TRANSITIONING TO LOW-GWP ALTERNATIVES in Residential and Commercial Air Conditioning and Chillers

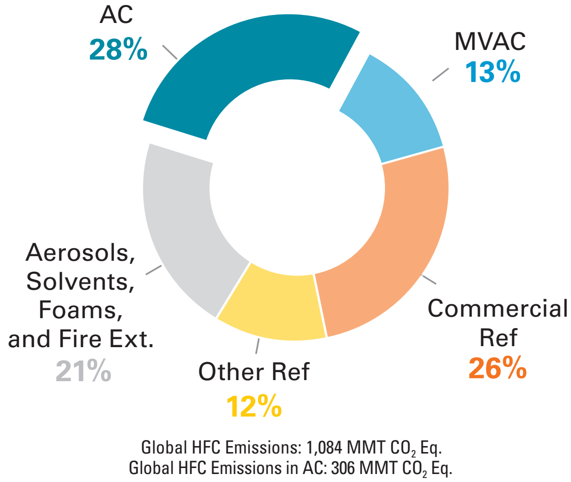
Background

This fact sheet provides current information on low global warming potential (GWP)[1] alternative refrigerants to high-GWP hydrofluorocarbons (HFCs) for use in residential and commercial air conditioning (AC) equipment, including chillers. HFCs are powerful greenhouse gases (GHGs) with GWPs hundreds to thousands of times more potent per pound than carbon dioxide (CO_2); however, more low-GWP alternatives are becoming available.

Globally, approximately 80% of HFCs are emitted in the refrigeration, AC, and motor vehicle AC (MVAC) sectors, with the remainder accounted for by the foam-blowing, aerosols, fire suppression, and solvents sectors. While developed nations have historically accounted for the majority of global HFC emissions, total HFC emissions in developing nations are projected to quadruple by 2030. This rapidly increasing rate of HFC emissions is largely driven by the increased demand for refrigeration and AC, particularly in the tropical climates of much of the developing world, and the transition away from ozone depleting substances (ODS).

HFC refrigerant emissions from AC applications are released to the atmosphere throughout the lifecycle of equipment—i.e., during equipment manufacture, installation, operation, maintenance, and at end-of-life.

Figure 1. Global HFC Emissions in 2020 by Sector



Source: Estimates based on U.S. EPA (2013).

AC Equipment

Residential and commercial AC equipment used in households and commercial buildings contain one or more factory-made assemblies that normally include an evaporator or cooling coil(s), compressor(s), and condenser(s). These include small AC systems (self-contained AC and split AC), large AC systems (single split and multi-split, variable refrigerant flow, and ducted and packaged rooftop units), as well as chillers. Descriptions of each of these AC equipment categories are provided below, followed by Table 1, which lists the typical capacity, refrigerant charge, and annual operational leak rate for each equipment type.

[1] GWP is a measure of a substance's climate warming impact compared to CO_2.

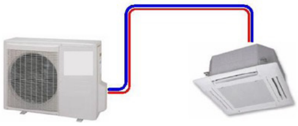
Small AC Systems

Small Self-Contained AC

Source: U.S. EPA (2015d)

- Small hermetically sealed AC units are used for cooling small rooms in residential and commercial buildings
- The compressor, evaporator, and condenser are all housed within a single unit
- Includes portable units, window-mounted units, through-the-wall units, and packaged terminal air conditioning (PTAC) units
- Portable units utilize flexible ductwork to supply outside air to the condenser and return heated air to outside of the room
- PTAC units are often used in the hospitality industry (e.g., inside hotel rooms)
- Packaged terminal heat pumps (PTHPs) are similar to PTACs and also provide heating

Small Split AC

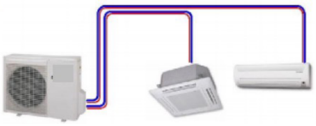


Source: UNEP (2015c)

- Small split AC units are used for cooling single rooms in residential and commercial buildings
- Systems contain two factory-built units interconnected by a refrigerant line; the indoor unit includes the evaporator, installed inside conditioned room on the wall, ceiling, or floor; the outdoor unit includes a compressor and a condenser
- Some systems can operate in reverse and provide heating in cold weather

Large AC Systems

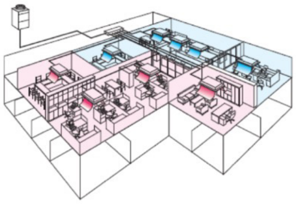
Large Single Split and Multi-Split AC



Source: UNEP (2015d)

- Larger versions of the small split system described above
- Multi-split systems have several indoor units connected to a single outdoor unit
- Some models are designed to provide both heating and cooling

Variable Refrigerant Flow (VRF) Systems



Source: Pacific Northwest National Laboratory (2012)

- More complex multi-split systems
- One or more air source outdoor compressor units serving multiple indoor fan coil refrigerant evaporator units
- Heated or cooled refrigerant moves throughout building in small diameter pipes and passes through coils in each conditioned room
- Systems can deliver heating and/or cooling to different rooms of the same building simultaneously through various units

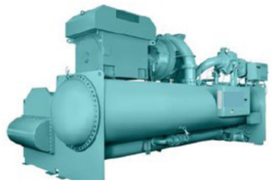
Ducted and Packaged Rooftop Systems

Source: U.S. EPA (2015d)

- In ducted systems, the evaporator is located in an air handling unit to cool air
- In packaged rooftop systems, the compressor, evaporator, and condenser are all housed within a single unit
- Air is circulated throughout the building via a ducted air ventilation system

Chillers

Comfort Cooling



Source: UNEP (2015e)

- Large buildings are often cooled by a central chiller that pumps chilled water to heat exchangers in air handling or fan-coil units that deliver conditioned air
- Often located in a machinery room (large buildings) or outdoors (small buildings)
- Small and medium-sized chillers typically use a vapor compression cycle with positive displacement compressors (i.e., reciprocating, rotary, scroll, or screw), while large chillers typically use screw or centrifugal compressors

District Cooling

Source: AEC Online (2007)

- Uses a centralized cooling plant to deliver chilled water via underground insulated pipes to several buildings using a single system
- Provides AC to multiple buildings in a central location (e.g., hospitals, universities, shopping malls, airports)
- Chillers using vapor compression technology and centrifugal compressors often used in cooling plant
- Increasing in popularity; commonly used in the Middle East; some installations in China, the United States, Northern Europe, and coastal sites such as Hawaii, Malaysia, and Mauritius, with sufficient deep water resources

Table 1. Typical AC Equipment Characteristics

Equipment Type	Capacity (kW)	Refrigerant Charge (kg)	Annual Operational Leak Rate[a] (%)
Small Self-Contained AC	2–7	0.2–2	<1
Small Split AC	2–12	0.5–3	1–4
Single Split and Multi-Split (Large)	10–40	3–10	1–4
VRF Systems (Large)	12–150	5–100	1–5
Ducted Systems (Large)	12–750	5–200	2–6
Small/Medium Chillers[b]	50–750	40–500	2–4
Large Chillers[c]	750–21,000	500–36,000	2–4

Sources: UNEP (2015a – e) and Johnson Controls (2014).

[a] Typical annual operational leak rate does not include additional refrigerant leaks that can occur during equipment installation, maintenance, servicing, and disposal.

[b] Typically use positive displacement compressors (i.e., reciprocating, rotary, scroll, or screw).

[c] Typically use screw or centrifugal compressors.

HFC Alternatives and Market Trends

Many residential and commercial AC systems in use contain ozone-depleting refrigerants CFC-11, CFC-12, and HCFC-22, which are being phased out globally under the *Montreal Protocol*. Many new units sold today contain HFCs, or HFC blends, namely R-410A and R-407C, with GWP values of 2,088 and 1,774, respectively. A number of lower-GWP alternative refrigerants are available and currently in use or under development for use in residential and commercial AC systems—including hydrocarbons, carbon dioxide, ammonia, water, as well as HFC and HFO[2] blends. These alternatives and their potential applications are described on the next page and summarized in Table 2.

[2] HFOs (hydrofluoroolefins) are unsaturated HFCs (i.e., containing a carbon-carbon double bond).

R-290 (Propane) and Hydrocarbon Blends (e.g., R-441A)

- Successfully used in some regions including China and India in small AC units that utilize less than 1 kilogram of refrigerant
- Used in small self-contained AC and small split AC in Europe, Far East, Japan, and India
- Used in small capacities and outdoor applications in air-cooled chillers in Indonesia, Malaysia, the Philippines, Europe, and New Zealand
- R-290 and R-441A are listed acceptable substitutes (subject to use conditions) in room AC units by the U.S. EPA Significant New Alternatives Policy (SNAP) program
- Efficiency and performance expected to be equal to or better than R-410A, particularly in regions with warmer climates
- Safety concerns for flammable refrigerants require technician training and can increase installation costs

Carbon Dioxide (CO_2, R-744)

- Can be used in large AC equipment, typically in ducted systems
- Air-cooled chillers using R-744 have been introduced in northern Europe

Ammonia (R-717)

- Suitable in chillers for numerous building AC applications and district cooling
- Used in medium and large chillers with screw or reciprocating compressors
- Central comfort cooling chiller plant installations exist in the Middle East, China, Europe, and the United States
- Ammonia is listed as an acceptable substitute by the U.S. EPA SNAP program in vapor compression chillers (with a secondary loop)
- Ammonia is also used in absorption systems, which are listed as acceptable by the U.S. EPA SNAP program for chillers and in residential and light commercial AC equipment
- Safety concerns in comfort cooling applications can increase installation costs and require technician training; restrictions often apply in some countries due to certain building codes or regulations

Water (R-718)

- Developmental chillers demonstrated in the Middle East, South Africa, and Europe
- Requires large space and use of complex compressor technology

HFC-32

- Small self-contained and split AC systems produced with HFC-32 are commercially available in 30 countries, including Japan, India, Indonesia, Australia, and soon in China and the United States
- HFC-32 is listed as an acceptable substitute (subject to use conditions) in room AC units by the U.S. EPA SNAP program
- Efficiency and performance expected to be equal to or better than R-410A

Low-GWP Fluorinated Compounds

- HFO-1234yf and HFO-1234ze(E) have similar properties to HFC-134a and are under development for ducted and rooftop unit systems
- Use of HFO-1234ze(E) is currently under development in large centrifugal chillers and large AC equipment and commercially available in small and medium-sized positive displacement chillers
- Chillers using HFO-1234ze(E) are available in the European market
- HFO-1234ze(E) is listed as an acceptable substitute in centrifugal, reciprocating, and screw chillers by the U.S. EPA SNAP program
- Solstice™ 1233zd(E) is currently used in centrifugal chillers in Europe, the Middle East, and Japan
- Solstice™ 1233zd(E) is listed as an acceptable substitute in centrifugal chillers by the U.S. EPA SNAP program
- HFO-1336mzz(Z) is under development for use in low pressure centrifugal chillers
- HFO-1336mzz(Z) is listed as an acceptable substitute in centrifugal and positive displacement chillers by the U.S. EPA SNAP program

HFC/HFO Blends

- Various blends of HFCs and HFOs (i.e., unsaturated HFCs) are being developed for all types of AC equipment
- R-450A and R-513A are listed as acceptable substitutes in centrifugal, reciprocating, and screw chillers by the U.S. EPA SNAP program
- Testing and trials using blends of R-444B, R-446A, and R-447A, in both small and large AC systems, are ongoing, with manufacturers in Japan, Korea, China, and New Zealand developing prototypes
- Safety regulations may be required for lower flammability blends (e.g., R-444B, R-446A and R-447A), especially in larger AC equipment

Table 2. Lower-GWP Alternatives for Residential and Commercial AC[a]

Refrigerant	GWP[b]	Small Self-Contained AC[c]	Small Split AC[c]	Single & Multi- Split AC (Large)[c]	VRF (Large)[c]	Ducted Systems (Large)[c]	Chillers[c]
HFC-32	675	◆+	◆	◆	◆	◆	☐
R-513A	630						◆+
R-450A	601						◆+
HFO-1336mzz(Z)	9						☐+
HFO-1234ze(E)	6					☐	◆+
R-441A	<5	◆+					
Solstice™ 1233zd(E)	4.7 - 7						◆+ [d]
HFO-1234yf	4					☐	
R-290	3	◆+	◆				◆
R-744 (CO_2)	1					◆	◆
R-717 (ammonia)	0						◆+

Note: R-444B, R-446A, R-447A, and R-718 are currently under development for use in various residential and commercial AC applications.

[a] ◆ = Available now; ☐ = Under Development; + = U.S. EPA SNAP-approved

[b] GWP values are from IPCC Fourth Assessment Report (2007) and U.S. EPA (2015c).

[c] UNEP (2015a – e).

[d] U.S. EPA SNAP-approved for centrifugal chillers only.

Reducing Emissions from Servicing and Disposal

Refrigerant emissions from AC equipment occur during various events, including manufacture, operation (i.e., leaks from fittings, joints, shaft seals, etc.), servicing (i.e., due to loss of refrigerant from fugitive emissions), and end-of-life (i.e., equipment disposal). When leaks are fixed during servicing, refrigerant recovery is necessary for certain applications.

During servicing events and end-of-life, the refrigerant losses depend on various factors including the existence of or compliance with refrigerant recovery laws, the technical efficiency of refrigerant recovery equipment, and the technical performance of technicians. Improvements in the technologies and practices associated with the use of these gases by manufacturers and technicians, the introduction of alternative gases and technologies, implementation of refrigerant recovery laws and standards, and market/policy drivers that provide financial incentives for recovery may help to offset most HFC refrigerant emissions from residential and commercial AC equipment.

Case Study: Hydrocarbon Refrigerants in China

With support from the United Nations Industrial Development Organization (UNIDO) and approval for funding by the Executive Committee of the Multilateral Fund for the Implementation of the Montreal Protocol in July 2010, two manufacturers in China—Guangdong Meizhi Co. Ltd and Guangdong Midea Refrigeration Equipment Co. Ltd—conducted a demonstration project to convert R-22 compressors and split AC units to R-290. The Meizhi production line, which has an annual production capacity of 1.83 million rotary compressors for split AC systems, was converted to produce R-290 compressors. The Midea production line was converted to an advanced mechanized line producing 200,000 R-290 split units annually. After 30 months of factory conversion the project was completed by the end of 2013 and two types of compressors (fixed and variable speed) and two types of AC units (split and portable) became available for mass production by these manufacturers. The R-290 AC units also meet both national and international performance standard requirements.

In converting the plants, engineering controls and safety measures were implemented into the production lines to address the flammability of R-290, including modified products, tools, parts, equipment, installation procedures, leak detection and containment, staff training, and technology dissemination. The success of this project and advancement of hydrocarbon-based AC technologies has already influenced other Chinese manufacturers to invest in conversion activities. For example, in 2015, nine AC manufacturers in China were designated by the Chinese Ministry of Environmental Protection to receive subsidies to convert to R-290. These advancements are expected to encourage other manufacturers in other developing countries to invest in alternative AC technologies.

Future Outlook

Together, the suite of known alternative chemicals, new technologies, as well as better process and handling practices, can significantly reduce HFC use in both the near and long term. Many countries are transitioning to lower-GWP alternatives in AC applications while satisfying the various international energy efficiency, safety, and environmental standards. The equipment manufacturers and chemical producers for the AC industry are continuing to work on developing new alternatives that can be marketed worldwide. Although much work remains to fully develop and adopt some of these low-GWP alternatives, and some unknowns still remain, the affected industries have proven through the ODS phaseout that they can move quickly to develop low-GWP alternatives that protect the environment.

References

AEC Online. 2007. "Empower and Logstor to build the UAE's largest pre-insulated pipe manufacturing facility." Available online at: http://www.aeconline.ae/13/pdcnewsitem/00/98/45/index_13.html

European Parliament and the Council of the European Union (EU). 2014. "Regulation (EU) No 517/2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006." Official Journal of the European Union. 16 April 2014. Available online at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0517&from=EN

Intergovernmental Panel on Climate Change (IPCC). 2006. "2006 IPCC Guidelines for National Greenhouse Gas Inventories." The National Greenhouse Gas Inventories Programme, The Intergovernmental Panel on Climate Change, H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Hayama, Kanagawa, Japan.

Intergovernmental Panel on Climate Change (IPCC). 2007. "Climate Change 2007: The Physical Science Basis." Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (Eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. September 2007. Available online at: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html

Johnson Controls. 2015. "Model YD Dual Centrifugal Compressor Chillers." Available online at: http://cgproducts.johnsoncontrols.com/YorkDoc/160.69-EG3.pdf

McNeil, M.A. and V.E. Letschert. 2007. "Future air conditioning energy consumption in developing countries and what can be done about it: the potential of efficiency in the residential sector." ECEEE 2007 Summer Study. Available online at: http://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2007/Panel_6/6.306/paper

Pacific Northwest National Laboratory. 2012. "Variable Refrigerant Flow Systems." Prepared for the General Services Administration by Pacific Northwest National Laboratory. December 2012. Available online at: http://www.gsa.gov/portal/mediaId/169771/fileName/GPG_VRF_Report_-_FINAL_DRAFT_4-16-13

Shecco. 2016. Manufacturers see openings for natural refrigerants in China. Hydrocarbons 21 Industry News. 14 April 2016. Available online at: http://www.hydrocarbons21.com/news/view/6948.

Schwarz, W., B. Gschrey, A. Leisewitz, A. Herold, S. Gores, I. Papst, J. Usinger, D. Oppelt, I. Croiset, P.H. Pedersen, D. Colbourne, M. Kauffeld, K. Kaar, and A. Lindborg. 2011. "Preparatory study for a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases." Prepared for the European Commission. September 2011.

Technology and Economic Assessment Panel (TEAP). 2013. "Decision XXIV/7 Task Force Report: Additional Information to Alternatives on ODS." September 2013. Available online at: http://ozone.unep.org/Assessment_Panels/TEAP/Reports/TEAP_Reports/TEAP_TaskForce%20XXIV-7-September2013.pdf

Technology and Economic Assessment Panel (TEAP). 2014. "Decision XXV/5 Task Force Report: Additional Information to Alternatives on ODS (Final Report)." October 2014. Available online at: http://ozone.unep.org/en/Assessment_Panels/TEAP/Reports/TEAP_Reports/TEAP_Task%20Force%20XXV5-October2014.pdf

Technology and Economic Assessment Panel (TEAP). 2015. "Decision XXVI/9 Task Force Report: Additional Information to Alternatives to ODS." June 2015. Available online at: http://conf.montreal-protocol.org/meeting/oewg/oewg-36/presession/Background%20Documents%20are%20available%20in%20English%20only/TEAP_Task-Force-XXVI-9_Report-June-2015.pdf

United Nations Environment Programme (UNEP). 2011. "2010 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee." February 2011. Available online at: http://ozone.unep.org/Assessment_Panels/TEAP/Reports/RTOC/RTOC-Assessment-report-2010.pdf

United Nations Environment Programme (UNEP). 2014. Addendum: Status Reports and Compliance. Executive Committee of the Multilateral Fund for the Implementation of the Montreal Protocol, Seventy-third Meeting Paris, 9-13 November 2014. UNEP/OzL.Pro/ExCom/73/17/Add.1. Available online at: http://www.multilateralfund.org/73/English/1/7317a1.pdf.

United Nations Environment Programme (UNEP). 2015a. "2014 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee." February 2015. Available online at: http://conf.montreal-protocol.org/meeting/mop/mop-27/presession/Background%20Documents%20are%20available%20in%20English%20only/RTOC-Assessment-Report-2014.pdf

United Nations Environment Programme (UNEP). 2015b. "Fact Sheet 7: Small Self-Contained Air-Conditioning." UNEP Ozone Secretariat Workshop on HFC management: technical issues. Bangkok, 20 and 21 April 2015. Available online at: http://conf.montreal-protocol.org/meeting/workshops/hfc_management-02/presession/English/FS%207%20Small%20self%20contained%20air-conditioning%20final.pdf

United Nations Environment Programme (UNEP). 2015c. "Fact Sheet 8: Small Split Air-Conditioning." UNEP Ozone Secretariat Workshop on HFC management: technical issues. Bangkok, 20 and 21 April 2015. Available online at: http://ozone.unep.org/sites/ozone/files/Meeting_Documents/HFCs/FS_8_Small_split_air-conditioning_Oct_2015.pdf

United Nations Environment Programme (UNEP). 2015d. "Fact Sheet 9: Large Air-Conditioning (air-to-air)." UNEP Ozone Secretariat Workshop on HFC management: technical issues. Bangkok, 20 and 21 April 2015. Available online at: http://ozone.unep.org/sites/ozone/files/Meeting_Documents/HFCs/FS_9_Large_air_to_air_air-conditioning_Oct_2015.pdf

United Nations Environment Programme (UNEP). 2015e. "Fact Sheet 10: Water chillers for air-conditioning." UNEP Ozone Secretariat Workshop on HFC management: technical issues. Bangkok, 20 and 21 April 2015. Available online at: http://ozone.unep.org/sites/ozone/files/Meeting_Documents/HFCs/FS_10_Water_chillers_for_air-conditioning_Oct_2015.pdf

United Nations Industrial Development Organization (UNIDO). Demonstrating the Feasibility of R-290 Based AC Manufacturing: China's Midea and Meizhi Case. OzonAction Fact Sheet. Available online at: http://www.unep.org/ozonaction/Portals/105/documents/events/MOP26/Fact%20Sheet%20UNIDO%20Meizhi%20Nov%2013.pdf.

United States Environmental Protection Agency (U.S. EPA). 2010a. "Federal Register Vol. 75, No. 115." Available online at: https://www.gpo.gov/fdsys/pkg/FR-2010-06-16/pdf/2010-14510.pdf

United States Environmental Protection Agency (U.S. EPA). 2010b. "Summary of Substitute Refrigerants Listed in SNAP Notice 25." Available online at: http://www2.epa.gov/sites/production/files/2014-11/documents/notice25substituterefrigerants.pdf

United States Environmental Protection Agency (U.S. EPA). 2011. "Federal Register Vol. 76, No. 60." Available online at: http://www.gpo.gov/fdsys/pkg/FR-2011-03-29/pdf/2011-6268.pdf

United States Environmental Protection Agency (U.S. EPA). 2012. "Federal Register Vol. 77, No. 155." Available online at: http://www.gpo.gov/fdsys/pkg/FR-2012-08-10/pdf/2012-19688.pdf

United States Environmental Protection Agency (U.S. EPA). 2013. "Global Mitigation of Non-CO_2 Greenhouse Gases: 2010-2030." EPA Report 430-R-13-011. September 2013. Available online at: https://www3.epa.gov/climatechange/Downloads/EPAactivities/MAC_Report_2013.pdf

United States Environmental Protection Agency (U.S. EPA). 2014. "Federal Register Vol. 79, No. 203." Available online at: http://www.gpo.gov/fdsys/pkg/FR-2014-10-21/pdf/2014-24989.pdf

United States Environmental Protection Agency (U.S. EPA). 2015a. "Federal Register Vol. 80, No. 136." Available online at: http://www.gpo.gov/fdsys/pkg/FR-2015-07-16/pdf/2015-17469.pdf

United States Environmental Protection Agency (U.S. EPA). 2015b. "Federal Register Vol. 80 No. 69." Available online at: http://www.gpo.gov/fdsys/pkg/FR-2015-04-10/pdf/2015-07895.pdf

United States Environmental Protection Agency (U.S. EPA). 2015c. "Substitutes by Sector." Significant New Alternatives Policy (SNAP) Program. Available online at: http://www.epa.gov/snap/substitutes-sector

United States Environmental Protection Agency (U.S. EPA). 2015d. "Transitioning to Low-GWP Alternatives in Residential & Light Commercial Air Conditioning." Available online at: http://www.epa.gov/sites/production/files/2015-09/documents/epa_hfc_residential_light_commercial_ac.pdf

Velders, G.J.M., D.W. Fahey, J.S. Daniel, S.O. Andersen, and M. McFarland. 2015. Future atmospheric abundances and climate forcings from scenarios of global and regional hydrofluorocarbon (HFC) emissions. Atmospheric Environment. Volume 123, Part A. December 2015. Available online at: http://dx.doi.org/10.1016/j.atmosenv.2015.10.071.

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EPA-430-F-15-028 • www.epa.gov • December 2016