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Cooling India with Less Warming:
The Business Case for Phasing Down HFCs in Room and Vehicle Air Conditioners

As living standards rise for tens of millions of Indian people, the enormous expansion in room and vehicle air conditioning could strain the country's electric grid, require increased fuel import, and magnify the impacts of global warming as a consequence of carbon dioxide and refrigerant greenhouse gas emissions. Choices made in the next few years will shape whether Indian consumers, companies, and government authorities can turn the challenges of the room and vehicle air conditioning expansion into a business advantage and national opportunity while reducing climate change, improving air quality, and making air conditioning more efficient and less costly to operate.

This paper explores the business case for Indian air conditioning companies to "leapfrog" and phase down unsustainable technologies based on chemicals with high global warming potential (GWP) called hydrofluorocarbons (HFCs) and move to a future based on climate-friendly refrigerants and energy-efficient equipment designs.

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CREDIT: MEREDITH CONNOLLY

INTRODUCTION

As living standards rise for tens of millions of Indian people, the enormous expansion in room and vehicle air conditioning could strain the country's electric grid, require increased fuel import, and magnify the impacts of global warming as a consequence of emissions of carbon dioxide (CO_2) and hydrofluorocarbons (HFCs)—manufactured chemicals currently used in large quantities in air conditioners and various other products. HFCs do not harm stratospheric ozone, but many HFCs are very potent contributors to global warming. Scientists estimate that unless measures are taken, HFC use and emissions will grow significantly as they replace hydrochlorofluorocarbons (HCFCs), which are being phased out by the Montreal Protocol. HFC use will accelerate the climate impacts of global warming.[1] As markets for room and vehicle air conditioning grow, HFC use in India will expand dramatically unless businesses, consumers, and government work together to develop and adopt energy efficient and climate friendly alternatives.[2] (See figure 1 and figure 2.)

In addition to the environmental impacts, there are compelling business reasons for Indian firms to look closely at next generation refrigeration and cooling technologies before committing to a technology path that the global market is leaving behind (see figure 3). Choices made in the next few years will shape whether Indian consumers, companies, and government authorities can turn the challenges of the room and vehicle air conditioning expansion into a business advantage and national opportunity while reducing climate change, improving air quality, and making air conditioners more efficient and less costly to operate.

India is already famous for "leapfrogging" to more efficient and economic technologies. It is one of the first countries in the world with companies introducing HC-290 and HFC-32 room air conditioners. Furthermore, India is among the first developing countries to develop HFO-1234yf air conditioners for cars planned to be sold in Europe, where refrigerants with global warming potential (GWP) of less than 150 will be phased out between 2011 and 2017 for car air conditioners.

This paper describes preliminary results of a collaboration 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) to explore the business case in India for avoiding HFCs in new room air conditioners and motor vehicle air conditioners and for adopting climate-friendly refrigerants and energy efficient equipment designs.[3] This paper is based on interviews with Indian businesses and government authorities.

GROWING DEMAND FOR ROOM AND AUTOMOBILE AIR CONDITIONERS IN INDIA

India is the second-fastest growing major economy in the world. Increasing affluence and changing consumer choices have helped establish a growing demand for air conditioning in buildings and automobiles. In 2006, there were approximately 2 million room air conditioners in India, and that number increased to as many as 5 million by 2011.[4] Room air conditioner sales doubled from 400,000 units in 2006 to 800,000 units in 2011.[5] The total power consumed by air-conditioning units consequently increased from 2,308 GWh in 2006 to 5,099 GWh in 2011—by far the largest component of overall residential power consumption.[6]

All of the following factors contribute to the demand for building and vehicle air conditioning point to continued high-growth rates in India:

- The market penetration is low.
- The number of households and income levels are increasing while the number of people per household is decreasing.
- Many locations in India have long cooling seasons with high temperatures and humidity.
- Most residential buildings have access to electricity at prices that are affordable to middle class Indian customers.
- Almost all new four-wheeled vehicles sold in India come equipped with air conditioning.

The Indian Refrigeration and Air-conditioning Manufacturers' Association (RAMA) reports a 20 percent annual growth rate for the past decade with 30 percent growth likely for the next five years. Based on RAMA and Lawrence Berkeley National Laboratory (LBNL) forecasts, nearly 200 million air conditioning units will be in service by 2030—an increase of almost 40 times the current number.[7] The power consumed by air conditioning will also increase to 50 TWh/year by 2030—more than 10 times the current number.[8]

FIGURE 1 Hydrofluorocarbons and Global Warming

Hydrofluorocarbons (HFCs) production and use are projected to more than double between now and 2050, with the vast majority of the growth occurring in China and India.

India will be particularly prone to adverse effects of climate change. This includes the threat of increased extreme weather events (both drought and floods) as well as greater variability in monsoon-fed crops. There will also be potential displacement of large numbers of people living along India's vulnerable coastline. Worldwide, environmental and economic impacts of climate change include sea-level rise of more than 1.6 meters by 2100, causing inundation of islands and lowlands and loss of coral reefs, forests, and other valuable ecosystems; a three-fold increase in extreme weather events causing crop and property destruction; and a massive flooding followed by drought if warming of the Himalayas causes monsoon precipitation to fall as rain rather than as snow, which in the past melted gradually to feed the rivers in the dry seasons.

FIGURE 2 Hydrofluorocarbons (HFCs) Versus Hydrofluoroolefins (HFOs)

Hydrofluorocarbons (HFCs) are partially fluorinated hydrocarbons containing only hydrogen, fluorine, and carbon atoms. The absence of chlorine eliminates their potential to destroy stratospheric ozone and the presence of hydrogen reduces their effectiveness as greenhouse gases because they are removed from the atmosphere via reaction with hydroxyl radicals.

Hydrofluoroolefins (HFOs) differ from traditional HFCs by being derivatives of alkenes (olefins) rather than alkanes. Olefins have very short atmospheric lifetimes of a few days and thus very low GWP.

FIGURE 3 Perspective of Confederation of Indian Industry (CII)

Major climatic changes, including a longer summer season with higher humidity, and the increasing purchasing power of the Indian urban population are fueling significant growth in sales of building and vehicle air conditioners. This, in turn, is driving a massive growth in the usage of refrigerants. Hydrochlorofluorocarbons (HCFCs) are being phased out to protect the ozone layer, but what is the best combination of refrigerants—HFCs, hydrocarbons, carbon dioxide, HFOs, and other alternatives—to replace them? The CII appreciates the dialogue and analysis that the participants in this paper have initiated.

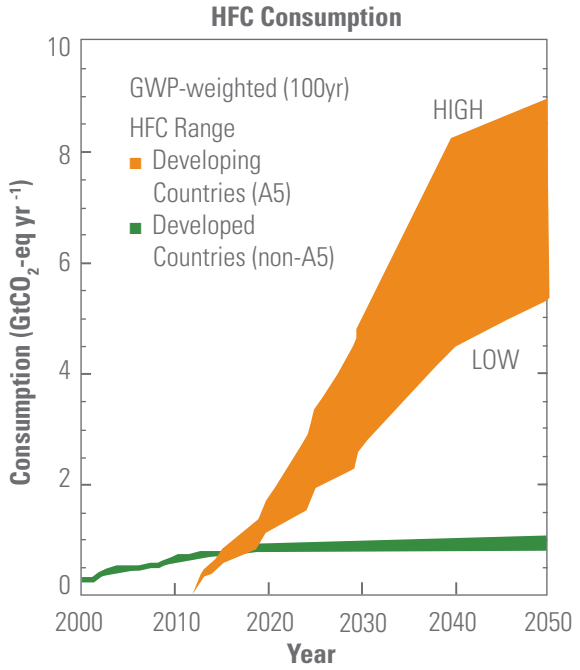
In response to CII recommendations, the project team has agreed to undertake the following additional work to increase awareness of the advantages and disadvantages of all alternative refrigerants:

- Prepare an environmental/economical/operational benefit matrix that analyzes alternatives to HFCs and HCFCs considering global warming potential, energy efficiency, specific energy consumption, investment requirements for firms, and impacts on consumers' initial purchase prices and lifetime energy costs.
- Perform a life cycle climate performance (LCCP) analysis on direct, indirect, and embedded emissions of technology using different refrigerants.
- Conduct a structured survey of various categories of stakeholders (including building, vehicle, and other applications of HFCs) to capture their views and perspectives.

CII looks forward to participating in further work on this important project.

Similar trends are predicted across the developing world. By 2050, global HFC production and consumption is forecast to increase five to nine times more than 2010 levels, with the largest growth in developing countries (see figure 1).[9]

FIGURE 4. Projected HFC Growth



Source: G.J.M. Velders et al., PNAS, 2009; 106:10949-10954.

FIGURE 5 Climate Impacts of Air Conditioning

Air conditioning has three impacts on the climate system: the *direct* emissions of refrigerant greenhouse gases; the *indirect* emissions from the combustion of fuel to power the equipment; and the *embodied* emissions of the production, transportation, service, and disposal over the product life-cycle. Life-cycle climate impact (LCCP) calculates all the total direct, indirect, and embodied greenhouse gas emissions as a carbon-equivalent metric.

FIGURE 6 Proposals Under the Montreal Protocol

Canada, Mexico, the Federated States of Micronesia, and the United States have proposed to amend the Montreal Protocol to phase down HFCs with high global warming potential (GWP). Both the North American and Micronesian proposals would reduce HFC production and consumption by 85 percent to 95 percent over the coming decades, avoiding the equivalent of 87 billion to 146 billion metric tons of carbon dioxide by 2050.

GLOBAL MARKET SHIFT TO OZONE-SAFE, CLIMATE FRIENDLY, ENERGY EFFICIENT REFRIGERANTS

Rooms and vehicles with air conditioners are global markets in which international companies compete for market share and achieve economies of scale. Many companies design products that satisfy the most stringent energy efficiency, safety, and environmental standards so they can be freely marketed worldwide. Current and emerging market trends and regulations in Australia, the European Union, the United States, and elsewhere are moving toward refrigerants with a lower impact on climate change (see figure 5). Some large developing countries, such as China, are already moving toward more climate friendly alternatives. In addition, more than 100 parties to the Montreal Protocol support opening negotiations on proposed amendments to phase down the use of HFCs with the most climate impact (see figure 6).

These market trends and regulatory measures are already affecting India's major export markets and providing an early commercial driver for change in India among export-oriented companies. They are also helping to scale up the availability of alternative refrigerants and air-conditioner technologies. HFC use in India can be minimized through the application of regulatory initiatives, resolution of safety concerns with technical standards, service-technician training, and affordable cost achieved through economies of scale. These trends pose the following strategic challenges and opportunities for Indian businesses and the Indian government:

- **Several large markets are already requiring a shift to vehicle air-conditioning refrigerants that cause less climate damage.** The E.U. Mobile Air Conditioning Directive will establish a schedule for transitioning air conditioners in all new cars sold in Europe after 2017 from HFC-134a (GWP of 1430) to refrigerants with a GWP no higher than 150.[10]

  A similar transition is being driven in the United States by the U.S. Environmental Protection Agency (EPA) greenhouse gas emission standards for new vehicles.[11] These standards cover HFCs as well as CO_2 and other climate-forcing tailpipe pollutants. As the limits tighten each year, from 2012 through 2025, vehicle makers will transition more models to low-GWP refrigerants, with the conversion of nearly all models expected during the next five years. In addition, the EPA is considering setting a specific schedule—under the Significant New Alternatives Policy (SNAP) program—for removing HFC-134a from the list of acceptable refrigerants for air conditioners in new vehicles. [12]

- **The European Commission and the United States are considering broader HFC phase-down requirements under existing authority.** The European Commission is currently assessing proposals, such as: "progressively limiting the supply of F-gases ('phase-down'), and possible bans on the use of F-gases in certain applications."[13] In July 2012, the European Commission proposed a regulation to strengthen E.U. legislation to cut Fluorinated gases—HFCs, perfluorocarbons (PFCs), and sulphur hexafluoride (SF6) by two-thirds of today's levels by 2030 (this is known as the F-gas regulation).

Finalization of this proposal is expected later in 2013 or early 2014. This regulation would, in effect, restrict imports of HFC-based products.[13]

The United States is also likely to consider a broad phase-down of high-GWP refrigerants under the Clean Air Act. These actions could lead to use-by-use restrictions, or an overall phase-down schedule.

- **Australia has enacted an import tax on HFCs** as an incentive to implement new low-GWP refrigerants and to better contain, recover, and recycle HFC refrigerants during service and when products are discarded.
- **Companies operating in China are investing in more climate friendly alternatives.** More than half the companies making room air conditioners in China have chosen low-GWP HC-290 with financial assistance from the Montreal Protocol's Multilateral Fund. Others are moving to HFC-32 (which has a GWP of 675).[14] In addition, a partnership of Shanghai 3F New Materials Company and DuPont has built a plant in China to supply HFO-1234yf, which is a low-GWP refrigerant for vehicle air conditioners and other applications. DuPont has agreed to supply Honeywell with certain quantities of HFO-1234yf from the facility in China. DuPont and Honeywell market and sell this refrigerant separately.
- **India's Bureau of Energy Efficiency (BEE) is working on improved energy efficiency standards** for room air conditioners under a mandatory Standards and Labeling Program. In 2012, BEE upgraded the requirements for the "star rating" of room air conditioners by about 8 percent for split air conditioners in the same rating band. Efforts are currently under way to develop test procedures that evaluate air-conditioner performance under India's unique climatic conditions.

"LeapFrogging" Potential in Room Air Conditioners

Who makes the room air conditioners sold in India?
The Indian room air conditioner industry ranges from small- and medium-scale enterprises to multinational corporations with some firms making only the components and others making the complete air-conditioner unit.[15] A dozen major companies manufacture and market room air conditioners in India, with the top five supplying more than 60 percent of the market (see table 1).

Industry stakeholders report that nearly a quarter of India's air-conditioner units are imported into the country completely assembled and that approximately 80 percent of them include imported components, such as compressors and indoor evaporator/air-blower assemblies.

About 70 percent of the room air conditioners now sold in India are split systems—compared with window air conditioners that accounted for about 70 percent of the market five years ago (figure 7).[16] Split systems are typically more energy efficient than window units.

Table 1: Top Five in Sales of Room Air Conditioners in India

COMPANY NAME	OWNERSHIP	MARKET SHARE
Voltas	India	~18.3%
LG	Republic of Korea	~17.7%
Samsung	Republic of Korea	~10.0%
Panasonic/National	Japan	~09.9%
Hitachi	Japan	~07.3%
Other[a]	Various	~36.8%

Source: GfK-Nielsen India; Market share data is based on multi-brand retail outlet sales figures and excludes single-brand outlet sales; Writankar Mukherjee, "Voltas leads air-conditioner market; LG slips to number 2 position," *The Economic Times*, July 4, 2012.
[a] Includes Blue Star, Carrier, Daikin, General Electric, Godrej, Haier, Onida, Swegon/Blue Box, and Whirlpool.

Which Lower-GWP Refrigerants Are Available for Indian Room Air Conditioners?

Today, almost all room air conditioners produced and marketed in India use HCFC-22, which is an ozone-depleting substance scheduled for phase-out under the Montreal Protocol. The current HCFC schedule for countries such as India requires a freeze in consumption at January 2013 levels and cutting national consumption (domestic HCFC production, plus imports and minus exports) 10 percent by 2015, 35 percent by 2020, 67.5 percent by 2025, and 97.5 percent by 2030, with consumption after 2030 restricted to the servicing of refrigeration and air-conditioning equipment. By 2040, HCFC production and consumption for refrigerant uses will completely cease. Most Indian companies have reported that they are planning to change from HCFC-22 refrigerant to HFC-410a (a blend of HFC-125 and HFC-32), which has a GWP of 2088.

Indian companies have an opportunity to limit their reliance on HFC-410a or to "leapfrog" it entirely. Shifting to HFC-410a temporarily, while planning to adopt a low-GWP alternative later, has the advantage of using a known technology in the short term and switching to another alternative after others have paved the way. On the other hand, leapfrogging HFC-410a has the advantage of avoiding the expenses of a double transition. In addition, it would position Indian companies to export room air conditioners without being affected by restrictions on high-GWP HFCs in other countries. Furthermore, choosing the next-generation refrigerant would allow Indian companies to take advantage of the latest energy efficiency engineering. One of the challenges in India is to coordinate the schedules of the HCFC phase-out and the upgrades in energy efficiency and energy-labeling standards with the local availability of next-generation technology at affordable cost.

When replacing HCFC-22, India and other developing countries have the choice of HFC-410a, HFC-32, HC-290, and at least three proposed HFO/HFC blends (see table 2).

Three companies manufacturing and marketing room air conditioners in India plan to offer systems with refrigerants other than HFC-410a:

- Godrej Industries now sells split systems with low-GWP HC-290 (GWP <5) and has achieved the highest five-star energy efficiency rating and superior "life-cycle climate performance" (figure 8).
- Daikin has chosen a split system with medium-GWP HFC-32 (GWP of 675) that achieves high energy efficiency and superior "life-cycle climate performance" compared with HFC-410a. Daikin will allow companies in India and other developing countries to use basic HFC-32 air-conditioning patents at no charge through "non-assertion contracts." Daikin will allow companies using their patents to sell in both Indian and export markets (including developed countries). Daikin is also building a facility in India to manufacture HFC-32 for its own use.
- Panasonic will offer split systems with medium-GWP HFC-32, similar to what Daikin will use.

FIGURE 7 **Window Versus Split Air Conditioners**

CREDIT: GODREJ & BOYCE MFG. CO. LTD

Room air conditioners sold in volume in India include split and window systems. Split air conditioners have the condenser and compressor assembly mounted outside the building and are connected by refrigerant hoses to the evaporator and cooling fan assembly mounted high on the wall or ceiling. Window air conditioners have all the components in the same box, which is mounted in a window or in a wall opening.

Table 2: Hydrofluorocarbons and Replacements in Room Air Conditioners and Their Availability in India

REFRIGERANT	GWP	ENERGY EFFICIENCY	ASHRAE & ISO FLAMMABILITY	MARKET STATUS	REGULATORY STATUS
Current High-GWP Refrigerant Used in Room Air Conditioner					
HCFC-22	High (1810)	High	Class 1: Not flammable	Scheduled for phase-out under the Montreal Protocol, with a reduction scheduled over time in India.	No longer allowed in new appliances sold in the E.U., the U.S., or other developed countries
Replacements for HCFC-22 in Room Air Conditioner					
HFC-410a	High (2088)	Low	Class 1: Not flammable	Has been licensed to a number of global chemical producers and its patents are expiring.	
HFC-32	Medium (675)	High	Class 2L: Mildly flammable	There will be multiple suppliers of HFC-32, since the chemical is already manufactured as a component of HFC-410a; patents for manufacturing HFC-32 have long expired, guaranteeing competitive pricing; and construction of new production is under way in India by Daikin. Daikin has announced that it will allow companies in developing countries to use basic HFC-32 air-conditioning patents at no charge through "non-assertion contracts."	
HC-290 (Propane)	Low (<5)	High	Class 3: Highly flammable, but is approved by respected national and international safety authorities for refrigeration and air-conditioning applications with relatively small charges and explosion-proof electrical connections and components such as switches.	Godrej in India produces room air conditioners using HC-290; Gree in China and more than half of the manufacturers in China have chosen HC-290. Two air-conditioner production lines and a compressor production line have already been converted. China adopted IEC 60335-2-40, which will enter into effect in July 2013, allowing air conditioners to be charged with up to 350 grams of HC-290.	Companies have yet to apply to the U.S. EPA for SNAP approval
HFO/HFC blends (DR7, L41, L20)	Medium (~350 to ~700)	Neutral to Positive	Class 1: (not flammable) or Class 2L: (mildly flammable)	DuPont, Honeywell, Arkema, and other companies announced plans to commercialize low-GWP blends suitable for room air conditioners; they are not yet available in commercial room air-conditioner products.	

All other companies manufacturing or importing room air conditioners to India have chosen to use high-GWP HFC 410a (2088 GWP) at this stage. Certain foreign companies manufacturing in India (e.g., LG and Samsung) or importing from abroad (e.g., Carrier and General Electric) have selected HFC-410a for the first stage of transition because that is what they currently produce for markets in Europe, Japan, and the United States, where the HCFC-22 phase-out has already occurred. By contrast, half of the companies making room air conditioners in China have chosen to use HC-290 and several more have chosen to use HFC-32.[17]

HC-290 and HFC-32 are flammable compounds but can be used with appropriate design and safety standards. Europe established safety standards for room air conditioners using these refrigerants, and such standards are in the final stages of approval in Japan, the United States, and other countries. India needs to adopt similar safety standards to ensure that inadequately designed products using these refrigerants are excluded from the market. Furthermore, it is important that installation and service technicians receive proper training and tools. For example, Godrej and Daikin technicians are specifically trained in safe installation and maintenance of the new models, and Godrej includes free installation from certified technicians.

The majority of Indian companies planning to offer room air conditioners with HFC-410a make the case that 1) alternative refrigerants available today, such as HC-290 and HFC-32, do not yet have a proven commercial track record; 2) consumers place higher priority on initial price and overlook long-term electricity costs and environmental impacts; 3) the Indian government has not discouraged the choice of HFC-410a, but instead has allowed each company to decide whether to leapfrog to other alternatives; and 4) safety standards are not yet in place in India for flammable refrigerants.

PHASING DOWN HYDROFLUOROCARBONS IN AUTOMOBILE AIR CONDITIONERS

Who Makes the Automobile Air Conditioners Sold in India?

The Indian automobile industry and mobile air-conditioner market consist of Indian and global brands catering to the domestic and export markets. A dozen major companies produce and sell cars in India, with the top three supplying more than 70 percent of those sold (see table 3).

Several companies supply the air conditioners used in these vehicles. For example, Tata Motors uses equipment made by Subros and four other local vendors affiliated with international companies.

Are Lower-Impact Refrigerants Available for Indian Automobile Air Conditioners?

Nearly all automobile air conditioners produced or marketed in India use HFC-134a, which has a GWP of 1430. However, the alternative refrigerant HFO-1234yf with a GWP of 4 is now

FIGURE 8 Godrej & Boyce Cooperation with GIZ

CREDIT: GODREJ & BOYCE MFG. CO. LTD

In 2002, Godrej & Boyce was the first company in India to introduce hydrocarbon refrigerants in refrigerators to replace chlorofluorocarbon (CFC) refrigerant and foam-blowing agents, which were phased out in India in 2010 under the Montreal Protocol.

In April 2012, Godrej & Boyce started a new production line in India of room air conditioners with HC-290, which was selected because it has zero Ozone Depletion Potential (ODP) and very low GWP. The line has a capacity of approximately 180,000 units per year. To date, several thousand units have already been sold in the Indian market and the full capacity of the line will be available for production in 2013. The HC-290 technology is a very suitable alternative for air conditioning even in high ambient temperatures. The new air conditioners have been designed on the basis of European and international safety standards, such that the charge size for the 1 T category is just 300g (as per EN 378, the allowable charge limit for a normal-size bedroom in India would be 361g).

The new models have the highest energy efficiency in their class. For example, the Godrej 5-star air conditioner using HC-290 technology in the 1.5 T split category (the most common air-conditioner segment in India) has an EER of 3.7.

The project has been implemented by GIZ Proklima (under the International Climate Initiative of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) through a bilateral agreement with the government of India, represented by the Ozone Cell, Ministry of Environment and Forests.

This partnership between India and Germany is meant to spread general knowledge of HC-290–based air-conditioning technology and equipment throughout India and the region and to encourage other air-conditioning manufacturers to select sustainable technologies when replacing HCFCs.

Table 3: Top 12 Passenger Vehicle Companies in India (April 2011 to March 2012)

MANUFACTURER	SHARE OF PRODUCTION	SHARE OF SALES	SHARE OF EXPORTS
Maruti Suzuki India	39%	42%	25.14%
Hyundai Motor India	25%	19%	47.51%
Tata Motors	11%	13%	1.46%
Nissan Motor India	5%	2%	20.18%
Ford India	5%	4%	5.12%
Toyota Kirloskar Motor	4%	5%	0.16%
General Motors India	4%	4%	0.09%
Volkswagen India	3%	4%	0.02%
Honda Siel Cars India	2%	3%	0.01%
Škoda Auto India Pvt	1%	2%	0.00%
Mahindra & Mahindra	1%	1%	0.00%
Fiat India Automobiles	1%	1%	0.29%

Source: Society of Indian Automobile Manufacturers.

being used in cars produced in North America, Europe, and Japan, and in some cars produced in China.

There are three viable refrigerant options to replace HFC-134a in automobiles: HFO-1234yf, HFC-152a, and CO_2 (see table 4). (Hydrocarbons have good cooling performance but car makers consider them to be too flammable for use in automobiles.)

HFO-1234yf is a "near drop-in" replacement requiring minor equipment modifications and using off-the-shelf or easily fabricated components. Some stakeholders point out that the current price of HFO-1234yf is about five times more than HFC-134a as a result of the more complex chemistry involved in its production and application patents. Consequently, the total cost of an HFO-1234yf system (including equipment modifications and refrigerant) will be more than an HFC-134a system. Assuming HFO-1234yf systems need service as frequently as HFC-134a systems, the lifetime ownership cost will also be more expensive. However, if automakers implement available technology to avoid leakage, the ownership cost will be comparable with current systems. And if car makers also implement available technology to increase energy efficiency, the ownership cost will be even lower than current HFC-134a systems.

Vehicles designed for CO_2 systems require entirely different components capable of substantially higher operating pressures. While CO_2 refrigerant, is much less expensive than HFC-134a, the cost of the components is significantly higher. HFC-152a refrigerant is also less expensive than HFC-134a, but vehicles designed for HFC-152a carry the additional expense of a secondary cooling loop to keep the flammable refrigerant from entering the passenger compartment.

Nearly all vehicle manufacturers in China, Europe, India, Japan, and North America have chosen HFO-1234yf as the next-generation refrigerant, and the first vehicles with this new refrigerant from European and North American automakers have entered the market. Significant issues remain, however, for Indian companies. The long-term price of HFO-1234yf depends on the number of suppliers and their pricing strategies. Indian suppliers of mobile air conditioning (MAC) systems and components do not manufacture refrigerants, so there is a need to identify and promote local refrigerant vendors and to incentivize local production to assure affordable cost and reliable supply. Patent claims of Honeywell are being challenged by companies in Europe and North America. These issues could be resolved by litigation or by licensing agreements that allow for more suppliers.

While most automakers concluded that they can safely manage HFO-1234yf's mild flammability through engineering design, Daimler recently raised concerns and informed European authorities that it wants to continue using HFC-134a systems, in violation of the E.U. MAC directive requiring refrigerants with GWP of less than 150. Standards organizations and government authorities are working to resolve Daimler's safety concerns. In the interest of continuing technical progress, there would be benefits from government or other funding to study the application of CO_2 as an automobile refrigerant and to iron out such technical concerns as high operating pressures, safety issues, and energy efficiency that stand in the way of commercialization.

ENVIRONMENTAL AND SAFETY CONCERNS IN A GLOBALIZED AUTOMOBILE INDUSTRY

As a result of highly globalized markets, automobile manufacturers generally prefer to design for the most stringent environmental and safety requirements of any of their markets. This simplifies manufacturing, requiring fewer parts and fewer types of refrigerant-charging equipment. Inventory costs are reduced since vehicles can be shipped to any market. The service sector's tool and training costs are also minimized once the fleet turns over and requires only one refrigerant. Early transition to next-generation technology also helps build and maintain brand loyalty because a car owner is less likely to face shortages of obsolete refrigerant or increasing prices due to shortages.

The challenge for Indian automakers is to anticipate foreign and domestic requirements and to balance the demands of their domestic and export markets. Furthermore, new car buyers in India may favor next-generation technology that is environmentally superior and not dependent on obsolete chemicals. In the near term, Indian companies that export cars to Europe or other large markets could elect to produce all their vehicles using HFO-1234yf, or to produce HFO-1234yf systems where required and HFC-134a systems for other markets.

Making all vehicles using HFO-1234yf has the advantage of reducing system-design costs and simplifying parts supply, manufacturing, and new vehicle inventory control. However, this path has the disadvantage of raising the cost of vehicles sold in India and in export markets that do not yet require a low-GWP refrigerant. One solution suggested by Indian automobile manufacturers is to put in place a credit mechanism to recognize and incentivize vehicle air-conditioning technologies that are environmentally friendly.

Automakers importing vehicles into India have similar options. They can readily design air conditioners to meet the demands of the hot and humid Indian climate and use a refrigerant charge of either HFC-134a or HFO-1234yf. Some companies may offer the HFO-1234yf system worldwide, while others may choose initially to offer HFC-134a refrigerant in the Indian market.

The Society of Indian Automobile Manufacturers (SIAM) and its members report that the energy efficiency of mobile air conditioners is a high priority in response to strong national and international policy drivers. Thus, a shift to HFO-1234yf would be more attractive if the new technology were upgraded to take advantage of the latest energy efficiency breakthroughs. Indian automobile manufacturers that market cars in Europe are ready and able to comply with the E.U.'s MAC F-Gas directive. In fact, two companies with a significant presence in India—TATA Motors and Maruti

Table 4. Technical Options to Replace HFC-134a in Automobile Air Conditioning

REFRIGERANT	GWP	MARKET STATUS	ALLOWED IN U.S. OR EUROPE	ASHRAE & ISO FLAMMABILITY
Current High-GWP Refrigerant Used in Automobile Air Conditioners				
HFC-134a	1430[a]	Replaced CFC-12 in new Japanese, North American, and European cars in 1994 and worldwide by 2010	Currently allowed under EPA SNAP, but under review to be removed; does not meet the E.U.'s F-Gas directive	Class 1: Not Flammable
Replacements for HFC-134a in Automobile Air Conditioners				
HFO-1234yf	~4[b]	Choice of automobile manufacturers in North America, Japan, and Europe; world-scale production plant now operating in China; first cars entering the market	Allowed under EPA SNAP; meets the E.U.'s MAC F-Gas directive	Class 2L: Mildly flammable
HFC-152a	124[c]	Prototyped, but not commercialized; no intellectual property barriers to manufacture or use	Allowed under EPA SNAP; meets the E.U.'s MAC F-Gas directive	Class 2L: Mildly flammable
Hydrocarbons	<5[d]	Not considered safe by any major vehicle manufacturer; no intellectual property barriers to manufacture or use	Not allowed under EPA SNAP; meets the E.U.'s MAC F-Gas directive	Class 3: Highly flammable
Carbon Dioxide (CO_2)	1[e]	Prototyped, but not commercialized	Allowed under EPA SNAP; meets the E.U.'s MAC F-Gas directive	Class 1: Not flammable

[a] 100-year GWP from IPCC Fourth Assessment Report. [b] Best available estimate. [c] 100-year GWP from IPCC Fourth Assessment Report. [d] Best available estimate. [e] 100-year GWP from IPCC Fourth Assessment Report.

Suzuki—have designed prototype HFO-1234yf systems for the vehicles they intend to export to Europe. Domestic and regional markets could rapidly transition to HFO-1234yf if consumer demands or government incentives favored a low-GWP refrigerant with superior "life-cycle climate performance" (LCCP). This comprehensive approach will require studying 1) the LCCP of mobile air conditioning systems in Indian driving conditions; 2) how much refrigerant is leaked into the atmosphere during vehicle use and service; and 3) opportunities for refrigerant recycling at the end of vehicle life. It will be particularly important for an appropriate organization to gather data on actual consumption of refrigerant for each vehicle type (passenger cars, urban transit vehicles, and commercial vehicles).

Indian suppliers can make mobile air-conditioning systems and components for low-GWP refrigerants. In interviews for this report, Indian automobile manufacturers and suppliers of air-conditioning systems and components were confident that with proper incentives and government support, HFO-1234yf could be implemented in new vehicles as quickly as in other countries. Most Indian suppliers of mobile air-conditioning systems and components have business affiliations with international companies that are already supplying European and North American markets with HFO-1234yf systems. Some Indian suppliers provide components for these systems. For example, Behr, Denso, Delphi, and Visteon are 100 percent foreign owned, allowing them to quickly supply HFO-1234yf systems for cars made in India using designs and parts already commercialized for cars sold in the European Union and United States. Delphi and Subros have sophisticated and capable research facilities in India that could develop components and systems suitable for the hot and humid Indian climate. Subros could also expand its joint-venture agreement with Denso to gain access to Denso's HFO-1234yf designs, which are already commercialized for vehicles made or imported to the European Union, Japan, the United States, and other markets. [18]

At least one system supplier is offering Indian automakers designs that can be charged with HFC-134a today, but are "HFO-1234yf-ready" on very short notice for vehicles exported to the European Union. These systems fit into the same space as existing HFC-134a systems.

The Mobile Air Conditioning Climate Protection Partnership (MACCPP), SAE International, TERI, and the United Nations Environment Programme have been proactive in evaluating alternatives and crafting the necessary technical standards for safety and service compatibility. In India, field personnel (particularly independent service workshops) need more training on how to recover and recharge refrigerant and on the importance of investing in recovery and recharge equipment.

ENERGY EFFICIENCY IMPROVEMENTS ENABLED THROUGH NEW REFRIGERANTS

Projects supported by both the EPA and the global automobile and air conditioning industries have demonstrated technical options to increase energy efficiency of both HFO-1234yf and HFC-152a by 30 percent or more compared with standard HFC-134a systems. In India's hot

and humid climate, operation of vehicle air conditioners can account for up to 20 percent of fuel consumption, compared to about 3.2 percent in Europe, 3.5 percent in Japan, and 5.5 percent in the U.S. Consequently, a 30 percent improvement in air conditioners' fuel consumption produces a greater savings in India than in these other regions.[19]

PRELIMINARY FINDINGS

India Is Technically Able to Minimize Reliance on HFCs, but Important Components Are Not in Place—Time Is Running Out

RAMA and SIAM are effective policy and technology focal points for room and vehicle air conditioners. They have highly capable staff and are well networked with excellent global and national engineering centers. RAMA and SIAM work closely with government ministries on policy to replace ozone-depleting substances with sustainable and affordable technology, particularly with the National Ozone Unit (NOU) in the Ministry of Environment and Forests (MoEF) and with the Ministry of Transportation and the Bureau of Energy Efficiency.

The room and vehicle air conditioning sectors in India are well-informed about alternatives to high-GWP refrigerants and understand that developed and developing country markets are beginning to move to low-GWP alternatives with superior life-cycle climate performance. They are aware that some markets are already ending use of high-GWP HFCs. The Indian government has worked with industry associations to build technical knowledge. For instance, the NOU, with the support of RAMA, has built strong awareness of low-GWP room air-conditioner technology and the German Society for International Cooperation (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)) has published detailed handbooks on HC-290 room air conditioner design for safety and energy efficiency, and for safety in manufacturing, installation, and service.

The government, however, has allowed companies to choose the technology they will use to replace HFCs and HCFCs, while encouraging voluntary decisions to further protect the climate. The government has not clearly signalled a direction for industry on leapfrogging and phasing down high-GWP HFCs. The GIZ/Godrej H-290 demonstration project was completed too late to influence the initial choices of other companies for HCFC Phase-out Management Plan (HPMP) and Multilateral Fund (MLF) funding.

RAMA and its members report that phasing out HCFCs and simultaneously upgrading air-conditioner energy efficiency are their highest priorities. The policy signals from the government of India, by way of a recent tightening of the BEE star labeling program for air conditioners, will make Indian appliance manufacturers invest in upgrading their technologies to meet the higher energy efficiency standards. Leapfrogging HFC-410a is a priority for three of its member companies, but others are planning to use HFC-410a primarily because the next generation of technology is not yet seen as widely commercialized and because access to new refrigerants and technology at affordable cost is uncertain. Room air-conditioner manufacturers understand that HFCs are a transition substance that ultimately will be phased down. Further elaboration is needed on the benefits and costs of a two-stage transition, first from HCFC-22 to HFC-410a, and then to sustainable alternatives.

The Indian mobile air-conditioning sector has already changed from CFC-12 to HFC-134a and is now considering the timing of a second transition to HFO-1234yf. However, there are major uncertainties regarding the supply of HFO-1234yf in India. Currently, no Indian manufacturer has access to the technology to produce this chemical. SIAM and its members report that their choices regarding refrigerants and energy efficiency are strongly influenced by national and international policy drivers. In India, there are currently no emission-reduction regulations for HFCs or other greenhouse gases. At the international level, there is no legally binding agreement for India to reduce greenhouse emissions at this stage, in contrast to the limits on ozone-depleting substances agreed upon under the Montreal Protocol.

Indian car manufacturers that export to Europe are ready and able to comply with the European directive requiring refrigerants with GWP of less than 150. The domestic market could be rapidly transitioned to HFO-1234yf if consumer demand, government incentives, or standards favored a low-GWP refrigerant with superior life-cycle climate performance.

POLICIES AND MEASURES TO HELP "LEAPFROG" TO ALTERNATIVE REFRIGERANTS

HFCs are not yet controlled by the Montreal Protocol or regulated under the government of India's regulations regarding ozone-depleting substances and hence do not qualify for the currently available financing necessary to develop, validate, and commercialize environmentally superior next-generation technology. Indian companies making and marketing mobile and room air conditioners are ready to implement new technologies as soon as there are signals from Indian environmental authorities, demands from consumers in Indian and export markets, or regulations in export markets that demand climate protection.

Some preliminary actions were identified for Indian stakeholders that could help companies with efforts to leapfrog to lower-GWP alternatives, including:

- The Indian Ministry of Environment and Forests and NOU could officially endorse the EC flammable safety standard as an interim measure while facilitating rapid development of Indian safety standards.
- Leadership companies in India could commit to produce low-GWP, better life-cycle climate performance, room air conditioners for green buildings, including apartments and condominiums. The government of India could signal endorsement of LCCP for appropriate applications.

Some actions from outside India would also help shift the market and spur efforts to leapfrog to lower-GWP alternatives, including:

- Market acceptance and promotion of HC-290 room air conditioners by governments and non-governmental organizations concerned with climate change would reward pioneer companies such as Gree and Godrej, whose domestic sales depend on confidence that these systems are safe and are the next-generation technology.
- The E.U. vehicle air-conditioning directive affects Indian automobile producers that export models to Europe. The market will be driven further if African and Asian countries that import Indian vehicles adopt similar provisions.
- Rapid transition to low-GWP refrigerants in European, Japanese, and North American markets would send a strong signal that HFC-134a is obsolete for mobile air conditioners and that HFC-410a is obsolete for room air conditioners. This action would bring HFO-1234yf to world-scale production for mobile air conditioners with lower competitive prices. It would also transform manufacturing of room air conditioners in China, India, Korea, Thailand, and other countries.

ABOUT THE PROJECT TEAM

The Council on Energy, Environment and Water (CEEW) is an independent, not-for-profit policy research institution. CEEW addresses pressing global challenges through an integrated and internationally focused approach. It does so through high-quality research, partnerships with public and private institutions, and engagement with and outreach to the wider public. www.ceew.in

The Institute for Governance & Sustainable Development (IGSD) promotes just and sustainable societies and seeks to protect the environment by advancing the understanding, development and implementation of effective, accountable and democratic systems of governance for sustainable development. www.igsd.org

The Natural Resources Defense Council (NRDC) is a highly effective environmental action group, combining the grassroots power of 1.4 million members and online activists with the courtroom clout and expertise of more than 350 lawyers, scientists and other professionals. www.nrdc.org

The Energy and Resources Institute (TERI) develops solutions to global problems in the fields of energy, environment and current patterns of development not only by identifying and articulating intellectual challenges straddling a number of disciplines of knowledge but also by mounting research, training, and demonstration projects leading to development of specific problem-based advanced technologies that help carry benefits to society at large. www.teriin.org/index.php

Endnotes

1 United Nations Environmental Programme, 2011, *HFCs: A Critical Link in Protecting Climate and the Ozone Layer, 2011,* available at: http://www.unep.org/dewa/Portals/67/pdf/HFC_report.pdf.

2 Source of data on impacts of climate change from R.V. Cruz *et al.*, "'Asia," in: M.L. Parry *et al.* (eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2007), 469.

3 The final report will consolidate relevant market data, characterize what makes the India market unique and challenging, catalogue the "drivers" changing Indian and export markets, and summarize the combined wisdom of industry leaders and engineers on what can be done when to leapfrog or phase-down high-GWP HFCs in India. The project team includes Stephen O. Andersen (IGSD); Arunabha Ghosh and Rajeev Palakshappa (CEEW); Anjali Jaiswal, Bhaskar Deol, David Doniger, and Jake Schmidt (NRDC); Rajesh Menon, Surender Rail and Jagpreet Walia (CII); and Girish Sethi and P. Sridhar Chidambaram (TERI). The views presented here are those of the listed authors and organizations and do not necessarily represent views of other organizations, including the Montreal Protocol Technology and Economic Assessment Panel, of which Stephen Andersen is a member.

4 Residential Consumption of Electricity in India, World Bank Data, July 2008, http://moef.nic.in/downloads/public-information/Residentialpowerconsumption.pdf

5 Ibid.

6 Ibid.

7 Use of ACs in Indian homes and businesses is projected to rise exponentially, from approximately 3 million units in 2009 to about 200 million units by 2030, meaning more than 150 million AC units will be installed over the next 20 years. *See* Michael A. McNeil and Maithili Iyer, *Techno-Economic Analysis of Indian Draft Standard Levels for Room Air Conditioners*, Lawrence Berkeley National Laboratory, March 2007; RAMA, 2011 (*updating LBNL study's projections*); The World Bank predicts increased installed inventory and annual sales of air conditioners in India, as well as the energy consumed from air conditioner use. By 2016, the World Bank projects that the installed inventory of air conditioners will reach 10.2 million—an increase of 118 percent above the inventory in 2011. According to this estimate, air conditioner sales are predicted to more than double between 2011 and 2016, reaching 1.7 million units. The resulting consumed power supply by air conditioning is projected to increase to 50,000 GWh/year by 2031 — an almost ten-fold increase. Source: Residential Consumption of Electricity in India World Bank Data, July 2008, http://moef.nic.in/downloads/public-information/Residentialpowerconsumption.pdf.

8 Ibid.

9 Guus J.M. Velders, David W. Fahey, John S. Daniel, Mack McFarland and Stephen O. Andersen, "The Large Contribution of Projected HFC Emissions to Future Climate Forcing," in the Proceedings Of The National Academy Of Sciences, 106, 10949-10954, 2009.

10 Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:161:0012:0018:EN:PDF.

11 More information available at: http://www.epa.gov/oms/climate/documents/420f12051.pdf.

12 The Significant New Alternatives Policy (SNAP) Program is administered by the US EPA under authority provided by Section 612(c) of the U.S. Clean Air Act. Under the SNAP program US EPA is authorized to identify and publish lists of acceptable and unacceptable substitutes ozone-depleting substances. A number of alternative refrigerants have been approved under this program that have a lower GWP; See Natural Resources Defense Council, IGSD, and EIA petition to the Environmental Protection Agency, available at: http://docs.nrdc.org/globalwarming/files/glo_12042701a.pdf.

13 Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:161:0012:0018:EN:PDF.

14 UNEP/OzL.Pro/ExCom/63/26 table 10 on page 72.

15 RAMA, in developing refrigeration and air conditioning sector strategies identified 214 manufacturers in all subsectors with market research agency IMRB surveyed a representative sample of 39 large-scale, 21 medium-scale and 50 small-scale manufacturers.

16 Shanthi Kannan, "Winds of change in Indian AC scene," *The Hindu*, Feb. 4, 2012..

17 The government of India National Ozone Unit, with the support of RAMA, has built strong awareness of low-GWP room air conditioner technology; GIZ has published detailed handbooks for HC-290 room air conditioner design for safety and energy efficiency and manufacturing installation and service safety. Godrej has offered its competitors the opportunity to tour its manufacturing facility. There have been numerous briefings from Indian and foreign companies offering technical solutions. However, industry stakeholders pointed out that the GIZ/Godrej H-290 demonstration project was completed too late to influence the choices of other companies for HCFC Phase-out Management Plan (HPMP) and Multilateral Fund (MLF) funding.

18 International workshops on next-generation MAC technology sponsored by The Energy Resources Institute (TERI), the Mobile Air Conditioning Climate Protection Partnership (MACCPP), SAE International, and UNEP Department of Technology, Industry and Economics (DTIE) were held in New Delhi in 2005 and 2010.

19 John Rugh, Valerie Hovland, and Stephen O. Andersen, *Significant Fuel Savings and Emission Reductions by Improving Vehicle Air Conditioning*, 15th Annual Earth Technologies Forum and Mobile Air Conditioning Summit, April 15, 2004.

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