goal is to provide decision makers within industry and government with a holistic overview of the range of alternative technologies available in the AC sector. In light of the adoption of the Kigali Amendment, he emphasized that it was particularly timely to focus on alternatives in stationary AC, given that the sub-sector presented particular challenges with respect to the adoption of alternatives and was projected to become dominant in terms of HFC use globally. Mr. Fay noted that it is fitting for the workshop to be held in 2017 as this year marks the 30^{th} anniversary of the Montreal Protocol. Since the inception of the Montreal Protocol, the industry has succeeded in achieving a complete transition from ODS and moving forward will turn its attention to reducing GHG emissions and improving energy efficiency in a need to address the Earth's changing climate. He noted that this is a forward-looking industry that serves both the planet and consumers by pursuing actions that are environmentally balanced and economically effective.

Session I: Overview and General Aspects of Air Conditioning

Session I covered general aspects of AC and included discussion on topics such as recent international regulations, alternative refrigeration technologies, and energy efficiency. The presenters were:

- Steve Yurek, AHRI
- Marco Schmidt, Technical University (TU) Berlin's Institute of Architecture
- Walid Chakroun, ASHRAE and Kuwait University
- Andrea Voigt, European Partnership for Energy and the Environment (EPEE)

2017 Climate & Refrigerant Outlook

Steve Yurek, AHRI

Mr. Yurek provided an overview of the HVACR industry's upcoming transition from high-GWP refrigerants to low-GWP refrigerants. Mr. Yurek noted that ODS and HFC refrigerants are widespread in the HVACR industry; however, drivers including the Kigali Agreement, U.S. regulatory actions through the U.S. EPA's Significant New Alternatives Policy (SNAP) Program, the European Union's (EU) fluorinated gas (F-gas) regulations, and recent Canadian regulations are requiring the development of alternative refrigerants. The Kigali Agreement, specifically, is historic in that it aims to reduce GHG emissions by 70 gigatons of carbon dioxide (CO_2) equivalent by 2050 by phasing out the use of high-GWP refrigerants. There are two phase-down schedules outlined in the Kigali Agreement: developed (Article 2) countries will begin the phase-down in 2019 and developing (Article 5) countries will begin in 2024.[1] These phase-downs will be guided by a technology and economic review process every 5 years.

HVACR equipment manufacturers will be impacted by this transition in several ways. Manufacturers must assess viable alternatives to the existing products and applications and conduct research and development on these alternatives, both individually and collectively. In addition, as an industry, manufacturers must adapt the existing regulatory codes and standards to allow for the safe use of alternative refrigerants. Throughout this process, manufacturers will have to retool and optimize the manufacturing practices and re-train technicians and building managers.

The Low-GWP Alternatives Refrigerants Evaluation Program (AREP) has started laying the groundwork for identifying suitable alternative refrigerants. In addition, the Air-Conditioning, Heating and Refrigeration Technology Institute (AHRTI) Flammable Refrigerant Research effort by AHRI, ASHRAE, the U.S. Department of Energy (DOE), and the California Air Resources Board is currently working to produce publicly available technical results to adapt the existing

[1] Article 2 countries are those subject to Article 2 of the Montreal Protocol. Article 5 countries are those subject to Article 5 of the Montreal Protocol, which states "Any Party that is a developing country and whose annual calculated level of consumption of the controlled substances in Annex A is less than 0.3 kilograms per capita on the date of the entry into force of the Protocol for it, or any time thereafter until 1 January 1999, shall, in order to meet its basic domestic needs, be entitled to delay for ten years its compliance with the control measures set out in Articles 2A to 2E."

codes and standards to alternative and flammable refrigerants. In the United States, updated safety codes are expected by the end of 2017 and updated fire codes are expected in 2018. These codes will then be used as models to be adopted by states and cities where necessary.

The codes and standards revisions will guide manufacturers to design new components and equipment with select alternative refrigerants. Another barrier to be overcome in all countries, but particularly Article 5 countries, is the training and education of technicians who will install and maintain equipment using alternative refrigerants.

The industry is moving forward, but time is needed to finalize the above mentioned research, safety standards revisions, and training efforts. Given the phase-down schedules of Article 5 countries, government officials in Article 5 countries have time to properly analyze the still evolving commercial availability of alternative refrigerants in their countries.

Not-in-Kind Alternatives (Evaporative Cooling and Façade Greening)

Marco Schmidt, TU Berlin's Institute of Architecture

Mr. Schmidt focused his presentation on a technology that uses the large energy shift of evaporative and condensing processes for heating and cooling applications. The goal of the technology is to avoid the production of exhaust heat in these processes to reduce the urban heat island effect.

Mr. Schmidt began his presentation with an overview of Watergy, the company founded by engineers at TU Berlin spearheading the research and development of this technology. The project is financed primarily by the German Federal Ministry for Economic Affairs and Energy responsible for energy efficiency and development. The Ministry aims to decrease the energy consumption of buildings by 50 percent by 2020, despite the expected increase in demand for energy consumption for cooling applications in this timeframe.

A significant driver of the increased demand for cooling includes the urban heat island effect. Globally, the majority of the solar radiation that enters earth's atmosphere is evaporated as latent heat rather than converted to sensible heat.[2] However, in urban areas the majority of incoming radiation is converted into sensible heat, increasing the temperature of the surrounding air and contributing to the urban heat island effect.

Green roofs are one strategy for reducing this effect as they release greater quantities of latent heat than sensible heat. Another strategy is to never use electricity to cool buildings. By cooling a building with electricity, sensible heat is expelled from the building, increasing the urban heat island effect. Therefore, Watergy uses green façades and evaporative cooling to cool buildings. For instance, in Switzerland, the company Swisscom installed a cooling system that uses outside air and rainwater to cool its IT system. Rainwater is collected in a tank and fed into a stream of hot air from outside the building, which removes heat through evaporation. The cooled

[2] Latent heat is related to phase changes between liquids, gases, and solids. Sensible heat is related to temperature changes.

air is then circulated throughout the building. In the winter, the exhaust heat from computers is used to heat the building. This system is not dependent on location; Watergy implemented it in Rio de Janeiro and it still gained 25˚F degrees of evaporative cooling during the day.

At Humboldt University in Berlin, Watergy implemented a rainwater harvest system in a building that provides evaporative exhaust cooling to eight AC systems and waters a green façade. In the evaporative exhaust air cooling system the building uses rainwater rather than tap water to avoid having to clean the water and to reduce costs. The rainwater in the eight systems can cool external air from approximately 90˚F without the use of any other water, saving 90 percent of the artificial cool produced by chillers. This reduces operating costs by 98 percent relative to compression or absorption systems.

The green façade is composed of 450 hanging plants in 150 planter boxes on one side of the building. To evaluate the effectiveness of the green façade in reducing energy consumption, Watergy compared the total primary energy required for heating and cooling on the side of the building with the green façade to a side of the building with conventional shades. Watergy found that compared to conventional shades, the green façade requires less total primary energy for heating and cooling (41 kWh/m^2 per annum for the green façade versus 65 kWh/m^2 per annum for conventional shades). The plants produce evaporative cooling and prohibit long wave radiation from entering the building, reducing energy consumption by 25 percent. Maintenance is also significantly less expensive for the plants compared to the conventional shades.

Energy Efficiency in the AC Sector

Walid Chakroun, ASHRAE and Kuwait University

Mr. Chakroun spoke on the importance of energy efficiency when selecting alternative refrigerants. Mr. Chakroun began his presentation with a discussion of the Kigali Agreement, which offers an opportunity to realize energy efficiency gains when replacing HFC and HCFC-based equipment. In addition, the CCAC Marrakech Communiqué recognizes that implementation of the Kigali Agreement can avert as much as 0.5˚C of warming over the course of the century, with additional climate mitigation possible from improving the energy efficiency of HFC-containing refrigeration and AC equipment. Thus far, a group of philanthropist organizations have pledged US$53 million in grants (the Kigali Cooling Efficiency Fund) to support energy efficiency alongside the phase-down of HFCs. To complement these funds, the World Bank Group announced it will make US$1 billion available in funding for energy efficiency in urban areas by 2020 that could include support for the development and deployment of high-efficiency cooling technologies using climate-friendly refrigerants.

Energy efficiency in the AC sector is an important consideration as the direct environmental impacts of refrigerants are significantly smaller than the indirect environmental impacts from energy consumption. Globally, direct CO2 equivalent emissions from HFCs are four times smaller than the indirect CO2 emissions resulting from energy consumption of the appliances in which HFCs are used. Considering that 15 percent of global energy consumption per capita is used in cooling applications and that this consumption is expected to increase by 7 percent annually through 2050; 40 percent of energy consumed in urban areas is consumed by AC and refrigeration; and AC accounts for 40-50 percent of total electricity consumption in developing countries, there is much to gain by improving energy efficiency throughout the lifecycle of equipment in this sector. However, the energy efficiency of entire buildings, not only AC units, needs to be improved to realize maximum gains.

Energy Efficiency and Its Role in the EU

Andrea Voigt, EPEE

Ms. Voigt provided an overview of the status of energy efficiency in Europe. She emphasized that achieving the EU climate and energy goals requires a holistic approach to the HVACR sector, with energy efficiency and renewable energies as key pillars. In addition, updated standards, codes, and training will contribute to achieving the highest energy efficiency and safety for users, installers, and manufacturers.

Ms. Voigt noted that the heating and cooling sector alone consumes 50 percent of Europe's annual energy demand and 80 percent of Europe's gas demands. However, by improving energy efficiency, Europe has the potential to save 10 percent of energy consumed, which would also avoid the release of 135 million tonnes of CO_2 by 2030.

In Europe there are three key directives to boost energy efficiency: a directive to improve the energy performance of buildings, a directive to improve energy efficiency in supply and end-use, and a directive to improve eco-design and use energy labels on products. The eco-design directive sets minimum energy efficiency standards by product. If a standard is not met, a manufacturer cannot place the product on the market. This directive has a large impact on industry, particularly in the AC, professional refrigeration, commercial refrigeration, and hydronic heat pumps and boiler sectors. Each product is assigned a minimum energy requirement and timeframe for achieving the requirement. If all requirements are achieved, there will be 166 million tonnes of oil equivalent of primary energy savings per year by 2020, which is equal to the annual primary energy consumption of Italy.

In addition to increasing energy efficiency, the European industry needs to adopt alternative refrigerants in these sectors. However, as many alternative refrigerants in these sectors are flammable, before adopting these refrigerants the EU must update standards and building codes at the EU, member states, and local level. The EU-level standards and codes, including EN 378, EN 60335-2-40, EN 60335-3-89, and EN 13313, are currently under revision to accommodate the use of flammable refrigerants. All of the standards interact and are equally important to facilitate the uptake of lower-GWP refrigerants.

Once the standards and codes are updated, training must be improved. While the current legislative framework for trainings at the European level appears appropriate to ensure the safe handling of equipment, shortcomings were identified in the trainings themselves. Recent regulatory actions are increasing the uptake of training for service personnel of equipment using climate-friendly products. Activities include awareness campaigns among end-users and the equipment distribution chain to promote training needs and exchange of best practices, as well as train-the-trainer programs for multiplication of effort and addressing geographic imbalances.

Summary of Discussion/Q&A

One participant asked whether any of the technologies had been applied in high ambient temperature (HAT) conditions.

Mr. Schmidt noted that implementation in HAT conditions is not a problem for evaporative cooling, as shown by the installation in Rio de Janeiro. The main concerns with implementing this technology are training technicians and updating safety standards and codes. Implementation in HAT conditions can be achieved as long as these concerns are addressed.

Ms. Voigt also responded that in terms of eco-design and energy efficiency in buildings, it is not enough to only have the product available, there also needs to be installation and maintenance frameworks to accompany the products. Unless concerns such as inspections and regular maintenance are addressed, the benefits of energy efficiency due to unforeseen issues and leaks will be lost. Building automation control is one technology that mitigates these concerns as it allows building owners and maintenance teams to take action as soon as performance starts to decline.

One participant asked about the current status of alternatives evaluation and standardization.

Ms. Voigt responded that the AREP Program is currently conducting refrigerant evaluations that focus on developed and developing countries and HAT conditions. In regards to flammability, the risk assessments will apply regardless of location. All of the research is publically available and accessible for free.

Session II A: Low-GWP Alternatives for Residential and Light Commercial Applications

Session II A covered alternatives for residential and light commercial unitary AC including window, portable, central ducted, split, rooftop and packaged terminal AC, and included discussions on topics such as energy efficiency, standards and safety issues, and performance under HAT conditions. The moderator of the session was Cindy Newberg of the U.S. EPA. The panelists were:

- Omar Abdelaziz, Oak Ridge National Laboratory (ORNL)/ U.S. DOE
- Allen Karpman, Arkema
- Jonathan Li, Midea Group
- Mark Stanga, Daikin
- Greg Picker, Refrigerants Australia

Panelist 1: Omar Abdelaziz, ORNL/ U.S. DOE

Mr. Abdelaziz focused his presentation on the selection of next generation, low-GWP refrigerants, beginning with a brief overview of such alternative refrigerants, including R-1234yf, R-1234ze, CO_2, hydrocarbons, and ammonia (NH_3). He noted that one challenge for the use of these refrigerants is flammability, as R-1234yf and R-1234ze are mildly flammable and hydrocarbons and NH_3 are flammable. He explained that flammability is a tradeoff when trying to reduce ozone depletion potential (ODP) and GWP. In refrigerants, the presence of chlorine increases ODP and fluorine increases GWP. To move away from chlorine and fluorine, hydrogen is added, but hydrogen unavoidably leads to flammability.

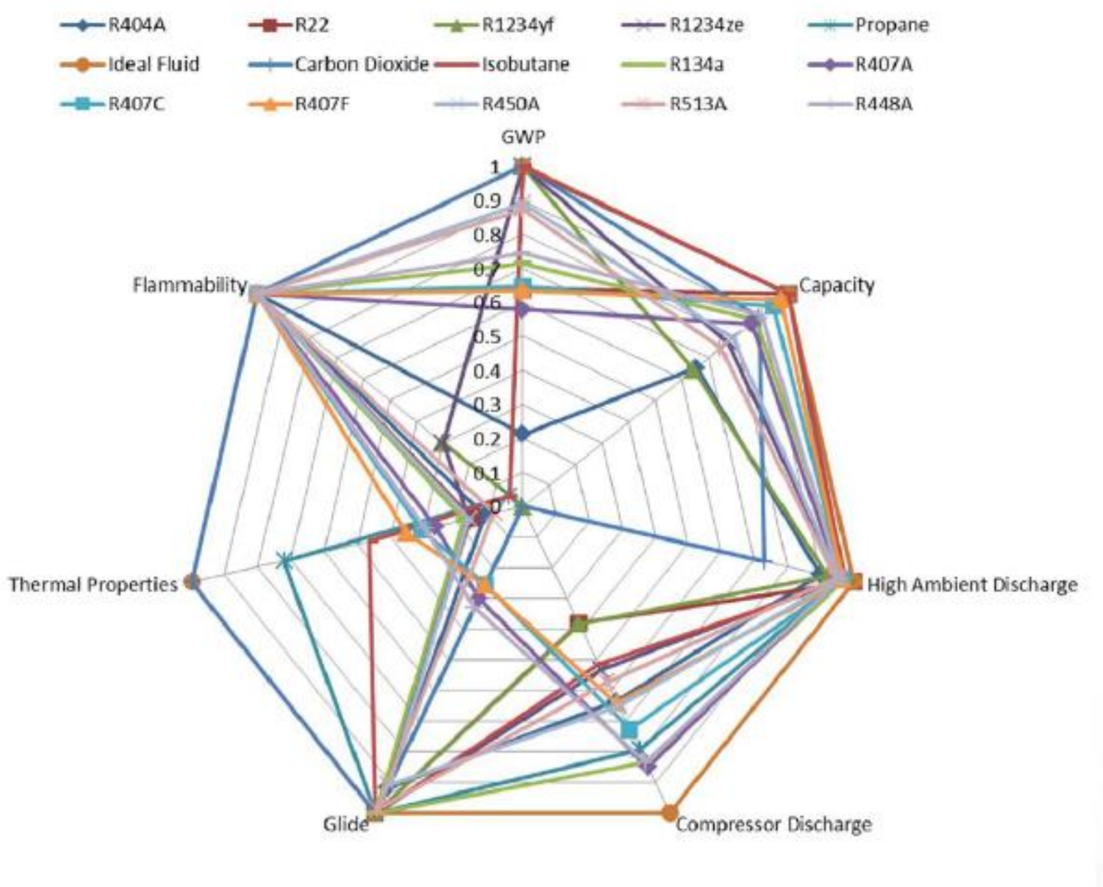
Mr. Abdelaziz explained that finding the ideal refrigerant is a never-ending challenge. Important characteristics to consider in a refrigerant include cost, toxicity, environmental safety, reactivity, thermodynamic efficiency, chemical stability, and compatibility with a wide range of materials. However, refrigerant selection requires tradeoffs. A spider plot (see Figure 1 below) is one way to weigh these various tradeoffs. This example considers refrigerants' GWP, capacity, high ambient discharge, compressor discharge, glide, thermal properties, and flammability. An ideal refrigerant would encircle the spider plot with a "1" rating for each consideration.

Refrigerant Evaluation Reports

Several full refrigerant evaluation reports are available online at info.ornl.gov. Resources include:

- Alternative Refrigerant Evaluation for High-Ambient Temperature Environments: R-22 and R-410A Alternatives for Mini-Split Air Conditioners (available online at: http://info.ornl.gov/sites/publications/files/Pub59157.pdf)
- Alternative Refrigerant Evaluation for High-Ambient Temperature Environments: R-22 and R-410A Alternatives for Rooftop Air Conditioners (available online at: http://info.ornl.gov/sites/publications/Files/Pub69980.pdf)
- The Future of Air Conditioning for Buildings (available online at: www.energy.gov/eere/buildings/downloads/future-air-conditioning-buildings-report)

Figure 1 Commercial Refrigeration Spider Plot



Panelist 2: Allen Karpman, Arkema

Mr. Karpman discussed fluorinated alternatives in residential and light commercial applications. Arkema is a global producer of performance materials and specialties with 19,000 employees in 20 countries. Arkema began producing refrigerants in Europe in the 1940s, in the United States in the 1950s, and in Asia in the 2000s. Arkema has developed multiple refrigerant alternatives for R-22, R-410A, and R-134a, including:

- R-427A: A non-flammable alternative to R-22 with a GWP of 2,024
- R-449B: A non-flammable alternative to R-22 with a GWP of 1,296
- R-20b: A mildly flammable alternative to R-22 with a GWP of 250
- ARM-42: A mildly flammable alternative to R-134a with a GWP of 131
- R-457A (ARM-20A): A mildly flammable alternative to R-22 and R-404A with a GWP of 139. It has a lower capacity and higher efficiency than R-22, and a lower capacity, similar discharge temperature, and consistently higher efficiency than R-404A. R-457A can be used in packaged, rooftop, room AC, split system, unitary AC, stand-alone refrigeration, and supermarket refrigeration applications.
- R-459A: A mildly flammable alternative to R-410A with a GWP of less than 500. It is an HFC/hydrofluoroolefin (HFO) blend that has been demonstrated more efficient than R-410A and has the lowest direct carbon footprint of R-410A replacements in its class. R-

459A can be used in split system, unitary AC, ducted split, packaged, rooftop, variable refrigerant flow (VRF), and positive displacement chiller applications.

Panelist 3: Jonathan Li, Midea Group

Mr. Li provided an overview of the introduction of R-290 refrigerant in Chinese AC manufacturing. Mr. Li highlighted the following key dates:

- 2009: Research began on R-290
- 2011: Development efforts began
- 2012: China developed its first R-290 compressor
- 2013: The first certification in China was received for the use of R-290 in AC
- 2014: Chinese R-290 portable ACs launched in EU markets, with the production line supported by the United Nations Industrial Development Organization (UNIDO)
- 2016: Third generation of production of R-290 in the Chinese AC manufacturing sector

One barrier to the manufacturing and use of R-290 in refrigerants in China is the need for new standards and regulations. Chinese regulations are in the process of being updated with the intent to increase production. Thus far, there has been growth in the market. China started selling R-290 AC units in 2014 and sold 9,000 units in 2016 to European markets. The volume is expected to continue to increase in 2017, especially in Southeast Asia. A significant increase by 2020 in European markets is also expected due to Europe's F-gas regulations.

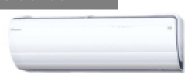
Panelist 4: Mark Stanga, Daikin

Mr. Stanga spoke about how Daikin determines the risk of alternative refrigerants. Daikin assesses four basic factors when making the best balanced refrigerant choice for each application: a comprehensive assessment based on safety, environmental impact, energy efficiency, and cost-effectiveness. As an example of this process, Mr. Stanga discussed how Daikin approved flammable refrigerants, specifically R-32, in Japan. The first step was to conduct a comprehensive assessment and determine the tolerable risk for any activity involving the use of flammable refrigerants, based off International Organization for Standardization (ISO) guide 51. For instance, for home appliances the tolerable risk is equal to 1/100 million accidents per year times the number of units for every million units on the market, which equates to approximately one accident per 100 years.

Next, Daikin conducted an A2L[3] risk assessment in collaboration with academia and Japanese experts, industry, and government. The results of the assessment and current R-32 regulated status can be found in Figure 2 below.

[3] A2L refers to the safety classification for refrigerants with lower toxicity and mild flammability as designated in ASHRAE Standard 34.

Figure 2 A2L Risk Assessment for R-32

Application	Cooling Capacity [kW]	Charge size [kg]	Ignition probability when used in room [No measures, Number/AC/year] Result	Risk during operation	Regulation	GWP ban
Residential 	2.2～8	0.5～2	3.9×10^{-15} (residential room・No mechanical ventilation)	Acceptable (Need a measure for floor standing indoor unit)	No	GWP≦750 (2018)
Light commercial 	3.6～28	3～19	4.2×10^{-12} (Office・No mechanical ventilation)	Acceptable (Need a measure for floor standing indoor unit and outdoor unit installed at narrow space)	No	GWP≦750 (2020)
	More than above	More than above	7.6×10^{-13} (Office・No mechanical ventilation)	Acceptable (Need a measure for floor standing indoor unit and outdoor unit installed at narrow space)	Yes to No	Under consideration
VRF 	14～150	5～88	7.6×10^{-9} (Office・No ventilation during night time)	Need a measure (according to charge size, room size)	Relaxed	Under consideration
Water source chiller 	8～1400	1～7000	6.2×10^{-5} (Machine room/no ventilation)	Need a regulatory requirement (Upon equipment capacity)	Relaxed	Under consideration

This risk assessment process has been ongoing at Daikin, serially, over last several years. It has resulted in a substantial market penetration of this technology: Daikin sold approximately 8 million R-32 units in 50 countries, out of a total market of 20 million units sold globally by all manufacturers. In conclusion, there is an acceptable pathway of assessing the risk of A2L refrigerants allowing for substantial market penetration.

Panelist 5: Greg Picker, Refrigerants Australia

Mr. Picker discussed the introduction of R-32 in Australia. Mr. Picker explained that there were several reasons Australia was chosen as a test market for R-32, including the country's technician licensing requirements, the capacity to roll out training nationally, and the ability to get all stakeholders in a single room. In Australia, technician licensing has a high compliance rate which provided confidence to manufacturers that the refrigerant supply chain would be well managed. The capacity to roll out training nationally was important and manageable as the country is highly urbanized and offers significant training to all technicians. Finally, due to the size and urbanization of the country, it was possible to get all stakeholders to meet to work out specific challenges and issues at once.

There were also challenges to the introduction of R-32 in Australia. Standards posed a challenge because the country had to add standards for flammability and ensure all stakeholders met the new standards. In addition, as a HAT country, the standards for tanks, valves, and cylinders are different than in other regions. This required re-testing materials at higher temperatures to ensure the temperature and pressure levels were adequate. Supplying all markets across the country also posed a challenge. Australia is highly urbanized and the majority of the population lives on the coasts, so there needed to be a reliable supply chain through the middle of the country to supply that population with units, especially as AC units are in high demand in the HAT zones throughout central Australia. Finally, the recovery and reclamation processes in Australia had to be refined to accommodate flammable refrigerants.

Despite these challenges, R-32 has achieved significant market penetration in Australia. Residential AC unit imports using R-32 align closely with imports of R-410A units. Refrigerants Australia expects that R-32 will have greater penetration than R-410A in the coming year. Mr. Picker also noted that thus far, there have been no accidents in Australia as a result of the use of this mildly flammable refrigerant.

Summary of Discussion/Q&A

The moderator, Ms. Newberg, asked panelists where they saw the most challenges and whether some end-uses present more challenges than others.

> Mr. Stanga noted that the larger the charge, the more likely the need is for safety restrictions and safety codes. He added that the easiest equipment to work with tends to be equipment with smaller charges.
>
> Mr. Abdelaziz responded that one refrigerant will not work for all applications. R-12 and R-22 were used in many applications, but this won’t be the case with this next generation of refrigerants. At this point, the industry is optimizing the refrigerant for each end-use.

One participant asked how refrigerants dissolve in the atmosphere and how refrigerant is reclaimed or destroyed.

> Mr. Abdelaziz noted that HFOs are short-lived refrigerants. He also explained that some refrigerants have impurities from leaks which means they cannot be reclaimed, but must be destroyed. Otherwise, there are guidelines on how to reuse or destroy clean refrigerants.

One participant asked which refrigerants are safe, cost-effective, and efficient for large charge size units, particularly rooftop units.

> Mr. Abdelaziz responded that R-32 and some of the Arkema, Honeywell, and Daikin alternatives meet these requirements. From a performance point-of-view, they all perform well, but countries should conduct risk assessments to determine their priorities (e.g., flammability versus environmental performance). However, so far risk assessments have shown that R-32 works well in roof top units.
>
> Mr. Picker added that Australia is about to entrench legislation that will increase the HFC phase-down; it will be 15 percent more aggressive than the Kigali Agreement. He added that Australia looks at sectors that will move quickly (e.g., splits and MVAC) and are “low-hanging fruit.”

One participant asked the panelists about their position on the use of R-32.

Ms. Newberg noted that the status of R-32 depends on the end-use. The U.S. EPA is in the process of reviewing and approving refrigerants, including flammable refrigerants, for different end-uses.

Mr. Abdelaziz added that the international building standard, ASHRAE Standard 15, is being updated to accommodate flammability requirements.

One participant noted that there is time for Article 5 countries before they need to be compliant with the Kigali Agreement and asked about steps that can be taken now to ensure Article 5 countries are as close as possible to low-GWP, energy efficient products by the time they are required to become compliant.

Mr. Abdelaziz responded that the industry can work with Article 5 countries to figure out which refrigerants can be used in different applications and based on different priorities. A U.S. DOE sponsored program is looking at AC units and defining the specifications for the best ACs.

One participant asked about the main drivers for the use of R-32 in unitary AC units.

Mr. Picker responded that Australia was well-suited for the introduction of HFC-32 as it is a very controlled market, compared to other markets internationally. He noted that Australia has national regulations regarding servicing tradespeople and who is allowed to access the refrigerants. In addition, one of the advantages is that the companies manufacturing the units have their own force of servicing tradespeople.

One participant asked for a table that lists all of the alternatives and in which end-uses they are used.

Ms. Newberg noted that both the Montreal Protocol’s Technology and Economic Assessment Panel (TEAP) and the AREP Program that AHRI runs have some tables, but that this may be homework for the folks here who want to provide that type of information.

One participant noted that the GWP of R-32 is 675 which is lower than the GWPs of other HFCs, but much higher than the GWPs of hydrocarbons. The participant then asked why the panelists plan to continue to use R-32.

Ms. Newberg responded that the U.S. EPA does not think all end-uses will transition towards hydrocarbons or non-fluorinated refrigerants at this time. The U.S. EPA thinks it is likely that HFOs and HFCs will continue to be used in certain end-uses based on characteristics other than GWP.

Mr. Stanga added that Daikin has focused on R-32 because of its thermodynamic properties; it is efficient and has many other benefits. However, in some end-uses, companies have concluded that there is room for lower-GWP solutions that have other benefits, such as lower charge sizes.

Mr. Picker noted that one of the broader policy issues is that it is not up to the government to favor any refrigerant. Industry will change and evaluate the technologies and competition will ensue. It is not appropriate for the government or industry as a whole to determine which refrigerant should be used.

One participant asked what qualifies a refrigerant as low-GWP.

> Mr. Picker noted that the point is not about identifying refrigerants that are low-GWP, but about increasing the efficiency of the sector as a whole and letting the market select refrigerants that will ensure that the national phase-down targets are met.

Session II B: Large Buildings/Commercial Air Conditioning

Session II B covered alternatives for large buildings and commercial AC, including chillers, multi-splits, and VRF, and included discussions on topics such as energy efficiency, standards and safety issues, and performance under HAT conditions. The moderator of the session was Dan Hamza-Goodacre of K-CEF/ ClimateWorks Foundation. The panelists were:

- Tomaz Cleto, Yawatz Engenharia Ltda.
- Torben Funder-Kristensen, Danfoss
- Lucas Velasquez, Empresas Públicas de Medellín
- Carlos L. Nunes Silva, Johnson Controls
- Mike Thompson, Ingersoll Rand
- Samuel Yana Motta, Honeywell

Panelist 1: Tomaz Cleto, Yawatz Engenharia Ltda.

Mr. Cleto focused his presentation on the challenges to adopting alternative refrigerants in Brazil. Mr. Cleto acknowledged that energy efficiency is an important consideration in developing alternative technologies and needs to be improved at the refrigerant and system level. Specifically, Mr. Cleto mentioned the possibility of achieving efficiencies by updating the design of systems to significantly reduce charge size and energy consumption.

In Brazil there are two main options for improving the existing systems: natural refrigerants and low-GWP refrigerants, mainly HFOs. While there is a market for these options in Brazil, training on how to handle flammable refrigerants must be developed. Flammable refrigerants pose a particular challenge in Brazil because many systems have high charge sizes, which are not conducive to the use of natural refrigerants. Therefore, in discussing next steps, Mr. Cleto called for developing systems that are capable of using natural refrigerants with large charge sizes.

Panelist 2: Torben Funder-Kristensen, Danfoss

Mr. Funder-Kristensen spoke about the questions that remain in regards to adopting alternative refrigerants. Mr. Funder-Kristensen began by noting that development must consider both sustainability (environmental impacts) and viability (short-term reasons for investment in low-GWP refrigerants). Currently, there is a convergence of new and old technologies as low-GWP applications become efficient, safe, and affordable. In addition, the energy agenda spurs innovations and eventually the premise of refrigerants. One thing to note is that heat recovery and storage will become more important when choosing refrigerants.

A3[4] refrigerants are most applicable in small systems due to low charge sizes. In the future, we need to develop ways of using A3 refrigerants in systems with larger charge sizes. One way to

[4] A3 refers to the safety classification for refrigerants with lower toxicity and high flammability as designated in ASHRAE Standard 34.

do so is by working with systems without oil. This way, we have the opportunity to move towards a more sustainable system.

Mr. Funder-Kristensen noted that what is critical now is not necessarily what will be critical in the future as technologies adapt and energy systems change. Specifically, in regards to environmental impact, it is important to minimize the tradeoff between GWP and energy efficiency now and in the long-term optimize the performance of refrigerants. At the same time, it is necessary to keep or reduce the current refrigerant capacity of the existing systems, mitigate refrigerant costs, and improve efficiency. The industry also needs to confirm A2L safety, implement updated codes, and prepare the market for flammable refrigerants.

Panelist 3: Lucas Velasquez, Empresas Públicas de Medellín

Mr. Velasquez discussed a recent district energy pilot project in Medellín, Colombia. In 2012, the Empresas Públicas de Medellín began a cooperative project, administered by Johnson Controls, to establish district energy in Colombia and to not only meet Colombia's obligations under the Montreal Protocol, but also increase energy efficiency to the greatest extent possible in buildings. Drivers for the project included an expansion of the client's equipment, a utility (Empresa de Servicios Públicos de Colombia), a strategy to promote new energy districts, and the creation of a chiller program by the Ministry of Environment and Sustainable Development. The utility is funding approximately 72 percent of the project and Switzerland is funding the remaining cost. The Ministry is funding less than one percent of the project.

The construction of the infrastructure, including the implementation of district cooling and energy efficiency measures for buildings, began in 2016. The project employs 2 ammonia and one absorption chiller including trigeneration and provides 2,000 tons of cooling capacity. It is expected to reduce GHG emissions by 30 percent and eliminate ODS. Once the pilot project is completed, Empresas Públicas de Medellín will analyze current regulations, identify business models, and map and develop energy districts in five additional cities. They will also focus on renewable energy technologies, training and dissemination, and exchanging knowledge and experiences internationally.

Panelist 4: Carlos L. Nunes Silva, Johnson Controls

Mr. Nunes Silva began his discussion by noting that while natural refrigerants seem to be a great solution, there are also challenges and limitations for natural refrigerants in commercial markets. Specifically, the use of flammable refrigerants must adhere to the ASHRAE and ISO standards for toxicity and flammability and historically, and updates to standards have taken years with a heavy influence from industry and government.

In order to achieve the best operating cost and environmental performance, Johnson Controls takes a holistic cost and climate performance view of the system. In this regard, the company attempts to minimize refrigerant charge size, improve leak detection, and reclaim and re-use refrigerants. Smart buildings are also important to consider when optimizing energy efficiency.

Panelist 5: Mike Thompson, Ingersoll Rand

Mr. Thompson provided a brief overview of his company's upcoming transition in response to the Kigali Agreement. Mr. Thompson began his discussion by noting that the industry is fully supportive of the Kigali Agreement, especially as the established vision and dates enable the industry to start investing now in new technologies for the future.

Mr. Thompson explained that the last refrigerant transition following the ratification of the Montreal Protocol forced the company to reengineer their products. With this coming transition, Ingersoll Rand has a goal to cease production of high-GWP products by 2030. Ingersoll Rand will start with chillers as there are already low, medium, and high pressure next generation, non-flammable refrigerants available including R-514A, R-1233zd, R-1234ze, R-1234yf, R-452B, and R-32. While there are tradeoffs with each refrigerant, their availability now enables Ingersoll Rand and other companies to begin the transition.

Panelist 6: Samuel Yana Motta, Honeywell

Mr. Yana Motta presented an overview of Honeywell's alternative refrigerants. Honeywell has two series: the N series which is non-flammable and the L series which is mildly flammable. The N series includes R-1233zd(E), R-450A, R-515A, Solstice N20, and R-448A. The L series includes R-1234yf, R-1234ze(E), R-444B, R-455A, R-452B, and R-447B. Mr. Yana Motta used the rest of his presentation to discuss alternatives to R-123 and R-134a in chillers and R-410A in direct expansion (DX) systems.

In low-pressure chillers, R-1233zd(E) is a non-flammable alternative with a GWP of 1 and a similar efficiency to and 40 percent higher capacity than R-123 and R-134a. R-1233zd was successfully used in the English Channel Tunnel project and achieved a 40 percent higher efficiency than the existing R-22 systems.

In medium-pressure chillers, R-1234ze provides a significant efficiency improvement relative to R-134a, but also a considerable loss in cooling capacity (-25%). R-515A has performance and thermal properties similar to R-1234ze and can be used while the safety standards and building codes are being modified for flammables as R-1234ze is mildly flammable while R-515A is non-flammable.

In DX systems, R-447B and R-452B are replacements for R-410A in both chillers and commercial AC. R-447B has a lower capacity and similar efficiency as R-410 and R-452B closely matches the performance of R-410A. The discharge temperatures of both alternatives are close to that of R-410A with a significant advantage in HAT. As both alternatives are mildly flammable, the inclusion of 2L[5] refrigerants in the building codes could enable use of these refrigerants in indirect systems.

Summary of Discussion/Q&A

One participant asked Mr. Funder-Kristensen for recent numbers on energy efficiency.

[5] 2L refers to the safety classification for refrigerants with mild flammability as designated in ASHRAE Standard 34.

Mr. Funder-Kristensen answered that for CO_2 refrigerant, efficiency measurements are very high, but he does not have specific numbers.

One participant asked if it is possible to use hydrocarbons in district cooling.

Mr. Nunes Silva responded that hydrocarbons have been used in a lot of systems, but not in district cooling applications. Hydrocarbon chillers are possible, but their capacity is at maximum 200 tons, whereas district cooling requires 2,000-3,000 tons. Safety would be a major concern because of the high refrigerant charge.

Mr. Thompson noted that for district cooling, HFOs are an ideal refrigerant as they can be used with very large charge sizes and are safe, non-flammable, and have a low-GWP. Mr. Thompson emphasized that there is no singular solution, but HFOs are a great option for district cooling.

One participant asked what qualifies a refrigerant as low-GWP.

Mr. Thompson noted that we need to be careful with GWP limits. If there is a limit, it is possible that a better refrigerant with a slightly too high-GWP might not be considered, even if it is the best fit based on all other characteristics. Instead, we should look at all aspects of a refrigerant, not just GWP.

Mr. Yana Motta added that we need to look at GWP in addition to performance and energy efficiency. We also need to take into account safety. He added that every country needs to take into consideration their national circumstances and do their own analyses on the direct and indirect impacts of next generation refrigerants.

Another participant noted that California has leveraged the EU's F-gas regulation with a GWP limit of 150 or less for stationary refrigeration and a limit of 750 or less for stationary AC. California decided these limits make sense and is looking seriously at making them mandatory.

One participant asked if energy efficiency savings are always accompanied by high capital costs.

Mr. Nunes Silva responded that the problem with the cost of energy efficiency measures is that most building owners only look at the cost of the initial investment. However, when looking at large buildings, the life cycle savings are higher than the initial investments. The return on investment will make sense in the long term. He added that one thing to consider is how to get government or financing institutions to help pay for upfront costs.

One participant asked about the experience to date with alternatives to R-410A systems in developing countries. The participant also asked for the global level penetration of R-410A.

Mr. Thompson noted that there is a tremendous amount of work going on to develop alternatives to R-410A. Thus far, Ingersoll Rand and the industry have done a lot of research and development on alternatives, but it is best to have industry consensus.

The moderator, Mr. Hamza-Goodacre, asked the panelists to give the audience advice for developing countries when it comes to adopting new alternatives and setting standards in 140 characters or less.

Mr. Yana Motta told the audience to use the knowledge being developed in developed countries. Learn from them and use it.

Mr. Thompson noted that the technology is available and we can manage the transition, given time.

Mr. Nunes Silva added that everyone is hoping for one solution, but multiple solutions may be necessary for different end-uses.

Mr. Velasquez told the audience to establish a holistic sustainability plan, not just in regards to refrigerants.

Mr. Funder-Kristensen said that each country needed to design its own phase-down strategy, based on its particular consumption pattern and alternatives available in the relevant sectors. He also suggested making a detailed plan and educating technicians in the field.

Mr. Cleto noted that it is important to train people, relearn how to use refrigerants, and ensure there is no leakage. In his view, we are moving towards a new phase of facing flammable, high toxicity refrigerants; we must react by learning how to work within these conditions.

Session III: Air Conditioning in Special Applications

Session III covered alternatives for air conditioning in special applications and included discussion on topics such as industrial and process cooling, data centers, and the use of water as a refrigerant. The emcee for the session was Mr. Daniel de Graaf from the German Environment Ministry. The presenters were:

- Richard Lord, United Technologies
- Juergen Suess, Efficient Energy
- Marc-André Lesmerises, Carnot Refrigeration

Process Applications and Systems Approach to Selecting Refrigerants

Richard Lord, United Technologies

Mr. Lord discussed alternative refrigerants in the industrial and process cooling sector. Mr. Lord began with an introduction to industrial and process cooling equipment. The equipment is primarily designed for unique applications, but can also include standard equipment that is adapted or modified. Industrial and process cooling applications include greenhouses, beverages and breweries, dairy foods, electronics, data centers, and aircrafts, among others. Typically, energy standards focus on HVAC products used for comfort cooling, leaving a gap in the standards for industrial and process cooling, despite the large energy requirements of these applications. Currently, standards such as ASHRAE 90.1 cover process cooling by exception and only apply to data centers and some refrigerator and reach-in products.

When determining refrigerants for use in industrial and process cooling, it is important to consider efficiency (indirect emissions) and GWP (direct emissions) as well as safety. Over 97 percent of emissions in these applications are indirect. Considering the lifecycle climate performance of refrigerants is one way to reduce indirect emissions. The recent updates to Clean Air Act Section 608 regulations in the United States will help improve performance, especially in regards to reducing leaks and promoting reclamation.

Industrial and process cooling efficiency is challenging due to the critical nature of the processes and unique conditions of each application. In addition, the efficiency is not accurately reflected by the efficiency of an equipment component at full load as is the method for measuring the efficiency of HVAC equipment. A more complete metric should consider:

- Complete system including pumps, towers, and fans;
- Annualized performance factoring at least a representative load profile;
- Regional climate data like those defined in ASHRAE 169 with 19 climate zones;
- Building characteristics, occupancy, or process cycle characteristics; and
- Use of hybrid systems, heat pumps, heat reclaim, and free cooling cycles.

Developing a baseline metric for industrial and process cooling is challenging due to the different nature of equipment applications. Instead, a metric based on a systems approach would better encapsulate efficiency. In this case, a system can be defined as a combination of equipment, operations, controls, accessories, and means of interconnection that uses energy to perform a specific function. The intent of a mechanical systems approach would be to move up the scale where it may be possible to obtain more energy savings. However, conventional tools and ratings metrics would need to be revised to allow for this approach. It also would likely require the use of regional requirements due to different efficiencies in warm versus cold climates.

In summary, conceptual approaches are being evaluated using standardized load profiles and benchmark cities across all 19 climate zones in ASHRAE 169. Key enablers to this include the development of full performance maps for equipment (ASHRAE 205); standardized climate data (ASHRAE 169/ASHRAE 90.1); and new tools to allow for easy simulation on an annualized basis for the complete system (AHRI/ASHRAE 90.1). This initial work is for HVAC comfort conditioning, but can be expanded for process cooling and it will likely be a future goal. The data center industry has already implemented a system metric with the power usage effectiveness metric, and it is helping them enable the use of new concepts like higher space temperatures and free cooling cycles.

Summary of Discussion/Q&A

The session emcee, Mr. de Graaf, asked for clarification on a point in the talk that stated 8 percent of the total electricity supply in the United States is consumed by data centers. Mr. Lord confirmed this was correct.[6]

A Novel Air Conditioning System with Pure Water as the Refrigerant

Juergen Suess, Efficient Energy

Mr. Suess presented a technology developed by Efficient Energy that uses water as a refrigerant in cooling applications. Mr. Suess began his presentation with a brief overview of Efficient Energy, a company working to establish water as the standard refrigerant in the industry, increase cost efficiency for customers, and also improve the environment with products that set new standards both economically and ecologically.

Mr. Suess emphasized that water has been used as a refrigerant for as long as humans have been sweating. Historically, water has been used in absorption systems, and more recently began to be used in compression systems such as centrifugal chillers. The main benefit of water as a refrigerant is that the critical point of water is very high. It can run up to 100˚C without any issues with the ambient pressure. Water also theoretically has a high coefficient of performance (COP). In addition, the use of water as a refrigerant is an efficient waste heat rejection and the entire vacuum process is decoupled from the application. Efficient Energy's machines behave like chillers and have different operational modes for different applications.

Efficient Energy conducted a field test at a data center in Bremen, Germany using a dry cooler. The temperature distribution at the data center ranged from -10˚C to 30˚C, but generally

[6]Other sources have estimated the share of electricity consumed by data centers in the United States to be lower, approximately 2 percent: https://eta.lbl.gov/sites/all/files/publications/lbnl-1005775_v2.pdf and Koomey, J.G. (2011) Growth in Data Center Electricity Use 2005 to 2010. Analytics Press, Oakland, California, available at: http://www.koomey.com/post/8323374335

remained between 5˚C and 15˚C. The data center wanted to maintain a cooling capacity of 25 kW year round. When in use, Efficient Energy's cooler consumed between 1.1 kW (free cooling mode) and 17 kW (two stage operation) with a COP range from 1.4 to 22 depending on the operational mode. In the first full year of operation, the cooler saw a cooling capacity of 170 MWh and an annual COP of 14, four times higher than an R-410A system. The cooler also realized a 50,000 kWh electricity savings, 7,000€ cost reduction; and 31 tons of CO_2 equivalent emissions avoided.

The perfect application of this machine has a constant cooling capacity requirement year-round with a cooling temperature above the heat sink temperature for 70 – 80 percent of the time and the remaining time below the heat sink temperature. This would generate an average COP of 120. Applications for this technology include data centers (new and refurbished), the plastics and chemical industry, commercial refrigeration, heat pumps, and commercial AC.

As for cost, the costs of the materials for the cooler do not indicate that it will be more expensive to mass produce than the technology used commercially today.

Summary of Discussion/Q&A

One participant asked if there are disadvantages to this technology.

> Mr. Suess responded that water freezes at 0˚C, so this poses a challenge in areas with low temperatures. However, above 10˚C a lot is possible. A strength is that water is not a dangerous substance, so could be used globally. As long as there is a constant suction, no matter how hot the ambient temperature is, it will maintain the capacity.

One participant asked about the cost of this technology.

> Mr. Suess noted that in regards to cost, with mass production there is no reason to believe this technology will be more expensive than the current systems manufactured today; it might even be cheaper.

One participant asked how to replace chillers in use today with this new technology.

> Mr. Suess explained that by using water you avoid the issues with CO_2 in warm climates. Also, technicians do not need extensive training to use this system as water is not a refrigerant.

> Mr. Suess added that the main problem for the company now is with credibility. In 2017 the company plans to make more than 50 machines, and the longer the machines are in operation and the technology matures, the more credibility the company will gain.

CO_2 Air Conditioning in Data Centers

Marc-André Lesmerises, Carnot Refrigeration

Mr. Lesmerises spoke about the use of CO_2 as a refrigerant in data center cooling. Mr. Lesmerises began his presentation with an overview of the importance and significance of the data center sector. From 2005 – 2015, Internet traffic volume increased by 60 percent, which has required additional cooling capacity in data centers. In 2015, the International Institute of Refrigeration estimated that 17 percent of the electricity produced worldwide is consumed for cooling applications. Mr. Lesmerises also referred to a United Nations report stating that synthetic refrigerants could account for up to 20 percent of GHG emissions in the future and hamper efforts to curb climate change. There are a variety of high efficiency cooling technologies that could satisfy the demand in data centers, but most require many components which increases the risk of failures and leaks. Therefore, Carnot Refrigeration uses CO_2, a well-documented, energy efficient refrigerant for several industry sectors including supermarkets, refrigerated warehouse and processes, chillers, and data centers.

Four years ago, the largest communication company in Canada, Bell, approached Carnot with a request to transition all of Bell's data center AC units, which ran on R-22, with an easy, long-lasting solution that reduces GHG emissions and energy consumption. Carnot decided to replace the existing units with used CO_2 Computer Room AC (CRAC) units, which are able to operate at high pressure. This characteristic is important because at approximately 24˚C, for each degree of temperature there is a 30 psi differential. It is not required to have the compressor circulate the refrigerant. Instead, the system follows a natural rain cycle which equates to free cooling. Most of the year, this eliminates the need for a mechanical system. After three years, this level of free cooling equates to 150,000 kWh saved per site and a 99.9 percent reduction in GWP.

These systems are much more compact than traditional systems and reduce maintenance requirements as CO_2 piping can run through a building. CO_2 as a refrigerant is also energy efficient. Results from trials comparing a natural refrigeration system to a traditional HFC system show reductions in GHG emissions of 62 percent, installation costs of up to 15 percent, electrical energy usage of up to 15 percent, and heating gas usage of up to 20 percent.

Summary of Discussion/Q&A

One participant noted that in this case, Carnot replaced R-22 equipment with a new CO_2 system. The participant then asked about the cost effectiveness of the technology and if it requires replacing the entire system. The participant also asked if the new technology would require a new risk assessment.

> Mr. Lesmerises clarified that the goal of this technology is for it to be an easy retrofit. Units are transitioned at the end of life instead of using a transition refrigerant. The initial cost will be higher than a transition refrigerant system, but the lifecycle costs will be greatly reduced as free cooling is gained when using CO_2.

One participant asked if it is possible to use hydrocarbons in this system.

> Mr. Lesmerises responded that it is possible, but it will not allow for free cooling.

One participant asked about the market size.

> Mr. Lesmerises noted that Bell is the primary customer and there are currently 30 systems installed.

Session IV: Challenges to Adoption of Alternatives

Session IV included discussions on a number of challenges surrounding the adoption of alternatives in the stationary AC sector, including challenges for developing countries in particular and those associated with: the manufacturing and use of flammable and toxic refrigerants; intellectual property rights; HAT conditions, and standards and codes. The moderator of the session was Xiaofang Zhou of the United Nations Development Programme. The presenters were:

- Ole Nielsen, UNIDO
- Ayman Eltalouny, United Nations Environment Program (UNEP)
- Mary-Ellen Foley, World Bank
- Bassam Elassaad, a member of the Refrigeration Technical Options Committee (RTOC)
- Xudong Wang, AHRI

Challenges to Deploying Alternatives in Developing Countries, Including Installation and Maintenance of Appliances with Flammable and/or Toxic Refrigerants

Ole Nielsen, UNIDO and Ayman Eltalouny, UNEP

Mr. Nielsen and Mr. Eltalouny discussed the manufacturing and post-production processes for deploying flammable and/or toxic refrigerants in developing countries. Mr. Nielsen presented first and focused on the manufacturing process and Mr. Eltalouny presented second, focusing on the post-production process.

Mr. Nielsen began his presentation by noting that in response to the requirements of the new Kigali Agreement, a number of test programs have confirmed that potential alternatives are available. However, products and manufacturing processes must be redesigned to meet requirements for these alternatives, particularly in regards to flammability.

In an assembly line, the steps for manufacturing AC units are as follows: a helium leak test, evacuation, refrigerant charging, process tube sealing, a leak test, a performance test, and extended performance test. Within this process, the steps with increased risk due to flammable refrigerants include refrigerant charging, process tube sealing, the leak test, and both the performance test and extended performance test. If a leak is discovered during any one of these steps, it is important to ensure recovery or ventilation of the hydrocarbon being tested.

So far, factory conversions for flammable refrigerants have been relatively unproblematic. However, the post-production process (i.e., updated safety standards and training for installation, maintenance, and de-commissioning) still requires attention and is the primary barrier to adopting flammable refrigerants. Additional challenges include conversion costs, limited technical capacity, component and refrigerant availability, and the cost impact on final product price. Mr. Nielsen trusts that in time, these challenges will be resolved and flammable refrigerants will be cost-competitive.

Following Mr. Nielsen's presentation on manufacturing, Mr. Eltalouny began his presentation by noting that the projected demand for HFCs in developing countries between 2011 and 2040 increases from approximately 200 kilotonnes to 1,600 kilotonnes. For comparison, the projected demand for Article 2 countries is expected to remain between 200 kilotonnes and 400 kilotonnes over the same time period.

There are five primary considerations in the post-production process for appliances with flammable and/or toxic refrigerants in Article 5 countries: 1) skills for identifying and handling different types of refrigerants, 2) tools to ensure jobs are done safely and efficiently, 3) proper labeling and logging (record keeping) measures, 4) standards and codes, and 5) integrated institutional and regulatory approaches. Mr. Eltalouny focused the rest of his presentation on the first, second, and fifth considerations.

Beginning with skills for identifying and handling refrigerants, Mr. Eltalouny noted that challenges include establishing effective certification programs for HVACR professionals and ensuring enforcement and monitoring of modalities and technical capacities. However, there are opportunities available to meet these challenges including the development of international standards (ISO) for setting competencies and skills requirements, model refrigerant certification programs, and industry initiatives to address skills requirements for the supply chain network through voluntary programs.

Mr. Eltalouny also explored the challenges and opportunities with tools required in the installation and maintenance of these refrigerants. The challenges include designating different tools for different refrigerants as well as developing precautionary arrangements towards leakage, flammability, brazing, charging, and other practices. However, there are similarities in the practice techniques for different refrigerants and in the case of zero- or very low-GWP refrigerants such as hydrocarbons in small applications, there may be fewer regulations regarding disposal procedures (i.e., venting versus reclamation). In addition, there are an increasing number of resources such as materials, manuals, and guidelines now available.

In regards to integrated institutional and regulatory approaches, challenges include the absence of comprehensive regulatory frameworks that address the whole issue of refrigerant management and the need for a risk assessment model for developing countries. However, the lack of frameworks and models presents the opportunity to update policies in response to the Kigali Agreement and HFC commitments and in anticipation of Stage II HCFC Phase-out Management Plans (HPMPs). In addition, updating policies could encourage South-South cooperation to coordinate and learn from the research and development occurring in other Article 5 countries.

Introduction of Alternative Refrigerant in the Thailand AC Sector and the Role of Intellectual Property

Mary-Ellen Foley, World Bank

Ms. Foley discussed the introduction of R-32 in Thailand's AC sector as well as the role of intellectual property throughout the process. Ms. Foley began the presentation with an overview of Thailand's AC sector. Thailand is the second largest AC manufacturing base in Southeast Asia and is an export hub, exporting 10 million units per year which accounts for 90 percent of the manufacturing market. At the project baseline (Stage I HPMP) in 2012, the sector was dominated by R-22 manufacturing. To meet Thailand's obligations under the Montreal Protocol, the country needed to achieve a 10 percent reduction in the manufacturing of R-22 from the baseline, so it was critical to slow R-22 demand in the manufacturing sector and in downstream servicing. The replacement refrigerant chosen was R-32. However, parts of the market were concerned about market acceptability (including flammability and costs), the availability of the technology, and the use of the technology in the face of capacity and policy constraints.

Market acceptability was tackled on several fronts including by creating confidence and scale through the involvement of a major player while assuring small enterprises were not shut out of the market. A dialogue with Daikin led to an agreement to launch R-32 in the market and a dialogue with the Thai industry led to six companies agreeing to switch from high-GWP refrigerants to R-32 to ensure that their products could continue to be sold in certain markets in light of recent regulations, such as the EU's F-gas regulation.

Another challenge faced in this project was that of intellectual property rights. In the case of residential AC, Daikin had already agreed to provide developing countries free access to 93 basic application patents as a means to encourage commercialization for R-32 based AC. However, the Thai industry was still concerned about lacking the intricate details of the technology. To resolve this issue, Daikin agreed to provide tailored support to Thai manufacturers to improve AC technology during project implementation. The result was a more reliable, quality R-32 AC market to build confidence in the product and demand for this new, high-profile refrigerant. Daikin also stood to benefit from direct access to the Thai market.

Standards and safety still posed a challenge with the introduction of R-32. However, after reviewing tests and evidence from the Thailand Council of Engineers, Department of Industrial Works, and World Bank, the Department of Public Works and Town Country Planning decided to modify regulation to allow installation of split-type AC with capacities up to 36,000 Btu/hour in high-rise buildings. For larger units, consultation is still underway.

An additional challenge was component availability and supply. The design of the refrigerant pathway required a new compressor as the one rotary compressor manufacturer supplying all refrigerant compressors in the market did not produce compressors for larger units (about 10 percent of the market). However, with critical mass and coordinated efforts the World Bank convinced the supplier to produce the R-32 compressor in the larger size.

In conclusion, the project was successful thanks to a comprehensive implementation process that included: identifying and isolating challenges; systematically addressing the challenge while consulting stakeholders; building consensus among stakeholders by singling out the interest of each; and fostering the confidence of policy-makers in new technology through information, particularly that from developed countries. Ultimately, in 2016 three Thai AC manufacturers introduced R-32 ACs and sold 30,000 units. Since the implementation, the performance of R-32 AC has been better than similar R-22 & R-410 units.

Challenges under High Ambient Temperature Conditions

Bassam Elassaad, RTOC

Mr. Elassaad focused his presentation on the primary considerations and challenges with operating HVACR units under HAT conditions. Mr. Elassaad began his presentation with an overview of the four methods for classifying HAT conditions: the percentile method which uses the incidence of dry bulb corresponding to 0.4 percent, 1 percent, 2 percent, and 5 percent per year for the last 10 consecutive years exceeding 35, 40, or 45 degrees Celsius (°C) and is published in ASHRAE manuals; the Climate Zone method defined in ASHRAE 169-2013 with zones from extremely hot and humid to hot and dry based on cooling degree days in a typical year; the Bin Weather Method which offers microanalysis useful for system design requirements; and the Average Monthly method which uses the incidence of hours or days at a certain temperature and which was adopted by Parties of the Montreal Protocol for temperatures above 35 °C for at least two months per year over 10 consecutive years.

Mr. Elassaad also noted the primary considerations for applications under HAT conditions including efficiency, safety, and design; reliability; and critical pressure and safety.

- Efficiency, Safety, and Design: As ambient temperature increases, condensing temperature increases, decreasing efficiency. In HAT conditions, the cooling load for a conditioned space can be more than three times greater than that for moderate climates. In order to cope with these requirements, a larger capacity refrigeration system may be needed, implying a larger refrigerant charge with implications for safety and design.
- Reliability: Higher temperatures and pressure ratios lead to higher currents and shorter compressor life. In addition, under HAT conditions refrigerant and oil decompose into water and carbon, the viscosity of the oil decreases, insulation of the motor deteriorates, and reliability decreases.
- Critical Pressure and Safety: Under HAT conditions, refrigerants operate closer to their critical pressure. The prescribed high pressure for safe operation approaches the critical pressure for some refrigerants.

Mr. Elassaad moved on to highlight four new research efforts including: Promoting Low-GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries (PRAHA); Egyptian Project for Refrigerant Alternatives (EGYPRA), ORNL-U.S. DOE's High-Ambient-Temperature Evaluation Program for Low-GWP Refrigerants, and the Low-GWP AREP project.

- The PRAHA project, sponsored by UNEP, UNIDO, and HAT countries, began in 2013 and has since been completed. PRAHA built 23 prototypes in the window, split, and AC package categories and tested R-32, R-290, and two HFC/HFO blends against R-22 and one HFC/HFO blend against R-410. The project showed that R-290 had lower efficiency and higher capacity than R-22 and other R-22 alternatives showed lower capacity and lower efficiency than the baseline.
- The EGYPRA project, sponsored by UNEP, UNIDO, and Egypt, began in 2015 and is expected to be completed in 2017. EGYPRA built 36 prototypes in the AC split and one AC package categories and is testing R-32, R-290, and three HFC/HFO blends against R-22 and three HFC/HFO blends against R-410A.
- The ORNL-U.S. DOE Evaluation Program began in 2015 and has since been completed. The project used soft-optimized tests of two base split AC units for R-32, R-290, and four HFC/HFO blends against R-22 and four HFC/HFO blends against R-410A. Throughout the tests R-290 showed better efficiency but lower capacity than the baseline R-22 and other R-22 alternatives showed lower capacity and lower efficiency than the baseline. In addition, R-32 showed better efficiency and capacity than R-410A and other R-410A alternatives showed similar or better efficiency than the baseline, but no trend for the capacity.

- The Low-GWP AREP project, sponsored by AHRI, began in 2014 and has since been completed. The AREP project used soft-optimization and drop-in tests of several AC, heat pump, and refrigeration applications and tested R-1234yf, R-32, D2Y60, L-41a, D-52Y, ARM-71a, DR-5A, HPR-2A, L-41-1, and L-41-2. The project found that R-32 showed better efficiency and capacity than R-410A, but lower results when matching superheat and sub-cooling with R-410A in one AREP-II test. In addition, other R-410A alternatives showed lower capacity than the baseline but equal to or 10 percent better efficiency when matching superheat and sub-cooling.

In conclusion, Mr. Elassaad noted that the test results should be carefully interpreted along with system modifications, test procedure variations, and other considerations. While some of the refrigerants tested show promise in meeting specific, current HVACR equipment requirements for operation under HAT conditions, there is a potential improvement through “soft optimization.” However, full optimization of systems will likely improve the performance of these refrigerants. Mr. Elassaad also noted that losses in cooling capacity are typically easier to recover through engineering optimization than are losses in COP. The COP losses and the increases in compressor discharge temperature are particularly important results, in that these variables will be the primary focus of future optimization efforts.

Research for the Development of Safety Standards

Xudong Wang, AHRI

Mr. Wang focused his presentation on the process and steps to take for the HVACR industry to use low-GWP flammable refrigerants in the field.

Mr. Wang began with a brief overview of the Low-GWP AREP Program. The AREP Program is a cooperative research and testing program to identify suitable alternatives to high-GWP refrigerants. The program is not focused on prioritizing refrigerants, rather testing and presenting objective results in a consistent manner. Phase I of AREP was completed at the end of 2013 and tested 38 refrigerants with 40 test reports. Phase II testing was completed in early 2016 and tested 17 refrigerants with 29 test reports. AREP has found that viable low-GWP refrigerants exist and many promising refrigerants are classified as A2L under ASHRAE Standard 34.

Mr. Wang also provided an overview of the relevant standards and model codes in the United States and internationally. The relevant ASHRAE standards include:

- ASHRAE Standard 15
  - Addendum D proposes to allow group A2L refrigerants in high probability systems for human comfort only. The second public review will be issued soon.
  - Addendum H proposes to allow group A2L refrigerants in applications requiring machinery rooms.
  - Other applications will be addressed in future addenda proposals.
- ASHRAE Standard 15.2 specifically addresses residential applications. The first advisory public review will be issued in early 2017.

Other standards include International Electrotechnical Commission (IEC) 60335-2-40 and Underwriters Laboratories (UL) 60335-2-40. The IEC standard is a product safety standard that includes requirements on how to construct units, including ACs, heat pumps, and dehumidifiers, and requirements regarding charge limits for flammable refrigerants. Working Group 9 of the IEC is in the process of incorporating A2L requirements, which is estimated to be completed in late 2018. Working Group 16 is in the process of incorporating A2[7] and A3 refrigerants, which is estimated to be completed in 2020. At this time, there are no plans to expand the charge limit for these refrigerants beyond 1 kg and additional mitigation measures are being investigated to enable the use of these refrigerants. Working Group 10 for the UL 60335-2-40 standard is in the process of incorporating A2L requirements for all products in the scope of IEC 60335-2-40. UL aims to publish this update in Q4 of 2017.

U.S. model codes include the International Mechanical Code, Uniform Mechanical Code, and International Residential Code. The Mechanical Codes provide safety regulations for the use of HVACR systems and draw many of their regulatory requirements from ASHRAE Standard 15. The Residential Code requires that all equipment be UL listed and equipment used in residences meet requirements developed and codified in UL standards. These codes are updated on a three-year cycle.

Globally, there is a trend towards increasing charge limits for flammable refrigerants. The current status of some relevant standards from a reference was presented.

Lastly, Mr. Wang discussed AHRTI's Flammable Refrigerant Research. AHRTI is conducting research on flammable refrigerants in collaboration with AHRI, ASHRAE, the California Air Resource Board, and U.S. DOE to produce publicly available technical results to support code and standards activities related to the use of flammable refrigerants. The program is administered and coordinated by the AHRTI Flammable Refrigerants Subcommittee which has surveyed relevant codes and standards committees and organizations on the main knowledge gaps for the use of 2L refrigerants; standing issues and gaps that require additional research; and current and past research activities on flammable refrigerants.

Seven high priority projects and one long term project were identified from this process; AHRTI and ASHRAE are each conducting three of the projects and U.S. DOE is funding two. The top priority project is "Benchmarking Risk by Real Life Leaks and Ignitions Testing" (AHRTI Project 9007). The objective of the project is to conduct A2L refrigerant leak and ignition testing under realistic conditions and understand the risk relative to the A1 refrigerants while considering ambient conditions and refrigerant lubricants. Similar tests to A3 refrigerants will be conducted later in 2017. The findings will provide input to the revision of relevant safety standards such as ASHRAE 15 and IEC/UL 60335-2-40s and follow-on revisions to building codes. The findings will also benchmark risk and determine the type of (or need for) hazard mitigation strategies. All high priority projects have been initiated and completion is expected by the end of 2017.

Summary of Discussion/Q&A

One participant asked for the timeline for IEC 60335-2-40.

[7] A2 refers to the safety classification for refrigerants with low toxicity and high flammability as designated in ASHRAE Standard 34.

Mr. Wang estimated that it will likely be published in 2018 and the updates from Working Group 16 will be published at the earliest in 2020. The participant noted that the publishing time will likely be sooner than the estimated according to the recent working groups activities.

One participant encouraged Mr. Elassaad to work further with African nations as these countries need additional guidance regarding the alternatives to current refrigerants.

Mr. Elassaad responded by noting that there are several alternatives available now. He added that the industry may need to see a clear strategy to move forward in Africa. He noted that it will have to be a collaborative work.

One participant asked when U.S. DOE will start to study A3 refrigerants.

One participant in the audience noted that within the next few months U.S. DOE will be studying hydrocarbons. The final report is due by September 30.

One participant asked about what the future holds in regards to an initiative in the HVACR field to follow-on to the success of the current research.

Mr. Eltalouny responded that we can develop the table of alternative refrigerants that had been suggested during the workshop. However, given the different situations faced by individual countries, it will not be a tool for decision making or direction for what to use, but simply a reference tool. He added that there also needs to be a discussion at the next Meeting of the Parties to the Montreal Protocol to discuss how to move from existing equipment to new equipment. While the focus has been on the HCFC business the last 10 years, it may be about time to start the next stage for Article 5 countries.

Concluding Remarks

Mr. Chemouny and Mr. Fay thanked the speakers, moderators, sponsors, and audience for a great workshop. Mr. Chemouny reiterated the agenda for the day, starting with a general overview of the industry and concluding with technology and policy discussions. Mr. Chemouny noted that audience members from developing countries were vocal throughout the discussion with respect to requiring more definite information on alternatives and next steps to implement the HFC phase-down. Speakers and fellow audience members reiterated that each country must consider its unique situation before determining how to proceed in adopting alternative refrigerants. As a next step, there is a need to synthesize key elements of alternative refrigerants and technologies to provide additional and comprehensive guidance to developing countries. Workshops such as these are important to help the industry congregate and share information to ensure we are all aware of latest developments. Mr. Fay concluded by stating that the reason this industry has succeeded in the transition towards climate- and environmentally-friendly technologies and practices since the implementation of the Montreal Protocol is discussions such as these.

Appendix A. Workshop Agenda

SUSTAINABLE TECHNOLOGIES FOR STATIONARY AIR CONDITIONING WORKSHOP
LAS VEGAS CONVENTION CENTER
LAS VEGAS, NEVADA, USA
WEDNESDAY, 1 FEBRUARY 2017

TIME	AGENDA TOPIC	SPEAKER/AFFILIATION
8:00 am	Registration of participants	
Opening Session		
8:30 – 8:40	Welcome and Introduction	Kevin Fay, Alliance for Responsible Atmospheric Policy Philippe Chemouny, Environment and Climate Change Canada
Session I: Overview and General Aspects of Air Conditioning **Format: presentations followed by Q & A**		
8:40 – 9:10	2017 Climate & Refrigerant Outlook	Steve Yurek, AHRI
9:10 – 9:30	Not-in-Kind Alternatives (Evaporative Cooling and Façade Greening)	Marco Schmidt, TU Berlin, Institute of Architecture
9:30 – 9:45	Energy Efficiency in A/C Sector	Walid Chakroun, ASHRAE/Kuwait University
9:45 – 10:00	Energy Efficiency and Its Role in the EU	Andrea Voigt, EPEE
10:00 – 10:15 Tea/Coffee Break		
Session II A: Low-GWP Alternatives for Residential and Light Commercial Applications **Format: 5 panelists with a moderator**		
10:15 – 11:40 (85 mins)	Alternatives for unitary AC including window, portable, central ducted, split, rooftop and packaged terminal air conditioning, to include discussion on topics such as energy efficiency, standards and safety issues, and performance under high ambient temperature conditions.	
	Moderator: Cindy Newberg, U.S. EPA Panelists: • Omar Abdelaziz, ORNL/U.S. DOE • Allen Karpman, Arkema • Jonathan Li, Midea Group • Greg Picker, Refrigerants Australia • Mark Stanga, Daikin	
Session II B: Large Buildings/Commercial Air Conditioning **Format: 6 panelists with a moderator**		
11:40 to 13:05 (85 mins)	Alternatives for large buildings and commercial air conditioning, including chillers, multi-splits and VRF, to include discussion on topics such as energy efficiency, standards and safety issues, and performance under high ambient temperature conditions.	
	Moderator: Dan Hamza-Goodacre, K-CEF / ClimateWorks Foundation Panelists: • Tomaz Cleto, Yawatz Engenharia Ltda • Torben Funder-Kristensen, Danfoss • Lucas Velasquez, Empresas Públicas de Medellín • Carlos L. Nunes Silva, Johnson Controls • Mike Thompson, Ingersoll Rand • Samuel Yana Motta, Honeywell	
13:05 – 14:05 Lunch Break (60 minutes)		

Session III: Air Conditioning in Special Applications Format: presentations followed by Q & A		
	Alternatives for air conditioning in special applications such as data centers and mines to include discussion on topics such as energy efficiency, standards and safety issues, and performance under high ambient temperature conditions.	
14:05 **–** 14:25	Process Applications and Systems Approach to Selecting Refrigerants	Dick Lord, UTC
14:25 **–** 14:45	A Novel Air Conditioning System with Pure Water as the Refrigerant	Juergen Suess, Efficient Energy
14:45 **–** 15:05	CO_2 Air Conditioning in Data Centers	Marc-André Lesmerises, Carnot Refrigeration
15:05 – 15:20 Tea/Coffee Break		
Session IV: Challenges to Adoption of Alternatives Format: 5 presentations followed by panel discussion and Q&A		
	Moderator	Xiaofang Zhou, UNDP
15:20 **–** 15:50	Challenges to Deploying Alternatives in Developing Countries, Including Installation and Maintenance of Appliances with Flammable and/or Toxic Refrigerants	Ayman Eltalouny, UNEP and Ole Nielsen, UNIDO (co-presentation)
15:50 **–** 16:05	Introduction of Alternative Refrigerant in the Thailand AC Sector and the Role of Intellectual Property	Mary-Ellen Foley, World Bank
16:05 **–** 16:20	Challenges under High Ambient Temperatures Conditions	Bassam Elassaad, RTOC member
16:20 **–** 16:35	Research for the Development of Safety Standards	Xudong Wang, AHRI
16:35 **–** 17:00	Discussion/Q & A	All participants
17:00 – 17:15 Closing Remarks		

Appendix B. Workshop Concept Note

Background

Air conditioning (AC) is, along with refrigeration, the largest field of application for hydrofluorocarbons (HFCs). Over the past decades, HFC use has been increasing, in part because HFCs are widely used as replacements for ozone-depleting substances (ODS), which are being phased-out under the Montreal Protocol. The demand for AC and thus for HFCs has also been steadily growing due to rising comfort requirements and changing climate in both developed and developing countries and to increasing private income in developing countries such as China and India. In October 2016, parties to the Montreal Protocol negotiated an amendment to globally phase-down HFCs. Hence, there is a need to introduce environmentally-sound solutions which enable parties to comply with any phase-down obligations agreed to and also allow for meeting the globally increasing AC demand.

In stationary AC, R-410A with a global warming potential (GWP) of 2,088[1] is most widely used especially in split units, replacing hydrochlorofluorocarbon (HCFC) R-22. Over 100 million room air conditioners, such as mini-split, multi-split and single packaged units, have been sold worldwide in 2015. Chillers which are applied for higher cooling demands mainly use R-410A and R-134a (GWP=1430). Whereas several chiller products using both non-fluorinated “natural” and fluorinated refrigerants with negligible GWP are available, split units are offered with only a few alternative substances. Across the stationary AC subsector, many alternative substances are flammable, so safety issues play a significant role in their application.

Energy efficiency performance of AC systems is a key issue due to the fact that the major share of greenhouse gas emissions caused by such systems is energy-consumption related. Therefore, it is critical to consider improving energy efficiency of AC systems when transitioning from HFCs to lower-GWP alternatives.

Purpose

The *Sustainable Technologies for Stationary Workshop* builds on a series of workshops addressing different fields of HFC applications. Held on the margins of the International Air-Conditioning, Heating, Refrigerating Exposition (AHR Expo) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Winter Meeting, the workshop aims to familiarize participants with climate-friendly and cost-effective AC technologies which have proven their applicability and show that phasing down high-GWP HFCs is manageable. All relevant application fields will be addressed by international experts from developed and developing countries in panel discussions including safety, high ambient temperature (HAT) operation performance, intellectual property rights (IPR), energy efficiency and technology transfer issues. In addition, issues related to policies and standards associated with introducing and using these refrigerants and technologies in both developing and developed countries will be discussed.

Participants

The workshop will give insights into the latest developments of AC technology and appliances operating with low-GWP refrigerants and corresponding issues as described in the paragraph above. Target audience members include AHR Expo visitors, interested National Ozone and Climate Protection Officers and other government representatives, as well as representatives from international organizations, industry, and environmental organizations.