INTERNATIONAL

# TECHNOLOGICAL CHANGE IN THE PRODUCTION SECTOR UNDER THE MONTREAL PROTOCOL

CENTER FOR CLIMATE AND ENERGY SOLUTIONS

Steve Seidel
Jason Ye
*Center for Climate and Energy Solution*

Stephen O. Andersen
*Institute for Governance & Sustainable Development*

October 2015

## INTRODUCTION

With negotiations under the Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol) considering limits on hydrofluorocarbons (HFCs) as potent greenhouse gases, this paper examines past transitions during the relatively short, but dynamic history of this international treaty. It focuses on past shifts from chlorofluorocarbons (CFCs) to hydrochlorofluorocarbons (HCFCs) to HFCs, with the goal of identifying lessons that can inform discussions aimed at transitioning from high-global warming potential (high-GWP) HFCs.[1]

At an HFC management workshop organized by the Ozone Secretariat in April 2015, a number of issues were raised about the availability and feasibility of alternatives to HFCs.[2]

- Whether and when alternatives to high-GWP HFCs will be available in adequate quantities, from multiple suppliers, and at reasonable prices;
- Whether patents on the new technologies held by a few companies could limit access to substitutes by other companies, particularly those in Article 5 Parties; and
- Whether the guidelines under the Protocol's Multilateral Fund would support funding for patents and licensing.

Answers to these questions are of critical concern to the Montreal Protocol Parties as they consider actions to phase down HFCs.

## KEY CONCLUSIONS

- Past responses to control measures under the Montreal Protocol demonstrate that substitute compounds (and not-in-kind substitutes and alternatives) will be available in a timely manner, from multiple suppliers, in sufficient quantities, and at prices far lower than currently expected.
- While production of CFCs and HCFCs was initially concentrated in non-Article 5 Parties, over time production of these compounds shifted, with substantial production occurring in Article 5 Parties.[3] For example, China rapidly expanded its production of these compounds due to the prevalence of inexpensive feedstocks, low energy prices, and its centers of chemical excellence.
- Similarly, HFC production was initially concentrated in non-Article 5 Parties, but over time shifted to Article 5 Parties, with China and India now accounting for half of global output.
- With very low global warming potentials, hydrofluoroolefins (HFOs) have recently been developed as substitutes for HFCs, and are being produced in both Article 5 and non-Article 5

Parties. This reflects the international trade in these chemicals, the ease of expanding or building new production facilities in Article 5 Parties, the growth of these countries as manufacturers of products using these chemicals for global markets, and the improved technological capabilities of their producers.

- Finance from the protocol's Multilateral Fund for the phaseout of production of CFCs and HCFCs in Article 5 Parties has been based on compensating for the lost revenues and premature retirement of existing production plants. Once an amount is determined, recipient countries have flexibility in how they use the funds to achieve the required production phaseout. In one case (China), a portion of this funding was directed to a new plant producing a chemical substitute (HFC-134a).
- A few transnational chemical companies initially controlled patents covering the production processes for HFCs, but over time other companies developed and patented additional processes, including companies in Article 5 Parties. Furthermore, HFC production processes developed and patented in response to the original 1974 warning about ozone depletion by Molina and Rowland were more than a decade old when the Montreal Protocol was signed in 1987 and were expiring by the time Article 5 Party control measures entered into force.[4]
- Application patents have been filed on the use (as opposed to the production) of certain low-GWP alternatives in a number of sectors. These types of patents have been used to some extent in the past and are generally addressed through cross-licensing and royalty arrangements among patent holders and users. Any licensing costs are typically reflected in the amount paid for the chemical alternatives or the covered technology. To the extent application patents are increasing in scope and number, they could potentially affect the costs of transitioning from high-GWP HFCs.
- Not-in-kind substitutes, recycling and emission reductions have historically replaced up to 85 percent of ozone-depleting substances. These typically unpatented solutions are likely to continue to play an important role in limiting demand for new chemical alternatives and in expanding the range of options available as substitutes. In doing so, they provide price competition and limit the cost impacts of patents on the production or use of specific chemical alternatives.

## RECOMMENDATIONS

- As part of its regular reports to the Parties, the Montreal Protocol's Technology and Economic Assessment Panel (TEAP) should provide information on the status of the production of alternatives to high-GWP compounds, including the number and location of producers, estimates on the quantities of alternatives produced and their market prices, and tracking of patents on critical alternatives and substitutes, including patent expiration dates.
- With the addition of any new controlled substances to the Montreal Protocol, the Parties will want to ensure that the Multilateral Fund continues to play an effective role in supporting compliance by Article 5 Parties. Based on the existing indicative list of incremental costs, an HFC amendment should identify any categories of costs where the Executive Committee should be asked to develop in a timely manner any additional or modified guidance related to controls on HFCs or the production of low-GWP alternatives.
- To address concerns about the potential constraints created by application patents, the Multilateral Fund should be directed to explore a range of options, including: ways to facilitate the continued use of licensing and royalty agreements between patent holders and users with resulting costs paid for by the Multilateral Fund; voluntary contributions by patent holders and technology developers for open use of these assets by all Article 5 Parties; and the feasibility of negotiating license agreements paid for by the fund for open access to specific technologies (sometimes referred to as patent pools) for use by Article 5 Parties.

- Significant production of low-GWP alternatives is already planned or occurring in Article 5 Parties. In addition, as leading suppliers of products (e.g., air conditioners, refrigerators) to global markets, manufacturers in many Article 5 Parties must shift in the near-term to avoid prohibitions on exports of products containing HFCs to a developed country where HFC restrictions are in effect. To facilitate a smooth transition to low-GWP alternatives, an HFC amendment should provide near-term funding of alternatives to high-GWP HFCs in Article 5 Parties, while limiting the length of the grace period between controls on Article 5 and non-Article 5 Parties.

## TECHNOLOGY TRANSFER UNDER THE PROTOCOL AND ITS MULTILATERAL FUND

From the earliest days of the Montreal Protocol, Parties recognized that effective technology transfer to Article 5 Parties was a critical element to the success of the treaty. In 1990, a significant amendment to the protocol was adopted with that goal in mind. The amendment called for the creation of the protocol's Multilateral Fund "to meet all agreed incremental costs of such [Article 5] parties in order to enable compliance with the control measures of the protocol."[5]

To implement the Multilateral Fund, the Parties also agreed to an indicative list of categories of incremental costs along with a set of guiding general concepts. The indicative list includes specific provisions related to the production sector that cover converting or retiring existing production facilities, the costs of establishing new ones, or the importation of substitutes. (Appendix A contains the indicative list of incremental costs.) While the indicative list itself has never been modified, one of the strengths of the Multilateral Fund has been the ability of the fund's Executive Committee (consisting of seven representatives from Article 5 Parties and seven from non-Article 5 Parties) to adapt how it applies these terms to the changing needs encountered by Article 5 Parties in meeting the protocol's control measures.

## AVAILABILITY AND PRICE OF ALTERNATIVES

One of the important issues identified at the April 2015 HFC Management Workshop in Bangkok involved concerns about whether and when new substitute chemicals to replace high-GWP HFCs would be available and whether they would be produced by multiple suppliers, in adequate quantities, and at reasonable prices.

These same issues were also front and center during negotiations of the original protocol when 55 countries and the European Economic Community gathered in October 1987 to grapple with decisions on possible limits on CFCs and halons, in what would become the Montreal Protocol. In fact, just as the Ozone Secretariat organized the recent workshop on alternatives technologies to HFCs in Bangkok, there was also a workshop in Rome in 1986 to help inform negotiators about the current state of alternatives to ozone-depleting substances as a lead up to the negotiations scheduled to culminate the following year in Montreal.

As is currently the case for alternatives to high-GWP HFCs, no single option was expected to replace CFCs. Hydrocarbons were being implemented in some countries as substitutes for CFCs in consumer aerosol products. HCFC-22 was also widely available and considered a possible replacement in some applications. New HCFCs had been identified as potential replacements, particularly HCFC-141b for foam applications, HCFC-225 for solvents, and HCFC-123 for building air conditioning chillers, but these new HCFCs were not yet fully tested or in commercial production. HFC-134a was widely viewed as a possible replacement for many refrigerant applications, but it too was not yet through toxicity testing or in commercial-scale production. Technology experts also recognized that emissions could substantially be reduced through recycling and recovery of CFCs, practices that now seem commonplace, but were not widely used prior to the Montreal Protocol. Certainty about the availability, timing and costs of alternatives was anything but settled at the time the protocol was signed in 1987.

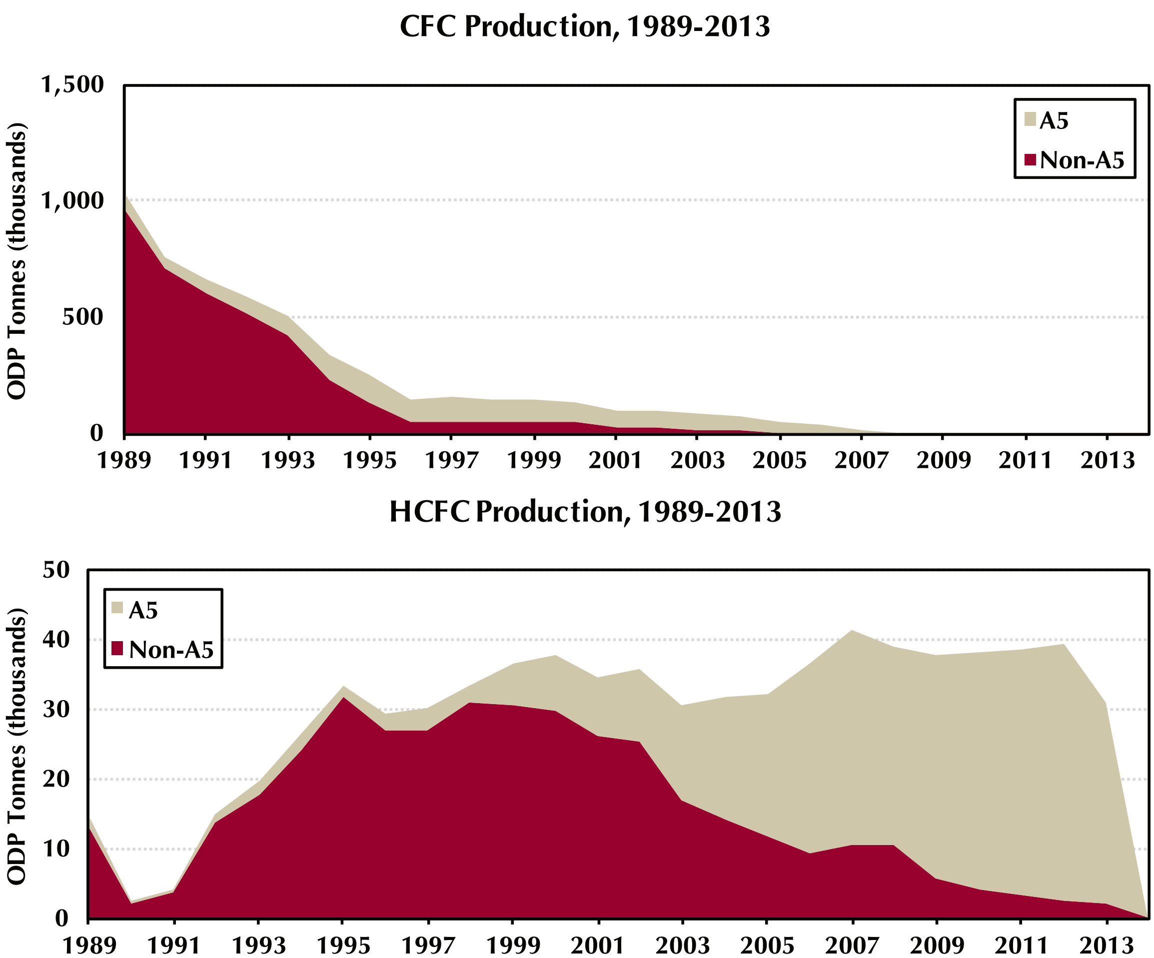
### TIMING OF AVAILABILITY OF HFC-134A[6]

HFC-134a was considered the primary alternative to replace CFC-12 across a range of applications because: 1) it was a close match for key thermal and physical properties, 2) it did not contribute to ozone depletion, 3) it had one eighth the GWP of the CFC it was replacing,[7] and 4) it was non-flammable and had low toxicity. But during the negotiations leading up to the Montreal Protocol in 1987, HFC-134a was only available in limited, laboratory-produced quantities. Commercial-scale production of HFC-134a would not begin until the early 1990s. While short-term toxicity tests had been done, long-term exposure testing was yet to be initiated and the substitute would not be submitted for approval under the Toxic Substance Control Act in the United States for several more years.[8]

An international panel of chemical experts organized by the U.S. Environmental Protection Agency in 1988 looked at the state of alternatives and what it would take to bring new substitutes to the market.[9] It concluded that the most significant barrier to the commercialization of alternatives was the absence of global controls on CFCs.

---

## FIGURE 1: CFC and HCFC Production by Montreal Protocol Parties, 1989–2013




*Source: "Data Center," Ozone Secretariat, last accessed June 29, 2015,* http://ozone.unep.org/reporting.

It also looked at the steps and time it would take to commercialize alternatives and concluded that it would take companies a minimum of five years and a maximum of 10 years to bring new compounds to market.

### GROWING NUMBER OF HFC-134A PRODUCERS IN BOTH NON-ARTICLE 5 AND ARTICLE 5 PARTIES

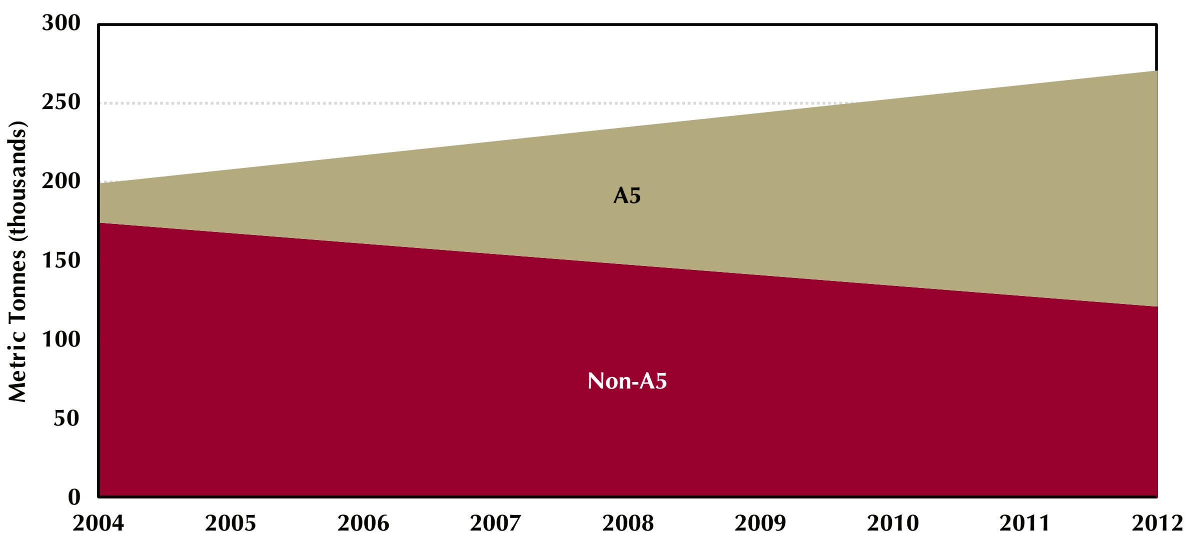
Of critical concern to potential users of any new chemical is whether adequate supplies will be available and whether there will be multiple suppliers to ensure price competition and reliability of supply. Despite conclusions by technical experts in 1988 that commercialization of alternatives would take a minimum of 5 years, the first commercial-scale HFC-134a production plants were opened by ICI and DuPont[10] in 1990. Over the next four years a number of additional producers opened commercial-scale production facilities, and volumes increased to 50,000 metric tons. Volumes would double again only three years later.[11] As regulatory restrictions on CFCs took effect in many developed countries and as many companies voluntarily shifted to alternatives in advance of these mandated controls, the growing demand for alternatives was being met by rapidly expanding production. The feared shortage of HFC-134a never materialized, and throughout this time it was sold at competitive prices that were substantially less than pre-commercial levels.

Based on data for 1986 submitted to the Montreal Protocol's Secretariat, nine Parties operating under Article 5 and thirteen non-Article 5 Parties operated facilities that produced CFCs. With a relatively simple production process, small-volume production was possible and scattered throughout the world. Nonetheless, the larger plants in developed countries were responsible for roughly 95 percent of total global output.

Figure 1 shows that, over time, production of CFCs shifted from non-Article 5 Parties to Article 5 Parties, in part reflecting the grace period which allowed use to grow in Article 5 Parties at the same time it declined in non-Article 5 Parties. This same shift of production to Article 5 Parties is even more pronounced for HCFCs.

The first HFC production facilities were built in developed countries, where demand was strongest due to early regulatory controls on CFCs. As shown in Figure 2, over time the number of producers and percentage of production of HFC-134a in Article 5 Parties, particularly in China, increased dramatically. While no comprehensive data exist, information on global HFC production supplied by the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) and the TEAP shows this

**FIGURE 2: HFC-134a Production, 2004–2012**




*Source: "Production and Sales Data," AFEAS, last accessed June 29, 2015,* http://www.afeas.org/data.php*. And "Decision XXVI/9 Task Force Report Additional Information on Alternatives to Ozone-Depleting Substances," Report on the Technology and Economic Assessment Panel (Nairobi, Kenya: United Nations Environment Programme Ozone Secretariat, 2015),* http://conf.montreal-protocol.org/meeting/oewg/oewg-36/presession/Background%20Documents%20are%20available%20in%20English%20only/TEAP_Task-Force-XXVI-9_Report-June-2015.pdf.

shift. Current estimates suggest that half of HFC-134a production now occurs in Article 5 Parties, with China by far the largest producer, but with India also producing HFCs.

### PRICES OF HFC-134A OVER TIME

Notwithstanding concerns about the high costs of CFC alternatives in the early days of the protocol, the cost of HFC-134a decreased over time as the number of production facilities expanded around the world. In the 1980s, CFCs had become commodity products, widely available from multiple suppliers at low costs. Prices were roughly $1.50 kg ($3.30 kg adjusted to current dollars). Given a more complex process and the need to build new production facilities, initial estimates were that HFC-134a would have to sell from as much as 3-5 times the current CFC prices (DuPont, EPA) to as much as 6-8 times current prices (ICI).[12]

While HFC prices have fluctuated over the years due to changes in the costs of feedstocks and temporary production disruptions, the early concerns about sky-high costs have proven to be unwarranted. With more companies becoming suppliers of HFC-134a and increased production capacity, the $7.00 kg price for HFC-134a is currently slightly more than double (in real terms) what CFCs had been in the 1980s, an increase substantially less than initial expectations.

### CONCLUSIONS

Concerns about the costs and availability of new chemical substitutes have been an issue dating as far back as the negotiations leading up to the original Montreal Protocol in 1987. With increased regulatory certainty, a wide range of HCFCs, HFCs and not-in-kind substitutes and alternatives were developed, their availability rapidly increased, and their costs decreased. While double the cost of the CFCs it replaced, HFC-134a is nowhere near the 3-8 times more expensive that had been predicted when it was first discussed as an alternative. While CFCs, HCFCs and more recently HFCs were first produced in non-Article 5 Parties, over time the majority of their production shifted to Article 5 Parties.

## ROLE OF THE MULTILATERAL FUND IN PRODUCTION SECTOR TRANSITIONS

### DEFINING INCREMENTAL COSTS FOR THE PRODUCTION SECTOR

The cost in Article 5 Parties of transitioning the production sector from CFCs to alternatives is directly addressed in the indicative list of agreed incremental costs that guides actions under the Multilateral Fund (See Appendix A). Specific to the production sector, the categories of incremental costs include: (i) the cost of converting existing production facilities; (ii) the costs of premature retirement (except where replaced by new or converted capacity); (iii) costs of establishing new production facilities for substitutes; (iv) net operational costs; and (v) cost of import of substitutes.

The indicative list specifies that any incremental recurring costs should apply only for a transition period to be defined by the Parties and that the "cost of patents and designs and incremental costs of royalties" qualify for funding under both converting existing production facilities and establishing new ones. The indicative list also states that the "most cost-effective and efficient option should be chosen, taking into account the national industrial strategy of the recipient Party." Balancing the goal of cost effectiveness, while taking a country's desired industrial strategy into consideration, has proven to be one of the most significant challenges faced by the Multilateral Fund.

### MULTILATERAL FUND'S EXPERIENCE WITH THE PRODUCTION SECTOR

The Multilateral Fund approved projects totaling $275 million for phasing out CFC production in five Article 5 Parties by the mandated phaseout date of 2010.[13] The incremental costs covered by the fund for these projects were estimated based on the costs of the premature idleness or forced retirement of the CFC production facilities. Project costs were calculated on this basis taking into consideration a range of issues including: the costs of premature plant closures; the proper dismantling and disposal of equipment; the degree of non-Article 5 ownership and extent of exports to non-Article 5 Parties; the time period to be covered by recurring costs; the ability to use the facility to produce feedstocks or to shift to the production of other chemicals; the amount of the capacity historically in use; and other factors.

The two largest production sector phaseout projects were in China and India. In 1999 the Executive Committee approved a project with $150 million earmarked for the CFC production sector phaseout in China. The following year, a CFC production sector phaseout project for India was approved for $82 million.

Once the Executive Committee approved the amount of the production sector phaseout for an Article 5 Party, recipient countries have latitude on how to most effectively use the allocated funds to achieve the mandated goals and timelines for eliminating production. In one case, China used some of the money ($17 million) included in its phaseout project to fund Xi'an Jinzu Modern to construct a 5,000 tons per year HFC-134a plant.[14] This was undertaken using the company's own proprietary patents for producing HFC-134a.[15]

In India's case, several producers explored the feasibility of licensing a patented HFC production process from a transnational company. They found that their only options were to pay an extremely high fee for access to an existing patent, to agree to become a minority stakeholder with a transnational chemical company in a joint venture, or to accept a licensing agreement with limits on exports. [16] None of these options proved to be acceptable, but over time one Indian company has become an HFC-134a producer.

The Multilateral Fund's decision on compensation for India for the phaseout of CFC production was based on estimates of the lost profits from its CFC production facilities and the net financial impact of converting its CFC production facilities to the manufacture of other substances including HCFCs. In keeping with Executive Committee policy to avoid funding double conversions—from CFCs to HCFCs and then from HCFCs to something else—the agreement with India contained language prohibiting any additional funding from the Multilateral Fund for related activities including the development of infrastructure for producing alternatives or for the eventual closure of any of the CFC facilities that may convert to HCFC production. The agreement states that this requirement would apply regardless of future changes to the protocol.[17]

The Parties addressed the issue of paying for second conversions in a decision accompanying their action in 2007 to accelerate the phaseout of HCFCs. In Decision XIX/6, the Parties called for replenishing the Multilateral Fund with sufficient funding to meet all agreed incremental costs related to the accelerated HCFC phaseout and directed "the Executive Committee of the Multilateral Fund to make the necessary changes to the eligibility criteria related to the post-1995 facilities and second conversions."[18]

Despite repeated efforts over several years to complete work on funding guidelines for the phaseout of HCFC production facilities, the Executive Committee has failed to reach agreement. The issue of whether CFC production facilities that were paid by the Multilateral Fund to convert to HCFC production should be paid when HCFCs are phased out remains a point of contention.

While continuing to discuss the guidelines, the fund's Executive Committee has moved forward and approved a project totaling $385 million (disbursed over 17 years) for phasing out HCFCs in China. This project covers the phaseout of an estimated 92 percent of total controlled HCFCs produced by Article 5 Parties. The remaining HCFC production is located in Mexico, India, Argentina, DPR Korea, and Venezuela.[19] The Executive Committee continues to debate issues concerning whether these facilities that had been converted under previous projects from CFC to HCFC production should be eligible for additional funding.

## PROVISIONS RELATED TO THE MULTILATERAL FUND IN HFC AMENDMENT PROPOSALS

Whenever the Parties have amended the protocol to add a new category of controlled substances, the role of the Multilateral Fund has been a key element of reaching agreement. The recent submissions for an HFC amendment from a number of Parties include language specifically addressing the role of the Multilateral Fund (see Table 1). The proposals from the European Union and North America make it clear that the "agreed incremental costs" of compliance with HFC controls by Article 5 Parties would be covered by the Multilateral Fund. The Island States proposal also specifies that the Multilateral Fund would continue in its role to support compliance by Article 5 Parties, but uses a different term, "agreed ***full*** incremental costs,"[20] to describe what would be covered. This proposal calls for the Parties to decide by decision what is covered by incremental costs and also calls for financing and technical cooperation to promote the use of energy efficiency.

The proposal from India also envisions an expanded role for the Multilateral Fund to enable Article 5 Parties to comply with HFC control measures. India's proposal describes in detail that the fund should pay for "full costs of conversion." The language it proposes is:

> The financial mechanism shall meet compensation for lost profit stream for gradual closure of production facilities of HFCs, "Full costs of conversion" to HFC production facilities, manufacturing unit of equipment (s)/product(s) from HFCs to low-GWP/zero-GWP alternative(s), operating costs for at least 5 years and adequate funding for servicing sector including training of technicians, awareness, equipment support to technicians, compensation for obsolescence/ immature retirement of equipment, etc.[21]

The proposal states that this scope of coverage would supersede existing guidelines under the Multilateral Fund as applied to controls on HFCs.

It also calls for the addition of a new paragraph to the protocol on technology transfer that states:

> "Protocol shall ensure that the transfer of technology including technologies with Intellectual Property Rights, process and application patents to Parties operating under paragraph 1 of Article 5 of the protocol for phasedown of Annex F and Annex G substances both for production and consumption."

The African Group also submitted a conference room paper that provides an outline of a proposal to limit HFCs. It addresses the role of the Multilateral Fund by stating that "the financial and technical support from developed countries to developing countries in order to transit from ozone-depleting substances and/ or high-GWP HFCs towards economically viable and environmentally sound alternatives to HFCs has to be confirmed, sufficient and unconditional."[22]

## CONCLUSIONS

One of the strengths of the Multilateral Fund has been its ability to work within the existing list of agreed incremental costs, but to modify existing guidelines or develop new ones to meet changing circumstances and needs encountered by Article 5 Parties. For example, it has created new categories for estimating incremental costs for low and very low emitting countries and for small and medium size enterprises. It has also funded institutional strengthening in Article 5 Parties as a critical program element despite it not being explicitly listed among the categories of incremental costs. In the context of any HFC amendment, it is critical that any unique issues be identified where the fund's Executive Committee

**TABLE 1: Multilateral Fund Provisions in Proposed HFC Amendments**

| COUNTRY | PROVISIONS DESCRIBING ROLE OF MULTILATERAL FUND (MLF) |
|---|---|
| *African Group* | Financial and technical support to Article 5 Parties must be confirmed, sufficient and unconditional. |
| *European Union* | Measures related to HFC controls by Article 5 Parties will be funded through the MLF with policies and obligations related to HFCs to be decided by the Parties through means of a decision. |
| *India* | The MLF shall pay for full conversion costs including:<br>• compensation for lost profit stream for closing of HFC production facilities;<br>• full cost of converting chemical production plants and/or manufacturing;<br>• operating costs for at least five years;<br>• adequate funding for service sector training and equipment;<br>• compensation for obsolescence or immature retirement of equipment. |
| *Island States* | Incremental costs shall be decided by the meeting of the Parties. The financial mechanism shall be strengthened in order to promote energy efficiency and to overcome barriers to uptake of low-GWP alternatives. |
| *North America* | The MLF will provide support to Article 5 Parties to implement the controls called for in the proposed amendment. |

may need to develop new guidelines or make changes in existing guidelines.

For example, given that HFCs are being addressed because of concerns for climate change, there may be a need for the Executive Committee to provide additional guidance to address issues related to how the impact of projects on energy efficiency should be considered.

Some portion of the HFCs produced in Article 5 Parties is currently exported to non-Article 5 Parties, either directly or in products. As near-term regulations limiting HFCs take effect in these countries, production of HFCs in Article 5 Parties also will have to shift to alternatives to meet changing market demand. As part of action on an HFC amendment, the Parties may respond to these changing market conditions in the schedule of reductions and grace period provided for Article 5 Parties, while also allowing for near-term funding for early action on HFCs by these Parties.

## ROLE OF PATENTS AND NOT-IN-KIND SUBSTITUTES (NIKS)

Despite concerns that a small number of chemical manufacturers in non-Article 5 Parties initially held patents on the production of HFC-134a, over time both the number of producers expanded and production by companies in Article 5 Parties grew significantly. A key issue is whether that pattern will be repeated in the transition to low-GWP alternatives and HFOs or whether new factors are in play that will limit access to production and use in Article 5 Parties of these next generation alternatives.

### IMPACT OF PATENTS ON FLUOROCARBON PRODUCTION

Past experience has shown that while one chemical company takes the lead in developing a new alternative and is first to file a patent for a particular production process, over time other companies develop alternative production routes also qualifying for patents. But process patents are not the only aspect of production subject to patents. Process innovations aimed at increasing yields, decreasing impurities, and utilizing certain catalysts or feedstocks have all been the subject of patents. The availability of inexpensive raw materials or feedstocks is also an important factor in determining the commercial viability of a specific production facility.[23]

Companies seeking to produce a new chemical compound generally have four options. They can: develop their own unique process for producing the compound; license the technology from another company; participate in a joint venture; or wait the 20 years covered by a patent, then utilize the information contained in it and begin production themselves. Several of these paths have been taken in the past and are likely to be taken again in the future.

HFC-134a was first covered by a production patent filed by DuPont in 1980.[24] Within a few years, a large number of companies in non-Article 5 Parties had developed their own unique processes for making HFC-134a and were producing at their own facilities.

Over time, growth of HFC-134a production expanded in Article 5 Parties, with extensive production by multiple producers in China and by a single producer in India.[25] It is important to note that the build-up of production in Article 5 Parties began around 2005, after the initial set of production process patents had expired. It is also worth noting that much of the production in Article 5 Parties was and remains locally owned and not part of a joint venture or a subsidiary of a transnational company. Some of these companies in Article 5 Parties have developed their own patents for producing HFC-134a.[26] It is unclear the extent to which the timing of expanded production of HFC-134a in Article 5 Parties was directly related to the growth in demand for these compounds in these countries or was delayed due to patent related constraints.

### EARLY STAGE PRODUCTION OF HFOS

With regulations limiting the use of high-GWP HFCs now in place in a number of non-Article 5 Parties, there is increased interest in substitute chemicals and not-in-kind substitutes and alternatives. A number of transnational chemical companies hold or have applied for a variety of production process patents on HFO-1234yf.[27] But patents on producing HFOs have been applied for by several different entities in China.[28]

Table 2 details the current status of production for several different HFOs and for existing HFC-32 (a low-

## TABLE 2: Production of Key Chemical Alternatives to High-GWP HFCs

| CHEMICAL | PRODUCER | LOCATION OF PRODUCTION | STATUS OF PRODUCTION |
|---|---|---|---|
| *HFO-1234yf* | Arkema Changshu | China | 2016 |
| | Chemours | Japan | In production |
| | 3F Zhonghao (Chemours) | China | In production<br>Expansion (2015)<br>Expansion (2016) |
| | AGC (Honeywell) | Japan | 2015 |
| | Honeywell | U.S. | 2016 |
| *HFO-1234ze* | Honeywell | U.S. | In production |
| *HFO-1233zd* | Arkema | TBD | TBD |
| | Central Glass (Honeywell) | Japan | In production |
| | Chemours | China | 2016 |
| *HFO-1336mzz* | Chemours | China | 2016 |
| *HFC-32* | Changshu 3F Zhonghao New Chemical Materials Co., Ltd. | China | In production |
| | Daikin | Japan | In production |
| | Jiangsu Meilan | China | In production |
| | Linhai Limin | China | In production |
| | Shandong Dongyue | China | In production |
| | Shandong Huaan New Materials Co.. | China | In production |
| | Sinochem Lantian | China | In production |
| | SRF | India | Announced plans to convert HFC-134a plant to make both HFC-134a and HFC-32 |
| | Zhejiang Quhua (Juhua) | China | In production |
| | Zhejiang Pujiang Bailian | China | In production |
| | Zhejiang Sanmei | China | In production |

*Source: Compiled from company announcements and websites.*

*The authors welcome corrections and additions to the information in this table.*

GWP substitute) production plants in both Article 5 and non-Article 5 Parties. It shows that several commercial-scale HFO-1234yf plants have been announced, with two located in China, one in the United States, and two in Japan. In China, Chemours (recent DuPont spin-off) has a partnership with 3F Zhonghao on an HFO-1234yf facility and Arkema Changshu has also announced plans to manufacture this alternative. An agreement has been announced that Asahi Glass will produce HFO-1234yf for Honeywell in Japan, and Honeywell has also announced plans for production in Louisiana.[29]

Table 2 also shows the initial plans for production of other HFO substitutes and the large number of producers, particularly in China, of HFC-32, a low-GWP substitute for many air conditioning applications.

The transition to HFOs appears to differ in important respects from the previous transition from CFCs to HFCs. Unlike HFCs, a significant portion of HFO production capacity is initially being installed in an Article 5 Party (China), and this early production is being undertaken both by a subsidiary of a transnational corporation and by a locally-owned company in cooperation with a transnational corporation.

A number of factors may be contributing to these differences. Article 5 producers of fluorocarbons have developed considerable expertise, have access to low-cost feedstock materials, and can sometimes more readily and quickly build new production plants at existing or new facilities. Much of the initial production in Article 5 Parties of HFOs will likely be used to meet growing market demand in non-Article 5 Parties where regulations on HFCs have been imposed. In addition, because Article 5 Parties manufacture some products for export markets to countries with national regulations on HFCs (e.g., air conditioners, refrigeration equipment, automobile air conditioning), demand for HFOs is likely to be stronger than in the past in these countries at the early stages of the new product cycle.

The use of a joint production agreement with a transnational company may also in part reflect the fact that patents on HFOs are relatively new. A producer in an Article 5 Party may decide not to take the time and resources to develop its own production processes or to wait for existing patents to expire because of concern that it might end up missing significant near-term market opportunities in these substitutes.

## ROLE OF APPLICATION PATENTS

While this paper focuses on the production sector, the role of application patents has the potential to play a part in limiting access in Article 5 Parties to the use of new chemical substitutes. Application patents focus on the use of specified chemicals in designated sectors or technologies. [30] They have been around for many years and are not new or unique to the sectors impacted by the Montreal Protocol. In the past, licensing of technologies covered by application patents has typically occurred between affected companies (e.g., patent holders and users), and the costs have been rolled into the amount paid for the new technology. There are a few cases where the Multilateral Fund has explicitly paid for licenses and royalties, but in the vast majority of investment projects, either the technologies were no longer covered by patents or any patent-related costs were simply imbedded in the price paid for the technology itself.[31]

Issues concerning application patents have recently been raised for two use sectors critical to a phasedown of HFCs—room air conditioning and motor vehicle air conditioning.

One potentially attractive option for replacing HCFC-22 with a low-GWP alternative in the room air conditioning sector is HFC-32. In 2011, the Indonesian Ministry of Environment and Ministry of Industry and the Japan Ministry of Economy Trade and Industry (METI) plus Daikin, Panasonic, Fujitsu, Hitachi and Toshiba—with the support of the United Nations Development Program and the Institute for Governance & Sustainable Development formed a partnership to commercialize HFC-32 room air conditioners to avoid shifting to a high-GWP HFC.[32]

Use of HFC-32 for room air conditioning is covered by a number of application patents held by Daikin. In 2011, Daikin announced free access to a number of these patents for all Article 5 Parties (except those that had changed status) to use in converting existing air conditioning manufacturing facilities to HFC-32-based technology.[33] In September 2015, Daikin announced that it would make 93 patents on HFC-32 use in cooling and heating technologies freely available globally to all manufacturers.[34]

Vehicle air conditioning is another significant end use sector for HFC-134a and, due to regulations in the European Union and the United States, the first sector shifting out of HFC-134a. The vast majority of companies in these countries have announced their intent to shift to HFO-1234yf. A use application patent has been issued to Honeywell for certain applications including mobile air conditioning.[35] Other companies holding HFO-1234yf production patents and other potential HFO-1234yf producers and users have challenged this application patent. While the EU has issued an invalidation ruling on this application patent, it is currently under appeal and remains in effect. Despite the existence of this application patent and the uncertainty of its legal status, approximately 7 million cars will be on the road by the end of the year with HFO-1234yf as their coolant.[36]

## BOX 1: The Shift Away from HFC-134a for Motor Vehicle Air Conditioners (MACs)

Vehicle manufacturers were one of the first sectors to shift out of CFC-12 and, over the last few years, have also led the way in transitioning to a low-GWP alternative. The industry is made up of a relatively few large manufacturers who worked cooperatively to test a range of alternatives. Despite concerns about the high costs of HFO-1234yf and the legal uncertainty about the application patent, a number of major manufacturers have already begun switching to this compound. This early shift is largely in response to the European Union's regulations requiring refrigerants with a GWP of less than 150 and United States' regulations awarding credit towards fuel efficiency standards for low-GWP refrigerants. In addition, EPA recently issued a rule removing HFC-134a from the list of allowed refrigerants for MACs by 2021 under its Significant New Alternatives Policy Program (SNAP). See 40 CFR 82; Federal Register Vol 80:138; 42870. July 20, 2015.

But other options are still being explored. One company, Daimler, is exploring a shift to a carbon dioxide-based mobile air conditioning system. Daimler's official reason for pursuing carbon dioxide is concern about the flammability of the HFO-1234yf, but such a move would also avoid high prices and supply issues related to the application patent for the use of HFO-1234yf in mobile air conditioning discussed above. In addition, the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants is working with the Institute for Governance & Sustainable Development to demonstrate a secondary-loop MACs system that would allow for the use of HFC-152a. This alternative has a low global warming potential (GWP=138), is unencumbered by patents, and has better energy efficiency, but requires a more expensive system utilizing a secondary loop to address flammability concerns. Other companies are looking at HFO and low-GWP HFC blends aimed at meeting regulatory restrictions while minimizing costs and flammability concerns. The competition from these other options serves an important function, providing a check on the costs of HFO-1234yf while continuing to drive innovation.

While the Multilateral Fund has not directly addressed the issue of application patents, in a decision at its 17th Meeting, it took action that could serve as one potential response. The Executive Committee, noting that several of the project proposals submitted included requests for the cost of the same technology transfer fees, from the same supplier, for projects in the same country, decided to request Implementing Agencies and countries:

> "to ensure that technology transfer fees wherever possible were negotiated to cover groups of projects in which conversion was to take place."[37]

This approach is a step toward the Multilateral Fund potentially funding a publicly held patent pool—the right to use a patent by all the projects it funds across some or all Article 5 Parties. This approach has not been utilized to date, and would not be necessary to the extent cross licensing between and among producers and users continues to be the norm. However, if such efforts do not adequately address all applications, the funding of a patent pool appears to fall within the existing Multilateral Fund guidelines, but would need to be evaluated on whether such an arrangement is necessary, commercially viable, and cost effective to the Fund.

### NOT-IN-KIND ALTERNATIVES

Not-in-kind (NIK) substitutes and alternatives have long played an important role in broadening the range of options available to manufacturers beyond the fluorocarbon chemical substitutes described above. Examples of NIK alternatives cut across all use sectors, including hydrocarbon and water-blown foams, no-clean soldering of electronics, a variety of "natural" refrigerants, hydrocarbon aerosol propellants, and dry powder inhalers. Along with reductions in leakage from equipment, recycling, and reclamation from discarded products, NIK alternatives have resulted in demand for chemical substitutes substantially less than what it otherwise would have been.

One early analysis that looks across all use sectors estimated that from 1986 to 1997 only about 20 percent of CFCs were replaced by HCFCs and HFCs compared to a business as usual case.[38] A more recent study estimates that only 15 percent of replacements for ozone-depleting substances were by fluorocarbon substitutes with the remainder either eliminated through recycling and leak reductions or replaced by NIK alternatives.[39] By providing an alternative to fluorocarbon substitutes, NIK alternatives can spur price competition, while also, in some cases, providing an alternative to products covered by patents.[40]

## CONCLUSIONS

While the widespread existence of patents is not new or unique to sectors impacted by the Montreal Protocol, past experience suggests that they have had limited impact on the transition out of ozone-depleting substances. However, concerns have been raised that patents on the HFO production process and application patents on their use in various sectors could adversely impact efforts to transition from high-GWP HFCs. While the initial patents for these compounds were held by several transnational companies, the list of applicants now includes a number of national entities in China. In addition, HFC-32 is being considered as a low-GWP alternative for certain applications and this compound is widely produced in China and a producer in India is planning production.

Unlike the case for HFCs where production in Article 5 Parties lagged that in non-Article 5 Parties, initial production of HFOs has been announced or has already begun both in non-Article 5 and Article 5 Parties (China). Moreover, Article 5 producers of HFOs are either subsidiaries of transnational companies or involved in partnerships with such companies. Their willingness to enter into such commercial relationships suggest that producers in Article 5 Parties have the capacity and infrastructure to cost-effectively produce these substitutes and see an economic advantage to becoming an early participant in the transition to alternatives.

If the shift to HFC-134a serves as a guide, other Article 5 fluorocarbon producers that do not participate in partnerships are likely over time to develop their own processes and become producers. Under current Multilateral Fund guidelines, once an amendment on HFCs is agreed to, funding should be available for assisting HFC producers in Article 5 Parties in making this transition to HFOs, including providing funds that can be used for the costs of licenses or patents.

Application patents represent an added layer of complexity in the transition from high-GWP HFCs. In past transitions, such patents have not proven to be an obstacle. In a few cases, the Multilateral Fund has paid for licenses and royalties, but in most cases either patents were not involved or their costs have been imbedded in the price the fund has paid for the technologies included in investment projects. Going forward, the Multilateral Fund will need to have the resources to pay for any such licenses (either directly or indirectly) and, where necessary should explore the use of voluntary agreements and the use of patent pools to cost effectively provide access to such technologies. Not-in-kind substitutes and alternatives have and are likely to continue to provide significant competition to fluorocarbon substitutes limiting prices and providing other options should access to patented technologies be restricted.

## APPENDIX A: INDICATIVE LIST OF CATEGORIES OF INCREMENTAL COSTS

1. The evaluation of requests for financing incremental costs of a given project shall take into account the following general principles:
   - (a) The most cost-effective and efficient option should be chosen, taking into account the national industrial strategy of the recipient party. It should be considered carefully to what extent the infrastructure at present used for production of the controlled substances could be put to alternative uses, thus resulting in decreased capital abandonment, and how to avoid deindustrialization and loss of export revenues;
   - (b) Consideration of project proposals for funding should involve the careful scrutiny of cost items listed in an effort to ensure that there is no double counting;
   - (c) Savings or benefits that will be gained at both the strategic and project levels during the transition process should be taken into account on a case-by-case basis, according to criteria decided by the Parties and as elaborated in the guidelines of the Executive Committee;
   - (d) The funding of incremental costs is intended as an incentive for early adoption of ozone protecting technologies. In this respect the Executive Committee shall agree which time scales for payment of incremental costs are appropriate in each sector.
2. Incremental costs that once agreed are to be met by the financial mechanism include those listed below. If incremental costs other than those mentioned below are identified and quantified, a decision as to whether they are to be met by the financial mechanism shall be taken by the Executive Committee consistent with any criteria decided by the Parties and elaborated in the guidelines of the Executive Committee. The incremental recurring costs apply only for a transition period to be defined. The following list is indicative:
   - (a) Supply of substitutes
     - (i) Cost of conversion of existing production facilities:
       - cost of patents and designs and incremental cost of royalties;
       - capital cost of conversion;
       - cost of retraining of personnel, as well as the cost of research to adapt technology to local circumstances;
     - (ii) Costs arising from premature retirement or enforced idleness, taking into account any guidance of the Executive Committee on appropriate cut-off dates:
       - of productive capacity previously used to produce substances controlled by existing and/or amended or adjusted Protocol provisions; and
       - where such capacity is not replaced by converted or new capacity to produce alternatives;
     - (iii) Cost of establishing new production facilities for substitutes of capacity equivalent to capacity lost when plants are converted or scrapped, including:
       - cost of patents and designs and incremental cost of royalties;
       - capital cost;
       - cost of training, as well as the cost of research to adapt technology to local circumstances;
     - (iv) Net operational cost, including the cost of raw materials;
     - (v) Cost of import of substitutes;
   - (b) Use in manufacturing as an intermediate good
     - (i) Cost of conversion of existing equipment and product manufacturing facilities;
     - (ii) Cost of patents and designs and incremental cost of royalties;
     - (iii) Capital cost;
     - (iv) Cost of retraining;
     - (v) Cost of research and development;
     - (vi) Operational cost, including the cost of raw materials except where otherwise provided for;
   - (c) End use
     - (i) Cost of premature modification or replacement of user equipment;
     - (ii) Cost of collection, management, recycling, and, if cost effective, destruction of ozone-depleting substances;
     - (iii) Cost of providing technical assistance to reduce consumption and unintended emission of ozone-depleting substances.

## ENDNOTES

1 While the paper generally talks in terms of transitioning from high-GWP HFCs, some portion of the transition will be directly from HCFCs, thereby avoiding a more costly two-stage transition first to high-GWP HFCs and then to more climate-friendly alternatives.

2 The workshop touched on a wide range of issues including the availability of alternatives in each sector and the suitability of alternatives in high ambient temperature climates. This paper focuses on a subset of these issues—only those directly affecting the production and availability of chemical substitutes.

3 As defined by the protocol, non-Article 5 Parties are essentially developed countries, while Article 5 Parties are developing countries. See "List of Parties categorized as operating under Article 5 paragraph 1 of the Montreal Protocol (considered as developing countries)," United Nations Environment Programme (UNEP) Ozone Secretariat, accessed September 16, 2015, http://ozone.unep.org/en/list-parties-categorized-operating-under-article-5-paragraph-1-montreal-protocol-considered.

4 For patent applications filed in the United States before June 8, 1995, and for patents still in force on June 8, 1995, the patent term is either 17 years from the issue date or 20 years from the earliest filing date.

5 "The Montreal Protocol on Substances that Deplete the Ozone Layer – Article 10: Financial mechanism," United Nations Environment Programme (UNEP) Ozone Secretariat, accessed September 16, 2015, http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/27.

6 This paper focuses primarily on experiences with HFC-134a because it was the most widely used of the HFCs and its use cuts across a number of key sectors.

7 While there was early recognition that HFCs were potent greenhouse gases, they were substantially less potent then the CFCs they were replacing. For example, CFC-12 has a GWP of 10,200 compared to a GWP of HFC-134a of 1300.

8 In order to expedite the completion and sharing of toxicity data, in 1988 eight major chemical companies organized the Partnership for Alternatives for Toxicity Testing (PAFT) with the goal of reducing by two years, the five to seven years typically required for such testing. The initial efforts by PAFT focused on HFC-134a and HCFC-123.

9 Thomas Nelson, *Findings of the chlorofluorocarbon chemical substitutes international committee,* (Research Triangle Park, NC: U.S. Environmental Protection Agency, Air and Energy Engineering Research Laboratory, 1988).

10 ICI and DuPont were significant producers of fluorocarbons at the time that the Montreal Protocol was established. In 2000, ICI sold its industrial chemicals business unit to Ineos Group Limited and DuPont recently spun off its fluorocarbon unit to what is now The Chemours Company.

11 "Production and Sales Data," Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), accessed September 16, 2015, http://www.afeas.org/data.php.

12 Estimates cited in Stephen O. Andersen, K. Madhava Sarma, and Lani Sinclair, *Protecting the Ozone Layer: the United Nations History* (London: Earthscan Publications, 2002), p. 199.

13 Executive Committee of the Multilateral Fund for the Implementation of the Montreal Protocol, *Report on the intermediate evaluation of CFC production phase-out agreements*, UNEP/OzL.Pro/ExCom/42/12 (Montreal, Canada: Multilateral Fund, 2004), p. 10, http://www.multilateralfund.org/sites/42/Document%20Library2/1/4212.pdf.

14 Ibid. p. 17.

15 "Sinochem Modern Environmental Protection Chemicals (Xi'an) Co., LTD.," Sinochem, accessed September 16, 2015, http://www.sinochem.com/g860/s1683/t4412.aspx.

16 This example is reported on as a case study in Veena Ju and Ulrich Hoffmann, *Achieving Objectives on Multilateral Environmental Agreements: A Package of Trade Measures and Positive Measures,* (United Nations Conference on Trade and Development: UNCTAD/ITCD/TED/6).

17 Executive Committee of the Multilateral Fund for the Implementation of the Montreal Protocol, *Report of the Executive Committee's subgroup on the production sector*, UNEP/OzL.Pro/ExCom/29/57 (Montreal, Canada: Multilateral Fund, 1999), p. 10, http://www.multilateralfund.org/sites/29/Document%20Library2/1/ex29-57_E.pdf. The language contained in this agreement states that the amount agreed to would be the total funding available for phasing out all CFC and HCFC production consistent with the current phaseout schedule "including future amendments, if any."

18 "Decision XIX/6: Adjustments to the Montreal Protocol with regard to Annex C, Group I, substances (hydrochlorofluorocarbons)," United Nations Environment Programme (UNEP) Ozone Secretariat, accessed September 16, 2015 http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/1164.

19 UNEP Ozone Secretariat, *Assessment of the Funding Requirement for the Replenishment of the Multilateral Fund for the Period 2015–2017*, May 2014 Report on the Technology and Assessment Panel Volume 6, (Nairobi, Kenya: United Nations Environment Programme, 2014), p. 201, http://conf.montreal-protocol.org/meeting/mop/cop10-mop26/presession/Background%20Documents%20are%20available%20in%20English%20only/TEAP-XXV-8-TF-report-May2014.doc.

20 The term "full incremental costs" is also used in Article 3.1 of the United Nations Framework Convention on Climate Change. See: "United Nations Framework Convention on Climate Change," United Nations Framework Convention on Climate Change, accessed September 16, 2015, http://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf. The Island States proposal includes this language in the discussion of their proposal, but the language is not included in the proposed amendment itself.

21 Open-ended Working Group of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer, *Report on the intermediate evaluation of CFC production phase-out agreements*, UNEP/OzL.Pro.WG.1/35/4 (Nairobi, Kenya: United Nations Environment Programme, 2015), http://conf.montreal-protocol.org/meeting/oewg/oewg-35/presession/English/OEWG-35-4E.doc.

22 Open-ended Working Group of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer, *Process to regulate the production and consumption of hydrofluorocarbons*, UNEP/OzL.Pro.WG.1/35/INF/3 (Nairobi, Kenya: United Nations Environment Programme, 2015), http://conf.montreal-protocol.org/meeting/oewg/oewg-35/presession/Information%20Documents%20are%20available%20in%20English%20onl/OEWG-35-INF3E.doc.

23 Ozone Operations Resource Group, Production Sector Working Group, *Technical Considerations for Chlorofluorocarbon Alternatives Production in Developing Countries*, Report Number 4. (Washington DC: World Bank 1993).

24 Gumprecht, William H (DuPont). Process for the manufacture of 1,1,1,2-tetrafluoroethane. US Patent 4311863, filed July 11, 1980, and issued January 19, 1982.

25 SRF Limited began producing HFC-134a in 2006 and recently expanded its production capacity of HFC-134a from 4500 tons per year to 17,000 tons per year. See "Transcript of Conference Call on Fourth Quarter Fiscal Year 2014," SRF Limited, accessed September 16, 2015, http://www.srf.com/Notifications/TranscriptConCall.pdf.

26 For example, Sinochem has three national patents for producing HFC-134a. See "Flourine Chemicals," Sinochem Taicang Chemical Industry Park, accessed September 16, 2015, http://www.sinochemfluoro.com/products.asp.

27 For example, DuPont, Honeywell, Arkema and Mexichem hold or have applied for a number of production process patents for HFO-1234yf.

28 See for example, patents filed in China for production processes for HFO-1234yf by Zhejiang University of Technology (104109077) and Xi'an Modern Chemistry Research Institute (102603465, 102603464, 102001911, 1020001910, and 101935268).

29 Honeywell has announced plans for producing both HFO-1234yf and 1234ze in Louisiana. See "Honeywell Starts Full-Scale Production Of Low-Global-Warming Propellant, Insulating Agent, And Refrigerant," Honeywell International Inc., last modified January 6, 2015, http://honeywell.com/News/Pages/Honeywell-Starts-Full-Scale-Production-Of-Low-Global-Warming-Propellant-Insulating-Agent-And-Refrige.aspx. See also "Honeywell Announces Major Investments

to Increase HFO-1234yf Production in the United States," Honyewell International Inc., last modified December 10, 2013, http://honeywell.com/News/Pages/Honeywell-Announces-Major-Investments-To-Increase-HFO-1234yf-Production-In-The-United-States.aspx.

30 There is also growing concern that overlapping patents (known as patent thickets) on aspects of production and use could slow down or impede the transition from high-GWP HFCs. While these have not proven to be a significant obstacle in past transitions, the increased role being played by application patents could potentially create new difficulties for companies in Article 5 Parties.

31 A separate paper being prepared by the author will examine this issue in greater detail and should be available in October 2015.

32 Sadatani, Satoshi, "Tipping the Balance Towards Climate Protection Through the HCFC Phaseout," special issue, *OzonAction* (2001).

33 "World's First Commercialization of Air Conditioning Equipment Using Next-Generation Refrigerant HFC32," Daiken Industries, last modified September 27, 2012, http://www.daikin.com/press/2012/120927/index.html. There is a long history of companies, individually and in partnerships, working to develop and implement technological alternatives and then making those advances available free of charge to any interested company. For a number of examples, see, Stephen O. Andersen, K. Madhava Sarma, and Kristen N. Taddonio, *Technology Transfer for the Ozone Layer,* (Earthscan 2007).

34 "Daikin Offers Worldwide Free Access to Patents for Equipment Using Next-Generation Refrigerant," Daiken Industries, last modified September 10, 2015, http://www.daikin.com/press/2015/150910/index.html.

35 Honeywell filed two patents that cover a wide range of uses for HFOs including refrigeration, air conditioning, foams and aerosols. See: Singh, Rajiv R., Hang T. Pham, David P. Wilson, Raymond H. Thomas, and Ian Shankland (Honeywell). Compositions and methods containing fluorine substituted olefins. US Patent 8033120, filed April 20, 2009, and issued October 11, 2011. See also Singh, Rajiv R., Hang T. Pham, Ian Shankland, Raynond H. Thomas, and David P. Wilson (Honeywell). Compositions containing fluorine substituted olefins. US Patent 8065882, filed March 26, 2009, and issued November 29, 2011.

36 "DuPont Statement: Extensive Distribution Network in Place to Support Accelerating Adoption of HFO-1234yf Refrigerant, which is Expected to be in 7 Million Cars by End of 2015," DuPont, last modified Ocotber 6, 2014, http://www.dupont.com/corporate-functions/media-center/press-releases/dupont-statement--extensive-distribution-network-in-place-to-sup.html.

37 United Nations Environment Programme, *Report of the 17th meeting of the Executive Committee of the Multilateral Fund for the Implementation of the Montreal Protocol, UNEP/OzL.Pro/ExCom/17/60* (Montreal, Canada: Multilateral Fund, 2002), para. 12. http://www.multilateralfund.org/sites/36/Document%20Library2/1/3631.pdf.

38 Mack McFarland, "Application and Emissions of Fluorocarbon Gases," in *Non-CO2 Greenhouse Gases: Scientific Understanding, Control and Implementation*, eds. J. Van Ham, A. P. M. Baede, L.A. Meyer, and R. Ybema, (Dordrecht, Springer Netherlands, 2000), 65–82, http://link.springer.com/chapter/10.1007/978-94-015-9343-4_3#.

39 Stephen O. Andersen, Duncan Brack, and Joanna Depledge, *A Global Response to HFCs through Fair and Effective Ozone and Climate Policies* (London: Chatham House, 2014), p. 24, http://www.chathamhouse.org/publication/global-response-hfcs.

40 Andersen et al. (2007), p. 257–62.

CENTER FOR CLIMATE
AND ENERGY SOLUTIONS

The Center for Climate and Energy Solutions (C2ES) is an independent nonprofit organization working to promote practical, effective policies and actions to address the twin challenges of energy and climate change.

2101 WILSON BLVD.  SUITE 550  ARLINGTON, VA 22201  703-516-4146  C2ES.ORG