Mobile Air Conditioning and Room Air Conditioning Strategy to Reduce Climate Forcing from Hydrofluorocarbons

Strategy Paper on HFC Emission Reduction Options
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Contents

List of Tables

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Mobile Air Conditioning and Room Air Conditioning Strategy to Reduce Climate Forcing from Hydrofluorocarbons

I Introduction

The mobile air conditioning (MAC) and room air conditioning (RAC) sectors both present opportunities for fast action to reduce hydrofluorocarbon (HFC) emissions and hence limit climate forcing. They offer big and fast climate mitigation that can be achieved through voluntary partnerships, domestic regulations, or consumer demands that can start to be accomplished even before inevitable controls under international agreements such as the Vienna Convention and its Montreal Protocol and/or United Nations Framework Convention on Climate Change (UN FCCC) and its Kyoto Protocol.

In the MAC sector, regions in Europe already require a shift to air conditioning refrigerants with global warming potential (GWP) of less than 150 by 2017.[1] In the U.S., manufacturers of cars and light trucks can earn credits towards their compliance with corporate average fuel economy (CAFE) standards by switching to low-GWP refrigerants in MAC systems for model year 2012-2016 vehicles.[2] California's legislation requires a self-sealing valve on all containers of refrigerant for servicing, improved labeling instructions, a recycling program for used containers, and an education program that emphasizes best practices for vehicle recharging.

In the RAC sector, the European Union (EU) is currently strengthening its f-gas regulations for stationary sources, with a particular focus on HFCs. The final f-gas directive, which includes an aggressive phase-down of HFCs, is expected to be finalized in March of 2014. The United States Environmental Protection Agency (US EPA) is using existing Clean Air Act authority under the *Significant New Alternatives Policy (SNAP) Program* to approve climate-friendly chemicals and remove some uses of high-GWP HFCs from its list of acceptable substances.[3]In the Netherlands, maximum sulfur hexafluoride (SF_6) emission thresholds were established in the permits for the aluminum industry, perfluorocarbons (PFCs) in the semiconductor industry and HFC-23 as an unwanted byproduct in the production of hydrochlorofluorocarbon-22 (HCFC-22) manufacturing facilities.[4] In the United Kingdom (UK), Gregory Barker, Minister for Climate Change, announced on 5 June 2013 that he was forming a task force on HFCs within the retail sector.[5] In Switzerland, a strengthened national f-gas regulation will ban HFCs in several air conditioning and refrigeration applications.[6] In addition to the levies and other restrictions on HFCs in Australia and New Zealand, Japan recently revised its national law to phase down HFCs, promote low-GWP equipment and products, improve containment in commercial equipment, and require registration and approval of fillers and recyclers.[7]

There are a relatively small number of producers of HFC refrigerant and product manufacturers in the MAC and RAC sectors and they have a strong market incentive to agree on a small number of low-GWP replacements for the current high-GWP refrigerants and to derive energy advantages. Alternative refrigerants should be selected on the basis of near-zero ODP, low relative GWP, and—most importantly—superior Life-Cycle Climate Performance (LCCP)[8] tailored to the climate, seasonal operating cycle, and comfort preferences of the equipment owners. The LCCP for flammable and toxic refrigerants should be calculated for equipment with all necessary safety systems installed and operated, and at the refrigerant charge size that satisfies appropriate safety standards.

TABLE 1: Alternative Refrigerants By Sector (IPCC 5th Assessment GWPs)

	Refrigerant Prior to the Montreal Protocol Phase-out	First Generation Ozone Protection Refrigerant	Next Generation Ozone & Climate Protection Refrigerant
MAC	CFC-12 (ODP=1; GWP=10,200)	HFC-134a (ODP=0; GWP=1300)	HFO-1234yf(ODP=0; GWP<1) HFC-152a (ODP=0; GWP=138) applied in a secondary-Loop system for safety and energy efficiency CO_2 if safety, reliability and price can be satisfied.
Small RAC	HCFC-22 (ODP=0.05; GWP= 1760)	HFC-410a (ODP=0; GWP=1923)	HC-290 (ODP=0; GWP<5) HFC-32 (ODP=0; GWP=677
Large RAC	HCFC-22 (ODP=0.05; GWP= 1760)	HFC-410a (ODP=0; GWP=1923)	HFC-32 (ODP=0; GWP=677 HFC-32/HFO blends (ODP=0; GWP 300-1000)

II THE IMPORTANCE OF INDUSTRY-GOVERNMENT PARTNERSHIPS

Encouraging partnerships between government and industry is a fundamental strategy for reducing climate emissions in the MAC and RAC sectors. One of the reasons the ODS phase-out was fast and affordable is that industry-government partnerships were organized to develop, demonstrate, and perfect technology and then to transfer that technology and technical know-how worldwide. Partnerships play an important role in developing and testing alternatives, demonstrating technical and environmental performance, removing market barriers, developing standards and implementing alternatives. Table 2 summarizes some of the partnerships that have played an important role in the development and commercialization of environment-friendly alternative refrigerants and technologies.

Table 2: Industry & Government Partnerships to Phase-out Ozone-Depleting Substances

Partnership Acronym	Partnership Name	Participants	Technology Output
AFEAS	Alternative Fluorocarbon Environmental Acceptability Study	Global chemical companies	Studies of the atmospheric and terrestrial fate of alternatives to ODS
HARC	Halon Alternatives Research Corporation	U.S. EPA and Department of Defense; halon and alternatives manufacturers, petroleum and aerospace industries; research and academic institutes	Basic research, bench, and full-scale fire testing, toxicity studies, demonstration projects
ICOLP	Industry Cooperative for Ozone Layer Protection (later renamed the Industry Cooperative for Environmental Leadership)	U.S. EPA and Air Force; electronics and aerospace manufacturers	Alternatives development, demonstration, transfer, and donation to the public domain
JICOP	Japan Industrial Conference for Ozone Layer and Climate Protection	Japan Ministry of Economy Trade and Industry (METI) and EA; ODS and alternative manufacturers; electronics, automobile, refrigeration, air conditioning, foam insulation, aerosol products and metal products manufacturers; agriculture and fire protection	Technology cooperation, alternative testing and demonstration, conferences, andphase-out projects in more than a dozen Article 5 Parties
PAFT	Program for Alternative Fluorocarbon Toxicity Testing	ODS and alternative manufacturers	Cooperative toxicity testing of eight transition and zero ODP alternatives to ODSs: (HCFC-123, HCFC-124, HCFC-225ca/cb, HCFC-141b, HFC-32, HFC-125, and HFC-134a)

MOBILE AIR CONDITIONING CLIMATE PROTECTION PARTNERSHIP (MACCCP)

The MACCP was a public-private partnership organized by the U.S. EPA that co-chaired from 1998-2010. While in operation, the partnership promoted vehicle air conditioning solutions that improved fuel efficiency and reduced the climate impacts of refrigerants. Many of these solutions, such as improved refrigerant recovery and recycling of equipment, leak-tight system design, and low-GWP refrigerants, are currently being implemented through regulatory and voluntary industry action. Members of the MACCP developed and tested CO_2, HFC-152a and hydrofluoroolefin (HFO)-1234yf as alternatives to HFC-134a. This included development of the GREEN MAC LCCP® model to calculate the lifecycle climate performance of mobile air conditioners with different refrigerants. In 2008, MACCP selected HFO-1234yf as the next-generation refrigerant to replace HFC-134a in automobile air conditioning because it had the smallest carbon footprint in all but mild climates where air conditioning is rarely needed(See case study below).

RESPONSIBLE USE OF HFCS PARTNERSHIP

In 2002, the USEPA, the United Nations Environment Programme (UNEP), and the Alliance for Responsible Atmospheric Policy (ARAP)established a partnership based on "Responsible Use Principles for HFCs." The partnership supports the use of HFCs for applications where they provide health and safety, environmental, technical, economic, or unique societal benefits. It also urges minimizing HFC emissions to the lowest practical level during chemical manufacture and during use and disposal of equipment, minimizing emissions, maximizing energy efficiency, and recovery, recycling, reclamation, and/or destruction of used HFCs where technically and economically feasible.

INDONESIA-JAPAN HFC-32 PARTNERSHIP

The Indonesia-Japan HFC-32 Partnership, established in 2011, is an example of partnership between developed and developing countries and industry to encourage the use of environmentally superior R-32-based RAC technology. This is significant because Indonesia and other developing countries will be first to use the technology, which will be later transferred "South-North," to developed countries (See case study below).

BUSINESS CASE FOR PHASING DOWN HFCS IN ROOM AND VEHICLE AIR CONDITIONERS IN INDIA

The business case is an investigative partnership in India organized by the Council on Energy, Environment & Water (CEEW), the Institute for Governance & Sustainable Development (IGSD), the Natural Resources Defense Council (NRDC), and The Energy and Resources Institute (TERI), in cooperation with the Confederation of Indian Industry (CII), the Refrigeration and Air-Conditioning Manufacturer's Association (RAMA), and the Society of Indian Automobile Manufacturers (SIAM). In 2013, this partnership published the "Business Case for Phasing Down HFCs in Room and Vehicle Air Conditioners."[9]Partner organizations continue to collaborate on making the business case for Indian air conditioning companies to phase down unsustainable technologies based on chemicals with high-GWP HFCs and move to a future based on climate-friendly refrigerants and energy-efficient equipment designs.

PARTNERSHIP FOR PROMOTING LOW-GWP REFRIGERANTS FOR THE A/C SECTORS IN HIGH-AMBIENT TEMPERATURE COUNTRIES (PRAHA)

PRAHA is a new partnership established in 2013 between UNEP, United Nations Industrial Development Organization (UNIDO) and about one half dozen Asian and Middle Eastern countries with high ambient temperatures. It aims to assess available technologies for high-ambient countries, study the availability of current and long-term commercially available refrigerants, assess relevant energy efficiency standards and codes, conduct economic comparison of alternative technologies, identify technology and regulatory gaps, and promote technology transfer.

REFRIGERANTS NATURALLY!

Refrigerants Naturally! is a not-for-profit partnership of four private companies (Coca-Cola, PepsiCo, Red Bull and Unilever)supported by UNEP and Greenpeace, which have committed to phasing out HFCs in point of sale food display and dispensing equipment using HC and CO_2 refrigerants. Refrigerants Naturally! is recognized by the UN Commission on Sustainable Development as a voluntary, multi-stakeholder a "Partnership for Sustainable Development" that contributes to the implementation of Agenda 21, Rio+5 and the Johannesburg Plan of Implementation.

CONSUMER GOODS FORUM AND OTHER RETAIL PARTNERSHIPS

The Consumer Goods Forum (CGF)—a global network of retailers, manufacturers, service providers, and other stakeholders—has partnered with non-governmental organizations (NGOs), such as the Environmental Investigation Agency (EIA); have partnered with retailers to reduce high-GWP HFCs. The CGF strategy agreed in 2010 is to "begin phasing-out HFC refrigerants as of 2015 in new equipment and replace them with non-HFC refrigerants (primarily natural refrigerant alternatives) where these are legally allowed and available for new purchases at point-of-sale units and large refrigeration installations."

Case Study: Mobile Air Conditioning Climate Protection Partnership

In 1998, the SAE International, the Mobile Air Conditioning Society Worldwide, and the U.S. Environmental Protection Agency formed a global voluntary partnership to reduce the climate impacts of mobile air conditioning. Since then, membership has grown to include representatives from Australia, Canada, Europe, and Japan, environmental and industry non-governmental organizations, and a global list of vehicle manufacturers and their suppliers. The partnership has four goals:

- To promote next-generation mobile air conditioning systems that are better for the environment while satisfying customer safety, cost, and reliability concerns.
- To develop cost-effective designs and improved service procedures to minimize refrigerant emissions;
- To communicate technical progress to policymakers and the public; and
- To document current and near-term opportunities to improve the environmental performance of mobile air conditioning system design, operation, and maintenance.

In 2007, MACCPP announced validation of new technology and service best practices that could:

- ✓ Reduce the energy used by the vehicle air conditioner by over thirty percent using commercially available technology,
- ✓ Reduce refrigerant leakage by half by using better parts,
- ✓ Reduce the temperature of the passenger cabin by over 10º F (6º C) by using solar-reflective paints and ventilation, and
- ✓ Cut refrigerant emissions tohalf using better components, quality control and professional service using best practices and new refrigerant recovery, recycling, and leak-detection technology.

Website: http://www.epa.gov/cpd/mac/

Case Study: Indonesia-Japan Partnership
For Ozone and Climate-Friendly Room Air Conditioners (RAC)

The Indonesia-Japan Partnership agreed to introduce high-efficiency HFC-32 air conditioners in the Indonesian market that are safe for the ozone layer and estimated to reduce life-cycle greenhouse gas emissions by more than fifty percent.

The partnership's first-stage strategy is for Indonesia and other developing countries to replace HCFC-22 with HFC-32, bypassing the high-GWP HFC-410A technology that most developed countries selected for their earlier transition away from ozone-depleting substances. The essential patented technology is donated to all developing countries providedthat RAC is designed to use the flammable HFC-32 in a safe manner. Japanese companies cooperate on the energy efficient design, and the government of Indonesia incentivizes climate protection with appliance energy efficiency standards and a ban on the import or manufacture of RAC using high-GWP refrigerants that are unsafe for future generations. The agreement is environmentally significant because it uses Life Cycle Climate Performance (LCCP) as the criteria for selecting and perfecting the technology.

The partnership includes: the Indonesia Ministry of Environment, the Indonesia Ministry of Industry, the Japan Ministry of Economy, Trade and Industry (METI), Daikin, Panasonic, Fujitsu General, Hitachi, and Toshiba. The Partnership is supported by the United Nations Development Programme (UNDP) and the Institute for Governance and Sustainable Development (IGSD) and has project financing from the Montreal Protocol Multilateral Fund (MLF) for the phase-out of HCFC-22 and the avoidance of high-GWP HFCs.

The Indonesia-Japan partnership incorporates comprehensive voluntary measures, binding regulatory obligations, and trade incentives to assure safety and energy efficiency, as well as local job creation and profitability. New safety standards and training will assure that products are properly engineered, manufactured and maintained. The RAC design developed in Indonesia can be tailored to reflect the local climate, energy, and economic circumstances.

Indonesia has pledged to reduce greenhouse gas emissions by 26% by 2020 in an effort to do its part to address climate forcing and its consequences, such as storms and sea level rise that would be catastrophic to Indonesia and other nations with coastal lowlands. The partnership combines the strengths of industry, government, United Nations organizations, and environmental non-governmental organizations to guide technology and explain the advantages to the government.

The partnership is a model of green economy and sustainable technology involving all stakeholders in its development, balancing of voluntary and mandatory measures, combining ozone financing and economic incentives, and assuring safe use of flammable refrigerants by technology licensing and project teamwork.

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IV THE TECHNICAL OPPORTUNITY TO REDUCE HFCS AND INCREASE ENERGY EFFICIENCY

Maximizing product energy efficiency through a shift to low-GWP refrigerants in the MAC and RAC sectors is also an important strategy to reduce climate forcing from HFCs. There are wide differences in the estimate of the portion of HFCs emitted in each sector. The authors, using data published by the Montreal Protocol Technology and Economic Assessment Panel (TEAP) and other sources, calculated the estimated emissions as follows:[10]

> Shifting to low-GWP refrigerants for MACs will eliminate up to 60% of global HFC emissions by weight or 50% on a GWP basis and avoid climate emissions up to 50 billion tonnes of CO_2-eq. The low-GWP HFO substitute for MAC refrigerants is also suitable in other applications ofHFC-134a that are not cost-effective with natural refrigerants. Success in this sector will be proof that new technology can help saveclimate.
>
> Shifting to low-GWP refrigerants for RACs will eliminate up to 20% of projected GWP-weighted production and use of HFCs and avoid climate emissions up to 35 billion tonnes of CO_2-eq. Significant additional climate mitigation in the MAC and RAC sectors will come from energy efficiency improvements that go hand-in-hand with the transition to the low-GWP alternatives.
>
> In the MAC sector, energy efficiency improvements of up to of up to 30% are possible. This is significant as 80% or more of total GHG emissions from MAC stem from energy use, and the remaining 20% from refrigerant emissions.Savings of 30% would reduce motor vehicle fuel consumption by ~ 62% in the U.S,~4-5% in the EU and Japan, ~2-3% in China, and 20% in India.

In the RAC and commercial refrigeration and air conditioning sectors, emissions from generating electricity account for between 70-95% of total climate emissions, with the site-specific portion depending on the application, generation mix and fuel type, and ambient temperature.[11]The phase-out of CFCs catalyzed substantial improvements in air conditioning and refrigerant energy efficiency-up to 60% in some subsectors.[12] For example, the US EPA estimated that CFC-free chillers were up to 50% more energy efficient in the U.S. and over 30% more efficient in India than the CFC-based machines they replaced.[13]

Although there have already been improvements in the efficiency of air conditioning and refrigeration equipment over the last several decades, substantial potential still remains. For example, a 2013 assessment by the Super-efficient Equipment and Appliance Deployment Initiative (SEAD) found that deploying the best available technology in RACs can significantly reduce energy use and CO_2 emissions by 2020 and avoid the need for approximately 123 medium-sized (500-megawatt) power plants in 12 of the world's largest economies, with the largest potential savings in India, China, and the EU.[14]By synchronizing a domestic HFC reduction schedule with increasingly strict efficiency requirements, countries could maximize the efficiency potential in the MAC, RAC and domestic and commercial refrigeration sectors before inferior systems are adopted. A comprehensive approach would coordinate country phase-out plans for HCFCs and the phase-down plans for high-GWP HFCs with upgrades in minimum energy efficiency requirements and energy labeling schemes.

A global phase down of HFCs would produce climate mitigation equivalent to up to 100 billion tonnes of CO_2 by 2050, and could avoid 0.5°C of warming by 2100.[15] This does not include the significant additional anticipated mitigation from improvements in energy efficiency in the air conditioning (A/C) and refrigeration (and other) sectors that will be catalyzed by the phase down. For A/C alone, the carbon dioxide savings potential is estimated at 241 million tons/year for 12 major economies.[16] Therefore, a (highly conservative) no-growth extrapolation for the period 2020-2050, suggests an additional 7.2 billion tons cumulative tons of avoided carbon dioxide emissions for stationary A/C alone.[17]

The transition to low-GWP refrigerants and to higher energy efficiency in new cars could be done within three years and in new RAC in as little as five years. It will take approximately 15 years for old RAC to be replaced and approximately 20 years for the fleet of older vehicles to be replaced (depending on factors such as durability, economic incentives, and the relative energy and maintenance ownership of the latest equipment compared to continuing use of the old equipment). Therefore, it is vital that these first transitions occur as soon as possible.

V ELABORATION OF MAC STRATEGY

MACs currently use HFC-134a (GWP 1,300) and account for up to 60% of HFC emissions by weight and 50% by GWP globally. The retail price for HFC-134a is in the range of US$10 per pound. Prior to the selection of HFO-1234yf for MACs, industry and government authorities considered several low-GWP alternatives, including HFO-1234yf (GWP <1), HFC-152a (GWP ~138), and CO_2 (GWP=1). See US EPA MAC fact sheet, reproduced in the appendix, and available online for elaboration of how and why action on MACs is so important to climate protection.

The replacement of choice is HFO-1234yf, which has been approved by the US EPA as a replacement in MACs and has been registered under the EC REACH program. Automobile manufacturers associations in the U.S., EU, and Japan have all endorsed HFO-1234yf. Some German car companies (Audi, BMW, Mercedes, Porsche, and Volkswagen) that had joined other European, Japanese and North American automakers in the 2009 choice of HFO-1234yf to replace HFC-134a announced in the fall of 2012 that they prefer CO_2 systems and asked the EC to suspend enforcement of the MAC F-Gas directive to allow time to overcome technical and safety problems. Later BMW withdrew support for CO_2 and pledged to use HFO-1234yd. General Motors also announced that they would be the first automobile manufacturer with HFO-1234yf and introduced some new models beginning in 2013. Chrysler announced that about one half dozen high volume automobiles will feature HFO-1234yf in 2014 models.

Nevertheless, there is some residual opposition to HFOs, including:

- From NGOs reluctant to accept anything but "natural refrigerants" (particularly hydrocarbons, carbon dioxide, and ammonia), and expressing concern for atmospheric byproducts such as trifluoroacetic acid (TFA) also concern for combustion byproducts from burning vehicles.
- From rival companies and partner NGOs promoting CO_2 for MAC, and
- From auto companies and service organizations concerned that the HFO-1234yf application patents claimed by Honeywell will make the price too high, and that HFO-1234yf production will be too low to meet global demand.

The most significant obstacle appears to be the potentially high price of HFO-1234yf if Honeywell prevails in their application patent claim and attempts to exercise monopoly powers over price and supply. This issue has emerged as a problem for China, as well as in Europe, Japan and North America. The estimated price of HFO-1234yf is between US$120/kilogram in very large quantities purchased by automobile manufacturers to US$ 275/kilogram in small quantities purchased from the parts departments of automobile dealers.

During Montreal Protocol meetings in 2010, the lead Chinese negotiator stated that China would not be able to transition to HFO-1234yf for MAC because it appeared that the patent holder (Honeywell) would be charging a "monopoly" or premium price. At least five global fluorocarbon production companies, including Honeywell and DuPont, have distinguishable patents for production of HFO-1234yf and would compete if not inhibited by Honeywell. DuPont and their Chinese partner, Shanghai 3F New Material Company, have completed a joint venture production facility in Changshu, Jiangsu Province, China to serve the European and North American markets. Asahi Glass Chemical (AGC) in Japan and other chemical companies are able to produce HFO-1234yf with alternate processes (but would still have to overcome the broad application patent or pay for a license). AGC has announced completion of a world-scale plant to produce HFO-1234yf under contract to DuPont and Honeywell.[18]

The price of HFO-1234yf is an obstacle to success and requires a separate set of strategies. In Europe, there are already several separate legal challenges related to the HFO-1234yf patent, according to contacts in the MAC and fluorocarbon sectors. Other NGO and industry strategies include investigating possible violations of antitrust law or business ethics in inhibiting technology necessary to protect against climate change. If the cost/price issue for HFO-123yf cannot be overcome in both developed and developing countries, the refrigerant strategy may be forced to change to resolve the three issues:

1. The risk is that systems designed for HFO-1234yf will be re-filled with HFC-134a during the first and/or subsequent maintenance,
2. The risk that implementation will be slow in regions not prohibiting HFC-134a in new MAC systems, and

3. The risk that flammable options will be improperly implemented resulting in public backlash if fires are linked to air conditioning systems.

One strategy could be to implement HFO-1234yf in developed countries, while promoting new MAC designs that can safely use more flammable refrigerants such as HFC-152a. For example, secondary loop, engine-driven HFC-152a systemsare already approved by U.S. EPA and are under consideration in Australia, India, and the United States.UNEP and environmental NGOs can reorganize and renew cooperation withvoluntary organizations such as Mobile Air Conditioning Climate Protection Partnership to improve refrigerant containment, low-leak service, recovery and recycling, and to destroy refrigerants at end of vehicle life. Superior service equipment includes refrigerant recovery machines that remove 20%+ more refrigerant prior to repair and have more sensitive leak detectors to confirm that repair has been successful.

Another critical strategy is to strictly limit the sale of HFC-134a to trained personnel with access to diagnostic and repair tools necessary to minimize refrigerant emissions. IGSD is organizing cooperation with the Mobile Air Conditioning Society Worldwide and their affiliate MAC service organizations in Australia, EU, and elsewhere to catalogue, assess, and publish best practices guidance in support of this project.The countries with significant automobile production include both domestic auto manufacturers and joint ventures in USA, Germany, France, Japan, China, India, and Korea. There are also domestic joint ventures for vehicle assembly in Canada, Mexico, Vietnam, and other countries. The auto companies most involved in new refrigerants include:

- Innovators: Audi, BMW, Daimler, Fiat, General Motors, Honda, Toyota, and Volvo
- Implementers: all of the above plus Ford, Hyundai, Kia, and Subaru
- Followers: automobile manufacturers that depend on systems suppliers for MACS are waiting for the technology to be proven, competitive, and required by regulations.

The suppliers most involved in technology for new refrigerants – such as CO_2, HFC-152a and HFO-1234yf-- include the following innovators: Behr, Delphi, Denso, Modine, Red Dot, Sanden, Visteon, and others.

The goals of the MAC Best Practice Strategy are to:

- Improve MAC in new cars by requiring refrigerants with GWP <150 (the EU and California Air Resources Board already have rules in place);
- Prohibit do-it-yourself (DIY) repair of air-conditioning systems without recovery of refrigerant from the system and prohibit the sale of HFCs to unlicensed technicians;
- Further professionalize refrigeration and air conditioning in all countries;
- Require repair before recharge of leaking air-conditioning (some MAC service shops already offer this ‘go-green’ service);
- Enact and enforce ‘no-venting’ regulations.

- Upgrade HFC recovery and recharge equipment (new equipment recovers 20% ± 10% more HFC);
- Require annual reduction in leak rates for new equipment (satisfied with quality parts and fewer fittings);
- Classifyair-conditioning system components as part of the emission control system, making it subject to manufacturer's warrantee, with the incentive to make systems last the life of the vehicle without service; and
- Dispose of MAC HFCs at end of vehicle life by rewarding and/or mandating recovery, recycling or destruction of HFC from scrapped vehicles.
- Manage an equitable and smooth transition by crafting a set of measures that maintain and increase service organization employment by implementing value-added best practices even as vehicleair-conditioning becomes more reliable.

Key activities for the MAC Strategy in are to:

1. Follow-Up on regulatory reform:

    - Un-SNAP (Significant New Alternatives Policy) HFC-134a (petition already submitted by NRDC, IGSD & EIA);
    - Require GWP<150 for all cars produced after the EC 2017 schedule or sooner;
    - Make MAC components part of emission control system;
    - Require Best Available Control Technology (BACT) for MAC fuel efficiency;
    - Prohibit sale of HFC-134a to unlicensed technicians lacking access to proper service equipment to minimize emissions; and
    - Strengthen existing qualifications for technician licensing.

2. Propose complementary national action with state and local incentives and programs:

    - Provide model best practices protocols to state and local governments (building on action by the Australia on fluorocarbon taxes,California Air Resources Board on product design, GWP, and education, Canadian Provincial governments f-gas policy, EU MAC and non-MAC F-Gas Directive, and enlisting the MAC service community worldwide); and

    - Encourage companies, universities, municipalities, etc. to sign the pledge to properly repair HFC systems (no recharge without repair, superior HFC recovery and recharge, quality parts, sophisticated leak checking).
3. Support a team of writers respected by industry and government to provide policy-relevant technical information that resolves uncertainties and supports win-win actions for businesses and their customers.

4. Help UNEP become more strongly identified as a reliable source of information on how to take fast action on MACs for climate protection by creating an editorial board of experts to identify and validate the technical accuracy of news.

5. Engage manufacturers, governments, and automakers to resolve supply access and fair-pricing issues.

6. Explore partnerships with the Chinese and Indian automobile manufacturers to ensure their access to new technology – motivated by environmental concerns and to satisfy requirements of western export markets. (Chinese and Indian cars are increasingly sold in Asia, Africa, and Europe; but so far only motorcycles have come to North America from these countries.) Carmakers in China and India made a fast transition from CFCs, and have the ability to move quickly to make the transition out of HFC 134a. The recent US EPA "SNAP" approval for HFOs is an important step. At the same time, the MAC Strategy is pursuing complementary and mutually reinforcing activities targeted at California, cities, and consumers. Success in the MAC sector will produce fast mitigation in its own right, while also strengthening the case for the Montreal Protocol amendment.

VI ELABORATION OF RAC STRATEGY

RACis one of the fastest growing users of high-GWP HFC refrigerants due to economic growth and consumer buying power in developing countries, because market penetration has been historically low, and because the accelerated phase-out of HCFC-22 under the Montreal Protocol will require a choice of new refrigerants.

Like the case for MAC, the RAC life-cycle carbon footprint is dominated by two contributions: the refrigerant greenhouse gas emissions and the energy demand to power the refrigeration and air conditioner system.[19] Therefore, it is important to operate on both directions to reduce the direct and indirect CO_2-equivalent emissions. For small RAC, HC-290 (propane, a natural refrigerant) is suitable, but for larger RAC the quantity of refrigerant charge necessary to achieve cooling is too large to satisfy reasonable safety standards. For example, sales of RAC in the Asia Pacific market is currently about 30 million units per year, but is expected to reach >100 million units by 2020. The global population of HFC-410a RAC is between 150-200 million units, mostly in developed countries, containing 200,000 metric tonnes of high-GWP refrigerant.

Table 3: RAC Sales in Asia/Pacific

Country	2009 Sales
China	25.00 million
India	3.10 million
Indonesia	1.35 million
Philippines	0.70 million
Thailand	1.10 million
Vietnam	0.45 million

The strategy to reduce climate forcing from RAC is similar to the strategy for MACs:

1. Select the refrigerant and technology to achieve lowest carbon footprint taking into account all climate forcing over the life of the product and the ambient temperature and humidity in the locations where the products will be used (Life-Cycle Climate Performance – LCCP).

2. Design and maintain the equipment to sustain low leak rates and high energy efficiency.
3. Recycle and recover refrigerant and destroy any unusable or unwanted stocks.

The Indonesia-Japan HFC-32 RAC Partnership is pursuing all of these strategies, particularly the commercialization of refrigerant HFC-32 technology that offers the lowest carbon footprint. Founding Organizations of the Indonesia –Japan HFC-32 Partnership include:Indonesia Ministry of Environment (MoE), Indonesia Ministry of Industry (MoI), Japan Ministry of Economy, Trade & Industry (METI), Daikin, Panasonic, Fujitsu, Hitachi, Toshiba, United Nations Development Programme (UNDP), and Institute for Governance & Sustainable Development (IGSD)

The Indonesia-Japan Partnership is a model strategy because it takes advantage of patented technology made available by Daikin to developing countries free-of-charge. Safety is assured by design and service training and energy efficiency is assured by national appliance energy efficiency standards. Sales are protected by trade barriers banning the manufacture or import of technology with GWP judged to be unsafe for future generations. Energy savings assured by the efficiency standards result in cost savings that quickly pay for any increased purchase price of the superior and sustainable technology.Once commercialized in Indonesia, the technology can be exported to other countries concerned about climate change and can be manufactured in any developing country for their own or export. Like the MAC sector, it is also important to use best servicing practices forboth next generation technology and forthe technology already in the market. Incentives and training in best service practice are needed, and unwanted and unusable refrigerants need to be collected and destroyed.

VII PILOT ACTIONS RECOMMENDED FOR REDUCING BOTH MAC AND RAC EMISSIONS

1. Collect deposit for HFC sales (collected at the time of import and production of bulk product, service canisters, and HFC contained in products) with revenue used to support recovery, recycle, and destruction(built on the Australia Refrigerant Reclaim model). The deposit is passed onto sales and consumption, increasing the price of newly-produced HFCs, which through market forces, encourages lower emissions. As a result:

    - Equipment manufacturers minimize charge
    - Service shops increase recovery
    - Equipment owners insist on repair before recharge
    - Do-it-yourself repair only undertaken for systems without serious leaks

2. Consumer Education explaining how the public can reduce emissions: repair your own equipment only if you have access to service instructions, leak detection, and recovery/recycle equipment and training.Select professional repair facilities with certified technicians, modern recovery and recharge equipment, and best practices

3. Climate leadership pledges encouraging organizations phase down HFCs and reduce carbon footprints (Consumer Goods Forum, Refrigerants Naturally, State and Local Governments, Universities and Colleges, etc.)

4. Replace refrigeration andair-conditioning equipment only with superior LCCP options, as available in models satisfying other performance criteria.

5. Service only at "Best Practice Facilities" demonstrating reduced life-cycle emissions

6. Certification of Repair: Allow the sale of refrigerants only to service professionals certified as trained and owning leak detection and recovery/recycle equipment ownership, and pledged to best practice.

7. Ensure registration of all technicians with minimum competency certificates with companies and dealers; guide and encourage customers to contact only certified technicians.

8. Improve and expand technician training through "train-the-trainers" programs, the national certification programs for technicians, and the creation of professional associations for technicians and technician handbooks and best practice guidelines.

VIII MAC Appendix from U.S. EPA

TRANSITIONING TO LOW-GWP ALTERNATIVES IN MVACs

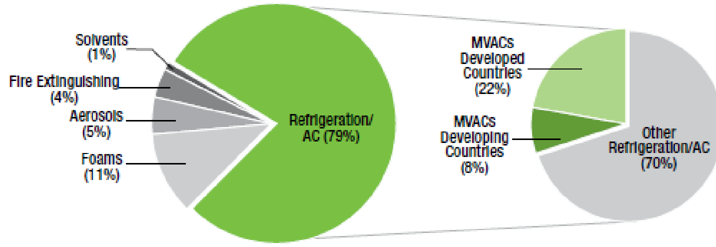
Background

This fact sheet[1] provides current information on low-Global Warming Potential (GWP) alternatives in newly manufactured Motor Vehicle Air Conditioners (MVACs) relevant to the *Montreal Protocol on Substances that Deplete the Ozone Layer.*

MVACs cool passenger cars, light duty trucks, buses, and rail vehicles. They have been produced in the United States since the 1960s and in Japan since the 1970s. MVACs were not widely used in Europe or developing countries until the 1990s. Charge sizes are 0.5–1.2 kg and average lifetimes are 12–16 years.

2010 HFC Consumption

(Estimates Presented in $MMTCO_2$eq.)



Global HFC Consumption Total: 1,087 $MMTCO_2$eq.
Global Refrigeration/AC Sector Total: 858 $MMTCO_2$eq.
Global HFC Consumption MVAC: 257 $MMTCO_2$eq.

MVACs in passenger cars, light duty trucks, buses, and rail vehicles account for an estimated 24% of today's global HFC consumption. In the refrigeration/air conditioning (AC) sector, these MVACs account for an estimated 30% of refrigeration/AC HFC consumption. Developing countries account for an estimated 68 million metric tons of carbon dioxide equivalent ($MMTCO_2$eq.) or 26% of global HFC consumption in these MVAC end-uses.

HFC Alternatives and Market Trends

CFC-12 refrigerant was historically used in MVACs. HFC-134a replaced R-12 in new equipment in the early 1990s. Today R-134a is the dominant refrigerant used in cars worldwide. In buses and trains, about 50% of global equipment uses HCFC-22 refrigerant; the remainder uses R-134a or HFC-407C (a blend of HFCs). Some low-GWP alternatives are summarized below.

HFO-1234yf[2]

- Cooling performance and fuel use comparable to R-134a
- Potential use as a direct substitute in R-134a systems
- Approved in Japan and for small volumes in Europe
- Proposed as acceptable by the U.S.; final decision expected in 2010
- Production update:
  - A pilot R-1234yf production facility is anticipated to be operational in less than two years with large-scale capacity by 2015
  - A production facility in China is scheduled to begin operation in 2011
- General Motors plans to manufacture some models with R-1234yf in model year 2013

Europe's Experience

The existing fleet of cars in Europe uses R-134a for AC. New European Union (EU) regulations require cars sold in the EU to use refrigerants with GWPs less than 150 beginning in 2011 for new vehicles and in 2017 for all vehicles. EC Directive 2006/40/EC requires the EC to consider extending this regulation to AC in buses, coaches, and trucks.

R-152a

- Good energy efficiency and cooling performance
- Requires additional safety requirements; other components remain the same as standard R-134a systems
- To date, no vehicle manufacturer has committed to using R-152a

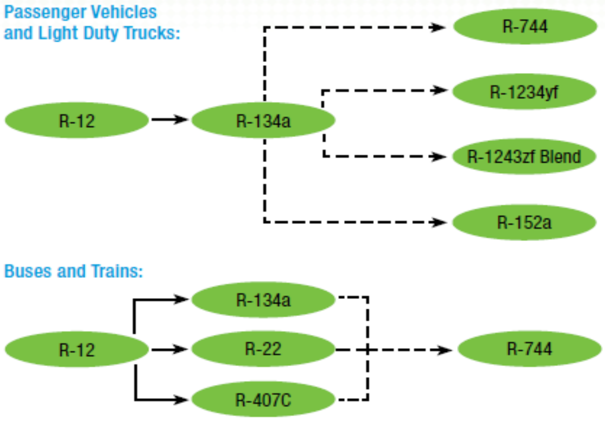
Carbon Dioxide (R-744)

- Cooling performance, energy efficiency, and fuel use comparable to R-134a systems in most cars
- Prototype R-744 systems are in use in buses and trains in Europe; commercialization is expected within two years
- Verband der Automobilindustrie expressed interest in R-744 for passenger vehicles

HFO-1243zf[3]/R-32/R-134a Blend

- Flammability similar to that of R-1234yf
- Energy efficiency is expected to be equal or better than R-134a
- Toxicity expected to be low
- Not currently produced in high volumes

Refrigerant Transition in the MVAC End-Use*



*Solid arrows represent alternatives already available in the market for these systems; dashed arrows indicate those likely to be available in the future.

Refrigerant	GWP	ODP[a]
R-12	10,900	1
R-22	1,810	0.055
R-407C	1,774	0
R-134a	1,430	0
R-1243zf/R-32/R-134a Blend	<150	0
R-152a	124	0
R-1234yf	4	0
R-744 (CO_2)	1	0

[a] ODP = ozone depletion potential

Challenges to Market Entry and Potential Solutions

The following table summarizes the challenges associated with the various alternatives as well as potential solutions to overcoming them.

Alternative	Challenges to Market Entry	Potential Solutions
R-1234yf	• Slight Flammability Risks • Limited Production Capacity • Regulatory Approval • Limited Availability May Prevent Full Market Penetration in the Near-Term	• Safety System Installation • Engineering Design • Increase Production Capacity • Currently Under EPA's Significant New Alternatives Policy (SNAP) Program Review • Currently Under EU Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH) Review for High Volume Applications
R-152a	• Higher Flammability Risks • Limited Production Capacity	• Safety System Installation • Engineering Design • Increase Production Capacity
R-744	• Needs New Servicing Infrastructure • Asphyxiation Risks • High Operating Pressures • Regulatory Approval • System Reliability and Leak Reduction	• Engineering Design • Training and Education • Inclusion of Odorant in Formulation as a Warning System • SNAP Proposed Use Conditions to Address Risks
R-1243zf/R-32/ R-134a Blend	• Slight Flammability Risks • Not Currently Manufactured • Needs Regulatory Review and Approval	• Safety System Installation • Engineering Design

Future Outlook

Together, the suite of known alternative chemicals, new technologies, and better process and handling practices can significantly reduce HFC consumption in both the near and long term, while simultaneously completing the HCFC phaseout. Although much work remains to fully adopt these chemicals, technologies, and practices, and some unknowns still remain, the industries currently using HCFCs and HFCs have proven through the ODS phaseout that they can move quickly to protect the environment.

List of acronyms and abbreviations

ARAP	Alliance for Responsible Atmospheric Policy
A/C	air conditioning
CAFÉ	corporate average fuel economy
CEEW	Council on Energy, Environment & Water
CFC	Chlorofluorocarbon
CII	Confederation of Indian Industry
CO2-eq	CO2 equivalent
COPD	chronic obstructive pulmonary disease
CR	commercial refrigeration
EC	European Commission
ENGO	environmental non-governmental organization
EPA	Environmental Protection Agency
EU	European Union
GtCO2-eq	gigaton CO2 equivalent
GHG	greenhouse gas
GWP	global warming potential
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
HFO	hydrofluoroolefin
IGSD	Institute for Governance & Sustainable Development
IPCC	Intergovernmental Panel on Climate Change
LCCP	Life-Cycle Climate Performance
MAC	mobile air conditioning
METI	Ministry of Economy, Trade & Industry
MOE	Ministry of Environment
MOI	Ministry of Industry
NASA	National Aeronautics and Space Administration
NGO	non-governmental organization
NOAA	National Oceanographic and Atmospheric Administration
NRDC	Natural Resources Defense Council
ODP	ozone-depletion potential
ODS	ozone-depleting substance
PRAHA	Promoting Low GWP Refrigerants for the A/C Sectors in High-Ambient Temperature Countries
RAC	room air conditioning
RAMA	Refrigeration and Air-Conditioning Manufacturer's Association
SEAD	Super-efficient Equipment and Appliance Deployment Initiative
TEAP	Technology and Economic Assessment Panel
TERI	The Energy and Resources Institute
SAP	Scientific Assessment Panel (of the UNEP Montreal Protocol)
SIAM	Society of Automobile Manufacturers
SNAP	Significant New Alternatives Policy Program
UK	United Kingdom
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization

[1] See e.g. European Commission (2013) Implementation of Directive 2006/40/ec – State of Play.

[2] U.S. Environmental Protection Agency (2011) *EPA and NHTSA Finalize Historic National Program to Reduce Greenhouse Gases and Improve Fuel Economy for Cars and Trucks*.

[3] California Air Resources Board, Small Containers of Automotive Refrigerant, 17 CA ADC T. 7, 17, Div 3, Chap1(1)10.5; *see also* Ammonia 21 (December 2009) *California Adopts Refrigerant Management Program*.

[4] Schwarz W., *et al.* (2011) *Preparatory Study For A Review Of Regulation (EC) No 842/2006 On Certain Fluorinated Greenhouse Gases: Final Report*.

[5] Press Release, Consumer Goods Forum, *3rd Refrigeration Summit Warms Retailers to Uptake of Natural Refrigeration Systems* (5 June 2013).

[6] Swiss Federal Office for the Environment, Ordonnance sur la reduction des risqué lies a l'utilization de substances, de preparations et d'objets particulierement dangereux, 2012-2708 (2012) (in French); *see also* Hydrocarbons 21 (November 2012) *Switzerland to Introduce HFC Bans in Several AC and Refrigeration Applications*.

[7] Ministry of Economy, Trade and Industry of Japan (April 2013) *Cabinet Decision on the Bill for the Act for Partial Revision of the Act on Ensuring the Implementation of Recovery and Destruction of Fluorocarbons concerning Designated Products*.

[8] LCCP includes direct and indirect greenhouse gas emissions, energy embodied in product materials, greenhouse gas emissions during chemical manufacturing, and end-of-life loss (typically refrigerant leakage).

[9] IGSD, NRDC, CEEW, TERI (2013) COOLING INDIA WITH LESS WARMING: THE BUSINESS CASE FOR PHASING DOWN HFCS IN ROOM AND VEHICLE AIR CONDITIONERS, Issue Paper.

[10] United Nations Environment Programme (UNEP). 2010. 2010 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee. Nairobi, p. 217; and Velders, Guus J. M.; David W. Fahey, John S. Daniel, Mack McFarland, and Stephen O. Andersen. 2009. The large contribution of projected HFC emissions to future climate forcing. Proc. Nat. Acad. Sci. 106: 10949-10954.

[11] De Larminat, P. (2013) *Development of Climate-Friendly Alternatives for Chillers* (presentation at Bangkok Technology Conference, 29 June 2013).

[12] Shende R. *2009 USEPA's Stratospheric Ozone Protection and Climate Protection Awards* (21 April 2009) ("Humanity has already benefited by about 60% improvement in energy efficiency in domestic refrigerators since the industry started looking at their design in order to change from CFC-12."); *and* U.S. Environmental Protection Agency (2002) Building owners save money, save the earth: replace your CFC air-conditioning chiller, 7 ("The most energy-efficient new chillers will reduce electric generation and associated greenhouse gas emissions by up to 50% or more compared to the CFC chillers they replace.").

[13] US Environmental Protection Agency (2002) Building owners save money, save the earth: replace your CFC air-conditioning chiller, 2 ("Building owners around the world have saved millions of dollars in electricity bills by upgrading air conditioning chiller installations and through concurrent investments to reduce building cooling load. Today's chillers use about one-third less electricity

compared to those produced just two decades ago. Building owners can typically pay back the investment cost of replacing an old CFC chiller in five years or less in virtually all locations that cool for more than three months a year."); *and* Todesco, G. (2005) Chillers +Lighting + TES: Why CFC Chiller Replacement Can Be Energy-Savings Windfall, ASHRAE Journal, 10 ("These CFC chillers serve an estimated3.4 billion to 4.7 billion ft^2 (315 million to 440 million m^2) of commercial floor space with a total electricity consumption of 49,000 to 66,000 GWh/year, and an annual electricity operating cost of $3.4 billion to $4.8 billion. In addition, the cooling and lighting loads in these buildings contribute an estimated 3,600 to 9,200 MW to the summer peak demand of North American utilities. Replacing the remaining CFC chillers with new efficient plants can reduce the electricity consumption and peak electrical demand significantly. The performance of chillers has improved significantly in the last 12 years compared to chillers manufactured in the 1970s and 1980s.").

[14] Shah N., *et al*. (2013) Cooling the Planet: Opportunities for Deployment of Super-efficient Room Air Conditioners*,* 80.

[15] Proposed Amendment to the Montreal Protocol (submitted by the Federated States of Micronesia) (16 April 2013); Proposed Amendment to the Montreal Protocol (submitted by the United States, Canada, and Mexico) (16 April 2013).

[16] Shah N., *et al*. (2013) Cooling the Planet: Opportunities for Deployment of Super-efficient Room Air Conditioners*,* 80.

[17] This is a conservative estimate for several reasons. First, it is more likely that growth will continue to increase through 2050 at a rate that is more constant (growth is projected to rise exponential through 2030 – see source 8). Second, it excludes the period 2014-2020. Third, important emerging economies, such as Indonesia, were not included in the study. Finally, efficiency is likely to continue to improve with experience as the HFC phase down is implemented.

[18] AGC Press Release, 23 January 2014, translated to English at: http://www.noodls.com/view/36269FD3223C63871CB267A303C28897A29C0B7A?7690xxx1390461440 (accessed 27 March 2014).

[19] Discussion paper: Transition to low - emission HVAC&R: Issues and solutions, Australian Institute of Refrigeration Air Conditioning and Heating (AIRAH); http://www.airah.org.au/iMIS15_Prod/Content_Files/UsefulDocuments/AIRAH_Transition_to_low_emission_HVACR_Issues_and_solutions.pdf