Ozone and climate at the crossroads

the *other* double phase-out

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ABSTRACT

This paper examines the intersection of climate and ozone policy in developing countries, primarily through study of projects under the Multilateral Fund (MLF) of the Montreal Protocol. Models of the unconstrained growth of Hydrofluorocarbons (HFCs), a replacement for CFCs and HCFCs that is also a greenhouse gas, indicate that without mitigating policy measures, global emissions could rise to 4577 MT in 2100. Under a 550 ppmV stabilisation pathway, by contrast, GHG emissions of all CO_2 and non-CO_2 greenhouse gases together would be constrained to 5967 MT. HFC emissions from developing countries are predicted to rise from 1/6th of global HFC emissions in 2000 to well over half by 2050. Analysis of the introduction of alternatives to HFCs in MLF projects indicates a number of barriers independent of technical and economic considerations. Techniques for considering global warming in ozone phase-out are found to lack real impact in the absence of political will to implement commitments already in place.

I. Summary of the issues

The subtitle of this study refers to the UNEP report *Avoiding a double phase-out, alternative technologies to HCFCs in refrigeration and air conditioning* (UNEP 1999). That report tackles the problem that hydrochlorofluorocarbons (HCFCs) introduced as replacements for chlorofluorocarbons (CFCs), being phased out under the Montreal Protocol on Protection of the Ozone Layer, are themselves scheduled for phase-out at a later date. Having to replace them in turn would require a double switch, representing a potential waste of money, and ozone damage in the interim.

This report extends the analysis of ozone depleting substance (ODS) replacement by examining hydrofluorocarbons (HFCs). HFCs are commonly used as refrigerants, are used to a lesser degree in foam blowing and are employed in a variety of smaller applications like fire suppression and medical aerosols. This set of substances has no ozone depleting potential, and have low or zero toxicity and flammability. They are furthermore manufactured by some of the same companies that make, or made, CFCs, thus softening the blow to them as they agree to phase out a product that was a household item worldwide. These qualities have made them popular replacements for ODS under the terms of the Montreal Protocol, including in projects in Article 5 (A5) developing countries (DCs) financed by the Multilateral Fund (MLF) of the Protocol. They are also likely candidates for replacing HCFCs once they are in turn phased out.

Unfortunately, HFCs are extremely potent greenhouse gases (GHGs). The most common of them, HFC-134a, has a global warming potential (GWP-100) 1300 times that of CO_2. Because of this, HFCs have been included as one of the six groups of gases to be addressed under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), which seeks to prevent dangerous anthropogenic climate change.

Hence the dilemma: if HFCs are a popular ODS replacement under the Montreal Protocol but are slated for control under the Kyoto Protocol, there may be a direct conflict between the two UN initiatives. If pressure on HFC emissions mounts in the future, emissions from HFCs promoted under the Montreal Protocol (or as replacements for HCFC projects) will either cost money to abate, will demand extra effort from mitigation in other sectors to meet GHG reduction goals, or will even lead to yet another investment to convert to a more acceptable alternative.

The most obvious potential conflict comes from the subsidies developing countries receive through the Multilateral Fund (MLF) of the Montreal Protocol. Ozone depletion is primarily a polar phenomenon (WMO 1998), while developing countries tend to be equatorial. Developing countries are therefore less affected, while having less historical responsibility for the problem and fewer resources to make needed changes. Nevertheless, 168 DCs have signed the MP and are bound to comply with its terms. Agreement to do so was in no small part due to the creation of extended timetables and financial assistance for phase-out through the MLF. The Kyoto protocol has a similar recognition of "common but differentiated responsibilities" (UNFCCC Article 4), and financial assistance both for adaptation to the impacts of climate change, and for technology transfer and clean development projects. There is a fundamental understanding that developing countries have a right to industrial growth and the services that come with it. Limiting the damage from that growth then becomes a collective responsibility of both the developing countries themselves and richer countries who have afford to help reach global environmental goals.

Under the terms of the Montreal Protocol, assistance for ODS phase-out can only happen once. Conversion to HCFCs as an interim solution using MLF help means developing country businesses must use their own resources to phase them out in turn. Similarly, switches to HFCs solve the ODS problem, but may leave companies and the countries in which they reside vulnerable to future greenhouse gas reduction requirements. Though these requirements would be self-imposed by taking part in a treaty, the lost opportunity of having used MLF money to switch to HCFCs or HFCs when alternatives were available may be regretted.

The available alternatives are ones often referred to as natural substances: hydrocarbons (HCs) such as pentane, cyclopentane and isobutane, ammonia, carbon dioxide, water, and air. Several of these are common as replacements for CFCs and the MLF also covers their use. Just as they are mentioned as alternatives to HCFCs to avoid a double phase-out, they same could be said of natural substances as alternatives to HFCs.

Unlike with HCFCs, however, there is no value judgement about HFCs built into the Montreal Protocol. While HCFCs are frowned upon but tolerated, HFCs and hydrocarbons go through similar assessments, and the fact of global warming potential doesn't enter into any decision-making in MLF project approval. The call to avoid a double switch via HCFCs is part of the logic of the Montreal Protocol alone, as HCFCs are to be phased out. Once HFCs enter the equation, the issue is more complicated—at technical, economic, environmental and political levels.

There are technical issues of importance with the most popular alternatives. As hydrocarbons are flammable and ammonia toxic, extra care is necessary in use and in some cases they should be avoided, as in cooling units placed underground. In a few cases alternatives are still lacking, for example in the full range of metered dose inhalers for respiratory ailments, for which some alternative delivery systems have yet to come into circulation. More important than issues with the technology itself, however, is the technical barrier of relative unfamiliarity with natural substances, among manufacturers and service technicians.

Economic barriers exist because equipment using natural substances can either be more expensive, or the safety measures needed to ensure their proper use can be over and above costs of similar HFC systems. This latter factor is a major issue in MLF project approval. Nevertheless, full life-cycle costs can be attractive, and the issue often reduces to the time scale under consideration and the size of the business in question.

Environmental considerations are at the heart of the debate over HFCs and their alternatives, but the calculations are not straightforward. HFC proponents argue that if they are used in efficient leak-proof systems and are captured during manufacturing, servicing and decommissioning, then there's no harm done, and nothing to argue about. An assessment of the overall impact is captured in TEWI—total equivalent warming impact. Proponents of natural substances argue that there is little difference between HFC and alternative systems on all fronts, except for direct emissions. If efforts to deal with those emissions are sub-par, then it will be direct emissions of HFCs that make the difference in TEWI, and therefore only natural substances can reach the lowest TEWI. On both sides of the argument there are many detailed technical considerations and measurements to be made that can vary from system to system; while rhetorical TEWI arguments are easily made, usually to defend HFCs, there is little experience of detailed head-to-head comparisons as the basis for decision making.

Finally, there are political barriers. Weighing the use of HFCs and natural substances on the basis of global warming considerations in MLF projects would require a decision to do so. On the donor side of the MLF, that means engaging in a commitment outside the current scope of the Protocol—on a very hotly contested issue in its own right, making a link difficult. On the developing country side there is reluctance to take on anything resembling hard commitments to reduce GHGs. The UN Framework Convention on Climate Change (UNFCCC) gives them limited commitments to monitor and report emissions, but there are no quantitative targets. There are certainly good examples of developing countries leading the way in climate change mitigation nationally, but in terms of international commitments they feel the ball rests in the court of northern countries, who need to follow through on their obligation under the UNFCCC to lead the way in reducing GHG emissions. On all sides of the Montreal equation there is the repeated assertion that no matter what the case, ODS phase-out should not be slowed down—a risk that avoidance of both HCFCs and HFCs is purported (but not always proven) to run.

Nevertheless the fact remains that HFCs are GHGs, there are opportunities to avoid them without slowing ODS phase-out, and those opportunities may be going under-utilised. The intention of this paper therefore is to examine how decisions about technology choice in developing countries has been influenced by the structure and implementation of the ozone layer and climate protection efforts, and will recommend a course of action that integrates both issues. In doing so it will address several fundamental questions:

- Should HFC emissions be avoided? Establishing a baseline
- Are alternatives getting a fair chance? Evolution of HFC policy in the climate and ozone regimes
- How are HFCs and alternatives compared? Technology choice in MLF projects
- Can we enhance opportunities to avoid GHG emissions? Harmonising ozone and climate policy

II. Should HFC emissions be avoided?
Establishing a baseline

Though HFCs are included in the Kyoto Protocol, there are many, particularly in the fluorocarbon industry, who claim that future emissions are likely to be so low that efforts to avoid HFC emissions need not be extensive[1]. They espouse a doctrine of voluntary "responsible use"[2] principles that aim to limit the egregious level of leakage witnessed before ozone depletion or global warming were concerns. By supplementing this doctrine with selective total equivalent warming impact (TEWI) studies of life-cycle emissions, and by fanning the flames of safety concerns about hydrocarbon alternatives, fluorocarbon-friendly industries manage to depict HFCs as the superior choice. Industry characterises the ultimate impact of HFC growth to be low—between 1-2% of total 2050 GHG emissions (ARAP 2001, ICI 1999).

Given the recent origin and dispersed uses of HFCs, trying to corroborate claims about future emissions with modelling is bound to be fairly difficult and inaccurate, but it does give some reasonable indications of the bounds of possibility. In this paper we compare some recent studies and make calculations of our own to determine whether HFCs could become significant sources of radiative forcing in the future in the absence of specific policy measures. We then touch upon the implications for mitigation measures.

A comparison of existing studies

Table 1 and Graph 1 show baseline (no additional policy intervention) HFC levels from a set of studies presented together at an important 1999 conference[3]. The range of predicted emissions of HFCs in CO2-equivalent in 2050 is 765.2 to 1470.2 MT, which when expressed as a percentage of 1990 total GHG emissions is 7.2% to 13.9%.

In order to extrapolate use of fluorocarbons into the future, two inherently different approaches are being used: top-down scenario models and bottom-up market or project calculations. Fenhann for example uses the four marker scenarios from the IPCC's Special Report on Emission Scenarios (SRES) to calculate future use of HFCs, in correlation with GDP, population growth and other factors. McCulloch extrapolates fluorocarbon emission on the basis of s-shaped demand curves and business as usual projections for CFCs combined with present-day rates of substitution of CFCs with alternatives. Pinto et al. also start from the bottom by taking existing MLF project data to acquire substitution rates, which in

[1] Even the title of an industry submission to the CoP gives an indication of their view that some people are too worried about the issue: "HFCs: facts, not emotions" (ICI Klea 1999).
[2] See ARAP: www.arap.org
[3] The studies examined as part of this report were all contributions to the Joint IPCC/TEAP Expert Meeting in 1999, and were published as proceedings of the meeting by the Energy research Centre Netherlands (ECN). They have been subject to considerable reworking to put them in comparable forms, but without altering any of the underlying data and projections.

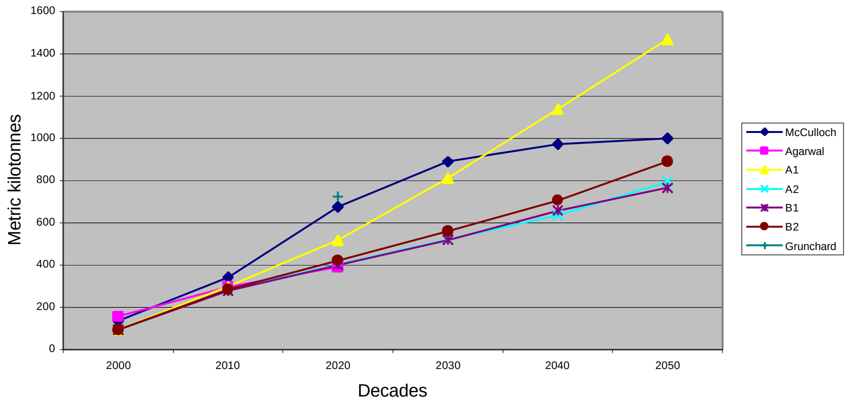
combination with market growth rate assumptions are used to extrapolate future HFC emissions.

The underlying parameters that authors decide to choose for their projections differ considerably, and this limits the extent to which their results are comparable. During the first two decades of the 21st century these differences are still small. Later on, however, divergence increases considerably. The actual shape of the curve described by future development of HFCs, determined by the underlying assumptions, only comes to the fore over a longer period of time.

TABLE 1: HFC Levels by 2000-2020, 2050 in kt

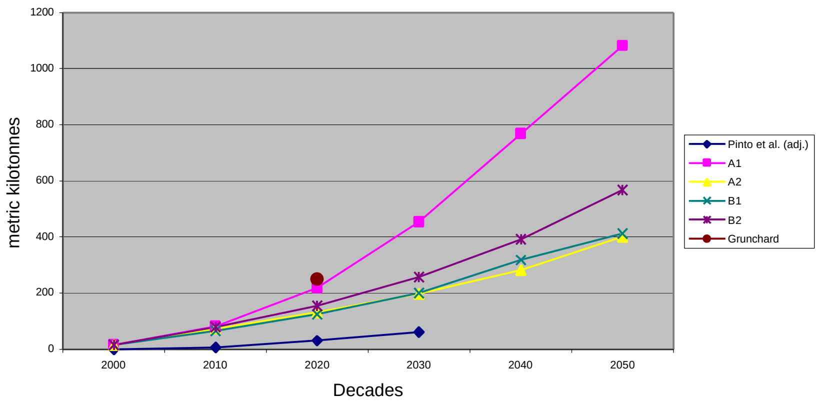
Study/year	2000	2010	2020	2050	Coverage
McCulloch	135	342	675	1000	Global
Agarwal	156	297	389		Global
Grunchard			725		Global
Fenhann –A1	92.6	298	517.9	1470.2	Global
-A2	92.6	281.6	403	793.5	
-B1	92.6	278.8	401	765.2	
-B2	92.6	284.9	422.2	890.8	
-A1	15.5	81.6	218	1081.7	A5 countries
-A2	15.5	73.7	131.8	401.1	
-B1	15.5	66	123.8	413	
-B2	15.6	79.2	155.6	567.2	
Pinto et al	6.4	30.0	61.3		A5 - MLF project level
Grunchard			250		A5 countries

Graph 1: Comparison of global HFC projections



The very few comparable values for A5 countries do not permit a detailed analysis. Graph 2 displays the A5 data from table 1: 2020 is the last year all studies provide data points[4]; by 2050, emissions range from 413 to 1082 MT. The share of global emissions from developing countries ranges from 50-73%.

Graph 2: Comparison of HFC projections for A5 countries



Future HFCs limited by environmental space

The predictions of future HFC emissions levels discussed above must somehow be compared to a reference level to get an idea of their significance. Most often they are expressed as a percentage of 1990 GHG emissions. A more complicated but meaningful approach is to compare future HFC emissions to a normative view of “allowable” GHG emissions. What is allowable can be defined by a stabilisation pathway that leads to a level that avoids serious human-induced climate change, the fundamental goal of the UNFCCC. The difference between the baseline, unconstrained growth, and the stabilisation pathway gives an idea of the level of effort required to divert growth from the baseline path.

An emissions trajectory that achieves the goal of reaching and maintaining a maximum atmospheric CO_2 concentration that would avoid serious climate change can serve to define an allowable “environmental space.” The IPCC has concluded that a rise in global average temperature of between 1 and 2 degrees Celsius would cause serious negative impacts. A warming of that range would be caused by an underlying rise in the level of atmospheric concentration of carbon

[4] The findings by Pinto et al present a special case because their estimates stem from a projects-only level and cannot cover country-wide emissions completely, which may explain their lower figures to some extent. Grunchard arrives at his figure for 2020 by simply transferring the status quo in developed countries by 20 years.

dioxide above 450 ppmV. Environmental organisations in particular have long emphasised that enacting policy to stabilise concentrations at 450ppmV would be a goal that, while still resulting in significant warming, would balance environmental damage against technical and financial practicality.

Here we choose to model 550 ppmV to give a conservative example (and not to reflect NGO priorities)[5]. To illustrate the pathways to reach that concentration we've chosen a proxy from among the studies reviewed here—the B1 market scenario used by Fenhann (1999), which is almost identical to a 550 ppmV pathway (see IPCC 2001).

Comparison 1: Allowable GHG emissions and HFC projections

Table 2 and Graph 3 show HFC emissions from each scenario expressed as a percentage of the total ("allowable") GHG emissions from the 550 ppmV stabilisation pathway.[6] This comparison is purely illustrative, but the implications are clear: if a baseline scenario predicts HFC emissions that would equal a small proportion of a sustainable total GHG emission level, we would have fewer concerns about their future (assuming confidence in the projections). But if the proportion were high, then we would have to consider policy measures to divert away from that baseline level: the higher the level, the greater the need for change.

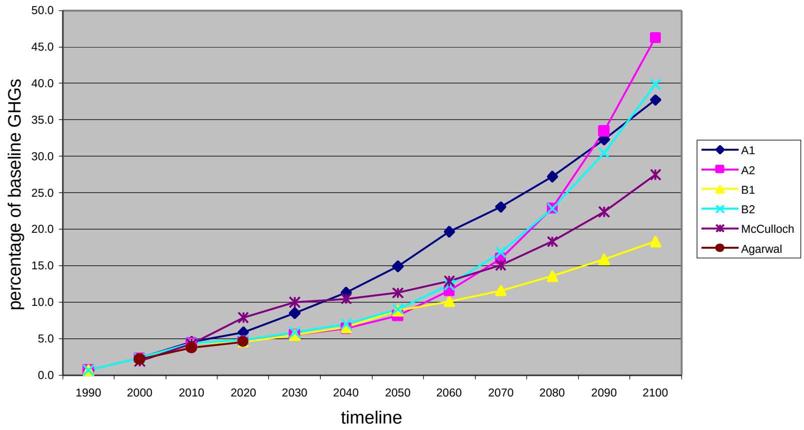
As the protocol allows a 6-gas basket in its targets, just what proportion of the total sustainable level is acceptable per gas is not simple to assess: but clearly, more of one leaves less room for others. An economic approach would simply find the point at which marginal abatement costs are equal. It is far beyond the scope of this study to predict such costs for the next century. It suffices here to say that if HFCs are on a path to rise to, for example, 50% of a sustainable total emissions level, this is very unlikely to leave enough "space" for emissions of the other 5 gases: pressure to limit their emissions should then be high.

[5] It should be emphasised that this doubling of pre-industrial CO2 levels is predicted to cause serious warming. A stabilisation at this level would entail strong negative impacts of climate change all over the world.
[6] The B1 scenario achieves 550 ppmV stablisation, so the HFC share could be seen as one option for a sustainable level.

TABLE 2 Global aggregate HFC emissions as a percentage of 550 ppmV stabilisation pathway baseline

Year	A1	A2	B1	B2	McCulloch	Agarwal	Grunchard
1990	0.7%	0.7%	0.7%	0.7%	0.0%		
2000	2.3%	2.3%	2.3%	2.3%	1.9%		
2010	4.6%	4.4%	4.3%	4.4%	4.3%	3.8%	
2020	5.9%	4.6%	4.6%	4.8%	7.9%	4.6%	8.5%
2030	8.5%	5.5%	5.5%	5.9%	10.0%		
2040	11.3%	6.4%	6.6%	7.0%	10.5%		
2050	15.0%	8.2%	8.9%	9.1%	11.3%		
2060	19.7%	11.5%	10.1%	12.4%	12.9%		
2070	23.1%	16.0%	11.6%	16.9%	15.1%		
2080	27.2%	22.9%	13.6%	22.8%	18.3%		
2090	32.3%	33.5%	15.9%	30.5%	22.4%		
2100	37.7%	46.2%	18.4%	39.9%	27.5%		

Graph 3: HFC levels as share of stabilisation baseline



This approach shows that under most non-intervention assumptions HFCs take a considerable portion of the limited environmental space—a maximum of over 45% of the total greenhouse gas emissions from a stabilisation scenario in 2100. The B1 scenario, which does lead to 550ppmV stabilisation, has the lowest share, ending at 18.4% of total GHG emissions in 2100.

Comparison 2: historic and future per capita services

Another way of looking at the level of possible future HFC use is to work backwards from potential levels of demand. In an equitable world, arguably everyone would have roughly similar access to the services provided by CFCs and their replacements. Per capita use of CFC and its substitutes in the OECD would be the same as per capita use in developing countries[7]. Predictably, this has never been the case, but it is illustrative to see what converging on similar per capita rates would mean in the future.

With that in mind, table 5 reflects a new comparison to the B1 scenario, a model by Kroeze (1995) where growth is linear and gas/capita converges worldwide by 2100.

TABLE 3: HFCs as a % of the 550 ppmV stabilisation pathway under 2 scenarios

Year	550 stabilisation pathway total GHG emissions (MMT)	% of stabilisation pathway	
		B1	Per capita gas use convergence by 2100
2050	13,791	8.9	13.3
2100	5,968	18.4	76.7

This additional scenario combines notions of equity, by specifying converging per capita emissions, with projections of HFC growth based on a linear growth model. The implications are clearly negative from an emissions standpoint, as uncontrolled HFC emissions rise to above three quarters of the 550 ppmV stabilisation pathway.

What does the baseline indicate about response measures?

The purpose of this chapter is to indicate a range of baseline estimates, and not to determine response measures. But as mentioned above, if the baseline indicates the potential for high growth, response measures will need to be more vigorous. Each of the scenarios examined here models a future that could arguably take place: the assumption of the SRES is that they are equally likely. Still, 4 of the 5 alternatives studies do not lead to 550 ppmV, and HFC growth is substantial. Furthermore, in the “equitable per-capita convergence” scenario, where equity could be seen as an exogenous priority, growth is highest of all. The presence of a preponderant number of possible negative outcomes gives weight to calls for significant attention to the limitation of HFC emissions.

What is significant depends on the likely impact of alternative response measures. The voluntary “responsible use” principles mentioned at the beginning of this chapter are the fluorocarbon industry’s suggested response. Unfortunately, these are largely already reflected in the models: they are found in the incorporated substitution rates for CFCs, which are well below 1:1, due to the vast improvement

[7] One makes a broad assumption that needs are similar—intuitively, if anything the fundamental demand for cooling, the major HFC application, would be higher in developing countries, which are more frequently found in warmer climates. Thus such an assumption is if anything conservative.

in leak-tightness and charge reduction of modern systems. What is called for by industry goes little beyond this trend which, though fortunately showing improvement, is already modelled. That the measures are furthermore voluntary and unstructured in their application leads to lowered confidence in their added value.

Kroeze (1995) models a hierarchy of response measures: a baseline reference, a "closed" scenario where only stationary air conditioning and closed cell foam blowing use HFCs, and one where only low GWP gases are allowed. Each of these is then allowed two possibilities: a reference level of emissions control, and a maximum level of containment, capture and destruction throughout the life cycle.

Table 4: predicted emissions given various response measures

Year	Reference Scenario		Closed applications		Low GWP only	
	No control	+MAX	No control	+MAX	No control	+MAX
2000	532	366	111	34	41	22
2040	3798	2166	2103	1172	356	209
2100	9382	5278	5906	3251	943	543

As can be seen in Table 4, maximum containment reduces emissions in each category by about 40%. Combining an assumption of limiting HFCs to "closed" applications with maximum control reduces emissions by two-thirds below the reference scenario. Using low-GWP compounds (including some low-GWP HFCs in this model) reduces emissions levels the most dramatically: 90% below the reference scenarios.

In this model, restrictions on emissions in the absence of significant shifts away from HFCs yield at best 40% reductions below the baseline. Whether that 40% is sufficient will of course depend on the baseline: several scenarios discussed above would no doubt require much more significant reductions. This level of containment also supposes effective implementation.

In Holland, a system known as STEK places strict certification requirements on technicians as well as supplying technical guidelines. Emissions reductions for new equipment are estimated to be on the order of 66% (Ecofys 1999). The full impact of this improvement will be felt as older equipment is decommissioned. A countervailing trend, however, is the quick rise in automobile air conditioning, which is far more leaky. By 2010, 50% of emissions could be from mobile air conditioning (Ecozone 2000).

An ultimate estimate of this approach's impact is still hard to determine, but can certainly be no better than the best achievements with new stationary systems (-66%) and probably much less, due to the influence of mobile air conditioning and systems that fall outside the system's reach. The STEK system is far more than voluntary principles adhered to by fluorocarbon users. The system is furthermore being implemented in the Netherlands, with the significant level of compliance characteristic of a well-ordered policy environment. It is an environment one could safely call an exception rather than the rule in an international context; applied on a global scale, a correspondingly lower level of success would be the likely result.

Conclusions

The illustrative scenarios presented here all reflect different hypotheses about the world. None of the baselines include explicit policy to limit HFC emissions, but rather depict differences stemming from economic or social conditions, and existing trends in technological improvement. What does remain constant is the "environmental space." The 550 ppmV concentration reflected here represents a science-based figure that defines limitations on emissions. In all of the examples cited here, the baseline emissions of HFCs were significantly above those of the single scenario that actually achieves 550 ppmV stabilisation. For that reason, it seems clear that policy is very likely to be needed to limit HFC emissions. An initial assessment of response measure modelling and experience from an existing system in the Netherlands indicates that under most baseline scenarios, response measures may well have to be more vigorous than even successful containment efforts can achieve. By extension, voluntary containment principles are even less likely to be adequate.

In the following two sections we will examine whether and how global warming is being taken into account in ODS phase-out, and the final section examines what the potentials are for achieving the reductions that the baseline scenarios presented here indicate may be necessary.

III. Technology choice in MLF projects

Taken as a whole, the percentage of ODP tonnes converted to HFCs by MLF projects is quite small, only 4%. This reflects the breadth of applications for which HFCs are either not appropriate technically, or are simply too expensive. Once commitment to phase out began, both in developed and developing countries, industry found that it was cheap to switch to hydrocarbons in aerosols, that in many cases no-clean systems could avoid the use of solvents altogether, or that CO2/water was perfectly adequate for blowing foams. In fact, there is one main sector where HFCs are used in volume in CFC phase out—refrigerants. Secondly, they are possible future replacements for HCFCs in rigid insulating foams, a role they are taking on more frequently in A2 (developed) countries.

In refrigeration nearly 90% of projects have chosen HFC-134a as the refrigerant (see table 5), which when measured by ODP replaced add up to 54% of all CFCs in the refrigeration sector. By 2001 there were 20 isobutane (HC-600a) projects, in manufacture of domestic units, accounting 12% of all refrigerants by ODP replaced. In refrigeration foams nearly 65% by replaced ODP were cyclopentane, and 45% HCFC-141b, though there were far more HCFC projects. In other rigid foams, HCFCs have a much higher share—76% of the sector by ODP phase out, and almost 90% of projects.

TABLE 5: Share of sector activity by technology

Sector	substance	# projects	Average ODP/project	total ODP	% of sector	% of total
Rigid Foams	HCFC 141b	324	39	12512	76.40%	8.45%
	Water/Co2	26	35	898	5.48%	0.61%
	Pentane	13	186	2417	14.76%	1.63%
	HCFC22	12	46	551	3.36%	0.37%
Domestic Refrigerants	HFC-134a	160	26	4211	81.47%	2.84%
	Isobutane	20	48	958	18.53%	0.65%
Domestic refrigeration insulation	Cyclopentane	94	136	12792	74.14%	8.64%
	HCFC-141b	80	56	4462	25.86%	3.01%
Commercial refrigerants	HFC-134a	221	7	1548	53.38%	1.05%
	HCFC-22	13	104	1349	46.52%	0.91%
	isobutane	1	3	3	0.10%	0.00%

Source: own calculations based on MLF secretariat 2001 database of projects

Refrigerants and foams therefore represent the applications where HFCs and HCFCs are most often weighed off against alternatives like hydrocarbons and water/CO2. Here we will focus on the factors affecting refrigerant choice, as the sector where HFCs play a significant role. And while there are existing and upcoming alternatives to fluorocarbons in commercial and industrial refrigeration, like ammonia or water, the focus here is on the most discussed and controversial, hydrocarbons. In the following chapter we will also discuss the possibilities for conversion of HCFCs to HFCs at a future date.

Decisions about which technology to use in replacing CFCs involve a number of factors and influences, from the technical to the political. The decision is supposed to rest ultimately with the local enterprise, acting within the framework of planning, regulations and standards set by the national government, and the rules of the MLF. In weighing the technology options, in theory there is a calculated decision: "The choice of technology considers a balance of maturity, availability, cost effectiveness, energy and other performance, safety and safety costs" (TEAP 1999). But beside the technology itself, Montreal Protocol bodies, implementing agencies and consultants all have input. Additionally, "the choice is also influenced by local circumstances, preferences of enterprises, their joint venture partners and customers, access to technology at affordable price, availability of training and other market circumstances and regulatory compliance" (TEAP 1999).

Arguing the technical advantages and disadvantages on both sides has been fairly acrimonious, allowing TEAP's most recent assessment of the issue to appear level-headed in its balanced tone: "HFC-134a and HC-600a, have demonstrated mass production capability for safe, efficient, reliable and economic use. The application of HC-600a or HFC-134a provides approximately equal efficiency…either alternative refrigerant may be the "right answer" for a specific set of conditions." The question is whether this approach introduces too many variables, and allows any decision to be deemed correct given the proper combination of justifications.

Technical characteristics of HFCs and hydrocarbons

Weighing the technical characteristics of alternatives can fill volumes, but in large measure the debate reduces to a few key issues, flammability foremost among them. This is the Achilles heel of hydrocarbons because it is, first of all, a real concern. But safety risks are also hard to measure and easy to invoke in precautionary language to defend HFCs. Flammability has also dominated the TEAP's reviews of hydrocarbons, occasionally seeming to reduce the issue of their acceptability to that one factor (as in the TEAP 1997 review of flammable refrigerants). The political nature of the issues is apparent when TEAP noted the role of environmental NGOs in the development and promotion of hydrocarbon refrigerators, saying "it is ironic that environmental organizations are advocating flammable and toxic refrigerants but industry is reluctant to accept the health and safety risks." Such barbs punctuate a number of otherwise technical analyses.

The flammability issue is of no small consequence: clearly it is only responsible to use hydrocarbons if flammability is managed in a way that reduces the possibility of accidents to a level low enough to be deemed insignificant. At the manufacturing site there is very likely to be larger quantities of hydrocarbon in storage, and systems will be filled in an environment full of personnel and machinery. Both storage and use require investment in safety equipment and training.

In products, there are three main factors: charge size, containment, and sparking. A large charge size means that should an accident occur, the results would be more damaging, regardless of how unlikely this was due to other measures taken—therefore on balance, risk management tends to favour smaller charge sizes. In Europe larger and larger charges are being applied, on the scale of supermarkets with systems kept in a controlled area and secondary loops with inert refrigerants that actually circulate in the store.

The vast majority of hydrocarbon systems, however, are domestic refrigerators under 400 litres where the refrigerant charge is less than 150 grams. Not only would ignition of this quantity be much less disastrous than ignition of several kilogrammes, but the possibility of reaching flammable concentrations in a room is reduced by the small volumes. Nevertheless, small refrigerators have small compartments, meaning the flammable concentration can be reached in the compartment itself, and they are also placed in the middle of a home and not in a controlled environment. Therefore systems have to be made as leak-proof as possible. Finally, any potential source of spark such as a light or thermostat in the cabinet must be specially designed.

The TEAP (1999) points out that although there had be no reported fires in the 25 to 30 million refrigerators sold worldwide, there had been one reported fire in a commercial system that it describes in detail and warns “is indicative of the types of accidents that can occur during maintenance of systems with HC charges larger than domestic appliances.” “Indicative” and “can occur” imply that this sort of accident can be expected to occur with some regularity, but there is no indication that there had been any accidents reported beyond the one mentioned from Australia.

System efficiency is the second area of contention in comparisons between HFCs and HCs. Energy saving is important in its own right and can become a priority without environmental goals—this is particularly noticeable in developing countries that are facing electricity supply crises. Nevertheless the rhetorical focus in the hydrocarbon-HFC debate is on minimizing indirect greenhouse gas emissions, which arise as a result of generating the electricity used in a system. A variety of studies find that isobutane refrigerants have a slight efficiency advantage over HFC-134a, particularly in warm conditions (the implications of efficiency is discussed more fully in the next chapter).

Hydrocarbons are compatible with standard mineral oils and handling of components is similar to CFC-12. The need for a larger compressor does mean a larger housing, and therefore some redesign. HFC-134a has the advantage that they allow similar size compressors. However, HFCs require use of synthetic lubricating oil that is much more difficult to work with and more expensive. Without strict cleanliness and care in manufacturing, moisture or contamination will almost always cause total system failure. Up to the mid-90s there were reported cases of "major problems in mass production of refrigerators and their components with HFC-134a" (GTZ 1997). While these problems may steadily improve in manufacturing, servicing will be an ongoing task that sees much less oversight and training.

While HFC-134a is a synthesized chemical, isobutane has to be refined to an acceptable level of purity for use. TEAP makes a point of noting that the 97.5-99.5% purity is not only necessary for performance and "protection against toxicity of probable impurities such as benzene, a carcinogen and n-hexane, a neurotoxin." Given the extremely small quantities involved and the vastly greater quantities of other hydrocarbons in daily use, this concern is relatively minor from a health standpoint. Similarly, hydrocarbons are also volatile organic compounds, but "the small amounts of hydrocarbons used in refrigeration (or aerosols), compared to the very large quantity used for combustion (more than 99%), leads to the conclusion that the VOC aspect of HC refrigeration will remain small" (TEAP 1997).

Absent from TEAP documents is any mention of cases of reported ill-effects associated with use of HFCs or the synthetic lubricating oils they require, the toxic by-products when burned, or trifluoroacetate (TFA), a breakdown product of HFC-134a that may bioaccumulate in seasonal wetlands. TFA, like VOCs, is likely to be a low level issue, though some find that TFA is a potentially global problem that should be avoided under the precautionary principle (GTZ 1997, Greenpeace 1999).

Developing country conditions

There are conditions specific to A5 countries that also impact technical considerations. Hydrocarbons may be new[8] to refrigeration, but they are a familiar substance. In manufacturing, hydrocarbons are relatively simple, and can be used with adequate safety precautions; HFCs demand higher production standards, and are most feasible in companies that are either partners with multinationals or achieve the same standards of production. They could be difficult for independent manufacturers who cannot maintain the standards required (GTZ 1997).

In Germany, where almost all new domestic refrigerators use isobutane, the manufacturers use their own teams to service hydrocarbon refrigerators, rather than leaving it to the entrepreneurs who dominate the service sector. This approach may not fit the pattern of servicing in A5. Servicing hydrocarbons does require additional training—the lack of familiarity with flammable substances as refrigerants is a concern[9]. Furthermore, equipment is used typically three times longer than in developed countries, and more challenging climatic conditions

[8] Or rather, recently re-introduced, as they were used prior to and to a limited extent during the reign of CFCs
[9] However, as one technician with years of experience in A5 countries stated, recognizing the label for flammability (which is absolutely necessary to have), a technician will take precautions for his own safety; but seeing a CFC or HFC refrigerator, his level of attention may be lower—in the likely absence of regulations or enforcement there are no repercussions for venting gases, and as system failure is not immediate there are no on-site repercussions for making mistakes.

mean an increased failure rate (Sharma et al 1999), making servicing more frequently required and increasing the opportunities for error. On the other hand, hydrocarbons can continue to use the same oil and charging equipment as CFC-12 in servicing, which is not the case for HFC-134a. Additionally, the required synthetic oils for HFC systems are expensive.

HFCs themselves are patented, synthetic chemicals and HCs are not, which opens the possibility of production at a wider variety of sites at lower cost. According to TEAP (1997) isobutane, even of a purity lower than that specified in German regulations (grade 2.5 or 99.5% pure), can be twice as expensive as HFC-134a. However, according to MLF project documents, isobutane in the major developing country market, China, is anywhere from equal in price to half as expensive as HFC-134a. In addition, around half as much isobutane is required as HFC in similar systems.

Costs are an important long-term factor. Both manufacturing and servicing sites have the incentive to switch back to the cheapest available substance following conversion: as HCs are usually cheaper than HFCs, there is a real risk of equipment designed for HFCs being filled with hydrocarbons. The result of using HCs in HFC equipment is a serious loss in efficiency and a possible increase in flammability risk. The possibility of retrofitting existing CFC equipment to use hydrocarbons has been explored, including in a UNEP TIE report (1999). TEAP (1997) notes that “Changing to a flammable refrigerant when the refrigeration circuit needs to be repaired is an option in countries where repair is an attractive option because of the low cost of manpower and the relatively high cost of new appliances.”

Currently, availability of hydrocarbons can be an issue, and an increase in supply would be needed to meet major growth: “if HC refrigerants are to become prevalent world-wide, then A5 countries will have to choose between developing an indigenous supply of purified HC refrigeration and importing them” (TEAP 1997)[10].

In manufacturing, producing hydrocarbon systems is increasingly competitive as the technology gains market share, particularly in Europe (GTZ 1997). While isobutane projects under the MLF required on average 27% greater capital investment for safety precautions (GTZ 1997), this is still below the 35% increase allowed.

[10] In 2000, the MLF approved over $23 million for new HFC-134a manufacture in China, indicating a willingness to support refrigerant supply in A5 countries that may extend to hydrocarbons.

Influencing choice

In the context of the MLF, technology decisions are made within the framework of many influences[11]. The competitive position of hydrocarbons in terms of performance, economics and environment indicates that lack of penetration of hydrocarbons in developing countries could be due to barriers in the marketplace and in MLF procedures (GTZ 1997).

In the MLF context, a clear barrier to movement in the early 90s was that HCs were allowed for aerosols and foams, but not for refrigerants—the decision was deferred during consideration of the "maturity" of the technology. At that point "more than the cost factor, it was felt that technicians in developing countries were not competent enough to handle the use of flammable substances" (Ratnasiri 1999). Technology decision was "a question of take it or leave it" (ibid).

The first refrigerant projects took place in 1991; it was not until 1995 that the first isobutane projects emerged, by which point 73 HFC-134a projects had taken place. On the economic level there were initial questions about financing safety costs. But even the MLF decision to finance extra costs didn't mean instant use of the mechanism. As noted in the second chapter, the 35% addition was first decided in the 17th meeting. By the 22nd meeting the Excom requested that the Sub-Committee on Project Review and the Secretariat "deal urgently with the question of safety-related costs for hydrocarbon projects so that the relevant projects could go ahead." A report was finally completed for the 25th meeting, and the executive committee decided that projects could be requested using this guidance from the 26th meeting onward.

The Secretariat's report (MLF 1999) notes differences among regions, where government policy, NOUs, and markets all vary. In Asia, "companies did not have a clear idea of the different technology options and their economic and environmental consequences. The policy was to convert to 141-b for the foam portion of refrigeration projects since there was no other choice offered." In Malaysia and Thailand, policy was open, while in China the environment agency

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[11] The MLF Secretariat completed regional refrigeration sector reports in 1999, where an examination of technology choice played an important part. The very interesting set of questions was an opportunity for a critical look at the influences on technology choice ranging from consultant bias to concerns about global warming. The resulting reports were much less wide ranging in their investigation. The questions were: "(a) What determines the choice of substitute technology? Are the various options systematically compared and valued? (b) What is the role of the interested company, the consultant preparing the project and of the Implementing Agency in the choice of technology? (c) How are the consultants selected? Do their CVs suggest any particular preference for the technologies proposed by them? How are they advised on technologies other than those they did work with in their professional past? (d) Are there preferences by region, agency, consultant, mother companies and type of projects? (e) What about the technical reliability and safety of the various issues? (f) Are the various alternatives comparable in terms of sustainable impact, that means irreversible substitution of CFC through non-ODS substitute products? (g) Is the level of technological competence of the interested company taken into account as limiting factor? (h) Is there a tendency by the agencies or the consultants employed to suggest certain technologies to the manufacturers because they are likely to receive a higher funding level than others? (i) Are the debates in the FCCC (climate convention) on HFCs and their effect on global warming being taken into consideration?"

SEPA coordinated the use of projects with both fluorocarbons and hydrocarbons to gain experience before making an assessment. India's government decided to favour HFC-134 and HCFC-141b, as was the case in Tunisia. Egypt chose HFC-134a and cyclopentane.

Most importantly, the report found that

> The comparison of technologies for each project was mostly superfluous, as either the decision had already been made by the country's NOU recommending one technology for the conversion, or by the counterpart company's experience and available technology. The NOU's rationale in recommending a particular technology is that the importation of a reasonable quantity of one substitute occurs instead of small quantities of various substitutes that should minimize costs and help import control and reporting. Where the company had a free choice and its parent company had converted using a particular technology, the company usually followed suit, as this was the lowest overall cost route.

While the choices of individual competitors was not important, the overall direction of the market was, as was the importance of export markets. Recognizing the European trend towards cyclopentane and isobutane, some companies reported that they would now choose them instead had they known this would be the case.

TEAP (1999) also finds that there "sometimes is inconsistency in the information made available…by the manufacturers of alternatives. In come cases, information on only one alternative is available to an enterprise through dealings with a single vendor. This leads to inappropriate choice of technologies. A co-ordinated approach to the provision of unbiased information will lead to more informed selection."

While there are hydrocarbon projects in Latin America, none were visited for the Secretariat's review (which would seem to diminish the usefulness of the assessment of technology choice decisions). In choosing HFC-134a and HCFC-141b "companies arrived at a final decision based on cost, market and technical criterion, using one or several consulting resources: a) IA consultants b) in-house resources. c) National consultants and d) strategic alliances or mother companies."

Two cases are illustrative of the decision making process: Atlas Electric considered hydrocarbons, but was unable to source a compressor, nor was there a supply of hydrocarbons, nor could they come to agreement with its international partner, which was already using 134a. Given these barriers, the choice of 134a was obvious. Another manufacturer, Mimet, also considered all the possibilities, but did not do any major economic or environmental studies. In the end, "the technology was chosen due to regional market considerations, competition, costs and safety" (MLF 1999).

Given these factors, the evaluation team comes to a very odd conclusion, that environmental factors were most important: "until a more environmentally friendly technology becomes available, HFC-134a and HCFC-141b replacements are deemed most suitable for the LAC" (MLF 1999).

Implementing Agencies often work with consultants, both for project preparation and evaluation. UNIDO generally sends its own staff for project preparation, but all three hire independent experts to evaluate the project prior to submission for review. According to the Secretariat's evaluation, "only the same experts were repeatedly hired." A limited pool of experts may make more novel ideas difficult to emerge. Indeed, consultants themselves bear a heavy responsibility and have a disincentive to run risks in the recommendations they make. When flammability is a consideration, however limited the risk, having a single person to whom advice can be traced makes that person much more sensitive to that risk. To the credit of the implementing agencies, "There was no evidence that the IAs chose a particular technology because they were likely to receive more funding" (MLF 1999).

Incorporation of Global Warming considerations

In Europe, hydrocarbons are selected for most new domestic refrigerators, due to "superior efficiency, low noise, use of mineral oil, low discharge temperatures, longevity of the compressor, and a high critical temperature" and most importantly, low GWP (TEAP 1997). The European eco-label "requires a very low GWP for substances to be applied (which in fact favours hydrocarbons)" as a result, "many manufacturers in Europe currently consider hydrocarbons to be the "final choice" in the conversion from halogen containing chemicals" (TEAP 1997)

There are cases where recognition of Europe's preference for HCs is causing DCs to reconsider HFCs and HCFCs, but that is due to export/import considerations. The global warming factor has little to do with it. In fact, although global warming was supposed to be an aspect of the secretariat's study cited above, in never came up as a factor in any of the resulting reports. Where climate change is mentioned by Montreal Protocol-affiliated bodies, it is done so very carefully.

While it is true that UNEP TIE provides information in an objective fashion, it provides only the information relevant to the approved goals of the MLF. Therefore, while TEAP (1999) suggests that climate goals be integrated into ODS phase-out decision making through UNEP advice, the crucial information necessary to decide between alternatives on the basis of global warming considerations is absent in UNEP publications. HFCs, hydrocarbons, ammonia and other alternatives are presented equally on their technical merits, mention of energy efficiency is made, but there is no assessment of climate impact, particularly of direct emissions. There would need to be a broadening of scope to follow the TEAP suggestion that UNEP TIE could be expanded to become a "Climate Action Programme" (TEAP 1999).

UNEP has produced a number of assessments of hydrocarbons which are quite technical and highlight the safe and efficient design and operation of hydrocarbon systems, without entering into comparisons with other systems. Of more interest are publications such as *Two Challenges, One Solution: Case Studies of Technologies that Protect the Ozone Layer and Mitigate Climate Change* (UNEP 2002) where global warming is supposedly a main feature, but there is no head-to-head investigation about HFCs versus other options. Clearly the lack of a political mandate hinders UNEP and other bodies from making such comparisons, though they are often discussed in theory.

The second switch: eliminating HCFCs in foam blowing

To many, one of the disappointments of the Montreal Protocol has been the heavy reliance on HCFCs as CFC replacements. Alternatives like cyclopentane, pentane and CO2/water have also been very popular in the switch from CFCs, and HCFCs have not replaced CFCs 1:1 in relevant applications. Nevertheless, some 17% of all ODP tonnes replaced by MLF projects used HCFCs, the vast majority in foams. There are several serious repercussions, including ongoing chlorine loading, the need for a second switch when HCFCs are no longer allowed, and the possibility of conversion to HFCs when this switch takes place. It is this latter issue that is the focus here.

Projects using HCFCs

In the refrigeration insulation foam subsector there are essentially two alternatives to CFCs: HCFC-141b and cyclopentane. While the number of projects funding HCFC-141b replacement of CFC-11 in domestic and commercial refrigeration foams (271) is significantly higher than the number of projects employing cyclopentane (119), the average size of cyclopentane foam projects is much larger. The total ODP tonnes replaced by cyclopentane is nearly twice that of the amount replaced by HCFC-141b. Other rigid foams have turned heavily on HCFC-141b, accounting for 325 of 375 projects. Those projects that have turned to pentane are clearly on a different scale, with an average ODP tonnes/project nearly 5 times that characterizing HCFC projects.

HCFCs are used because they are allowed, available, and have desirable qualities for the manufacturing and use of foam products. Their accelerated phase out in Article 2 countries is opportunity for certain players in the fluorocarbon industry to promote new HFC replacements. For polyurethane foam blowing, liquid HFCs (HFC 245fa and HFC 365mfc) are nearing commercialisation. Claims made in their favour include a lower k-factor than competing alternatives (better insulation value), ease of use, non-flammability and low toxicity.

At present it appears that HFC 245fa (Allied Signal's product in America) and HFC 365mfc (Solvay's product in Europe) are to be launched in 2002, requiring at least another 2 years for rollout in North America and Europe (Ashford 2001). Their acceptance in these markets will have large implications for eventual use in developing countries.

Factors for acceptance

Liquid HFCs are currently emerging from the laboratory to wider commercialisation. Meanwhile, HCFC phase-out in Article 2 countries is looming, and pressure has been mounting to switch to alternatives. But while waiting for liquid HFCs to become available, most users have been switching to other substances. Boardstock producers in the US who a year ago might have gone to HFCs are now switching to hydrocarbons (Ashford 2001). The foam industry is sensitive to blowing agent price, as they represent a high proportion of overall cost In North America, HCFC-141b sells for €2.40/kg. Hydrocarbons cost from €0.40/kg for pure n-pentane to €1.50/kg for cyclopentane/isopentane blends. HFC-134a sells for approximately €4/kg. Costs for hydrocarbon users include significant conversion to account for flammability. These can range from a few hundred thousand dollars up to $1 million Nevertheless, "payback still can be realized in as little as a year because the operating economics are very favourable" (Sherman 2001). With the relatively complex chemistry and manufacturing of liquid HFCs, and by emerging into a shrinking market, costs may be relatively high, initially around €9/kg.

On the other hand, the exploration of new blends that enhance desirable characteristics has been accelerating, broadening possible applications. Blends are being formulated to improve the thermal conductivity and to reduce flammability of hydrocarbons, with HFC proportions of roughly 50% and 80% respectively (Ashford 2001). The main foam blend will likely be one of HFCs with CO_2 (Jeffs 2001). Blends may increase their appeal and increase uptake, but HFCs are also diluted in the process. The overall picture is therefore unclear as to the ultimate reach and impact of liquid HFCs in future markets.

Slow liquid HFC take-up may signal the strength of natural substances, but unfortunately there's the possibility that HFC-134a will be more heavily promoted in that case. It has a higher GWP and relatively poor performance. Primarily this latter factor should limit acceptance, but with growing HFC-134a use worldwide, an expanding production base, falling prices and industry promotion, it may yield a larger market segment than it deserves, with implications for greenhouse gas emissions.

It will probably take until 2004 or 2005 to have a better view of the market shares of various non-ODS foam options. This should be an indicator of what will happen in developing countries in the even longer term. Despite development of both synthetic and non-synthetic blowing agents driven by A2 HCFC phase outs, at present there is a distinct danger that HCFCs will be seen as effectively long term in developing countries, as the phase out in 2040 for A5 countries is well past the horizon of current investment decisions. There is little or no incentive to avoid HCFCs. Furthermore, large developing countries like China are making HCFC 141b in ample quantities for domestic use and export.

As the focus of MLF foam projects shifts to smaller companies, even finding them can be difficult, and new ones keep appearing. The MLF set July 1995 as a cut-off date for establishment of eligible companies; any company established afterwards should have been told by their government that use of CFCs or HCFCs after that date makes them responsible for their own conversion (Jeffs 2001). However, the CFC-HCFC conversion is the easiest switch to make in foams. Second, the "low hanging fruit" is already gone, and the final phase-out plans will be significantly more difficult. Cost effectiveness is likely to continue to getting worse. These factors together could leave companies not only relying on HCFCs, but even holding on to CFCs or converting back to CFCs after an MLF project completes.

At MOP 13 in Sri Lanka, the European Community argued for a review of HCFC demand in developing countries over next 40 years, with an eye towards accelerating phase-out and introducing stepwise reductions. Developing countries prefer the freedom to choose this available and affordable option, and refused to approve the proposal. What may be more influential is the changing face of trade, where equipment containing HCFCs may become unwelcome in Article 2 markets. Import bans are considered unlikely, however (Ashford 2001). When the switch does happen, according to those close to the foam industry, the upper bound of the substitution rate of HCFCs with HFCs is 50%.

IV. Harmonising Ozone and Climate Policy

While the Kyoto Protocol does include HFCs in the basket of controlled gases, there has been little discussion of policy measures. As ODS replacements, HFCs are primarily at issue in the context of the Montreal Protocol, and Multilateral Fund (MLF) funding is the driving force behind ODS phase-out in developing countries. As such, the Meeting of Parties (MOP), and the Executive Committee (Excom) of the MLF are *the* fora for considering the role of HFC introduction, and HCFCs that may turn to HFCs, in A5 countries. Therefore, the significant role of HFCs and HCFCs witnessed in its projects over the years raise questions about the level of discussion within the Meeting of Parties and/or the MLF concerning the potential negative impact of these compounds.

In fact, a review of all of the reports of the Meeting of Parties, the full Executive Committee and the project subcommittee of the MLF reveal a history of statements followed by limited action. Overt discussion of global warming has been essentially limited to a decision recommending more study, a declaration with no power, a workshop, and statements by observers. There has, however, been a history of discussion within the MLF about how to treat technology choices, most importantly focusing on the acceptability of HCFCs and the allowable costs for hydrocarbon safety measures in funded projects.

HCFCs

As discussed above, HCFC use is important for HFCs, because the latter are likely candidates for HCFC replacement as these are phased out.

It is perhaps surprising that, based on the executive committee reports, it was not until the 15th committee meeting that the issue of HCFC use was discussed in open session. It was noted that in domestic refrigerator insulation foam, there are two main choices: cyclopentane and HCFC-141b. A switch to cyclopentane would be permanent from the ODS perspective, but a switch to HCFC-141b would ultimately require another switch to become ODS-free. The conclusion was that "Implementing agencies should note a presumption against HCFCs when preparing projects. Where HCFC projects were proposed, the choice of this technology should be fully justified and include an estimate of the potential future costs of second-stage conversion." The 17th and 19th meetings made further clarifications, and required a statement by project participants and governments that, when using HCFCs, they would expect no further funding for switches from HCFCs, and they were the best option in this particular case.

As HCFC projects continued to be funded, there was an exhortation at the 27th meeting that statements about the consideration of the HCFC option should not be just a paper exercise. During the 35th Excom the NGO observer stated that this was exactly what was happening. This raises questions about the effectiveness of "presumptions" where there are neither incentives nor consequences designed to promote alternatives or discourage fluorocarbons.

Hydrocarbons

During its 16th meeting the Excom adopted cost-effectiveness thresholds, designed to rationalize the decision-making process for project development on the basis of ODS avoided per dollar invested. At the same time the committee noted that safety costs for hydrocarbon technologies were significant, and decided that these costs should not be included in the cost-effectiveness calculations. The 17th Excom recognized that the exception for safety costs of hydrocarbons, without any quantification, left an extremely wide range of possible expenditures—estimates placed safety costs at 30-70% of project cost. It therefore fixed the allowance for safety as a recalculation of cost-effectiveness with a 35% discount of the cost side of the equation.

The 20th Excom reaffirmed this decision based on a Secretariat report indicating that additional capital costs ranged between 15.6 and 55.1% for hydrocarbon safety. It found that "Discounting the numerator by 35 per cent was sufficient to maintain parity between HCFC-141b/HFC-134a and cyclopentane/HFC-134a technology options in the domestic refrigeration sector" also noted that "The number of projects approved for cyclopentane/isobutane technology was not sufficient to enable reliable conclusions to be drawn." It also decided there was no need to extend similar provisions to either commercial refrigeration or other rigid polyurethane foam projects.

Excoms 22, 23, and 24 continued to work on this issue. The 22nd noted that it was urgent to resolve outstanding issues to allow projects to go ahead. The 23rd decided to apply European-level safety standards to hydrocarbon projects when these were higher than local standards. The 24th accepted the secretariat's hydrocarbon safety cost study as the basis for further decision-making.

HFCs and global warming

The first MOP noted that CFC phase out would help the global warming problem as they are themselves powerful greenhouse gases, but noted that HCFCs and HFCs have high GWPs, "which should be taken into account when their suitability as substitutes is being considered." How this should be done was not operationalised.

The second MOP requested the Scientific Assessment Panel to evaluate the global warming potential of HCFCs and HFCs, but did not go on to say that a high GWP meant there should be further consideration of their use. In the 4th MOP the TEAP was requested to report annually to the open-ended working group (OEWG) on "technical progress in reducing the use and emissions of controlled substances and assess the use of alternatives, particularly their direct and indirect global-warming effects."

At the 8th MOP an NGO noted the use of HFCs with concern, and at the 9th there were calls for more attention to hydrocarbons, including a TEAP assessment of their use as alternatives to HFCs.

The 10th meeting of parties took place following the creation of the Kyoto Protocol during the 3rd Conference of Parties of the climate convention. It passed decision X/16 that represents the first direct recognition of the interrelation of the UN ozone and climate efforts. While noting that HFCs and PFCs are both ozone replacements and greenhouse gases, the MOP requested that Montreal bodies provide input on the issue to Kyoto bodies, that there be a joint workshop with IPCC on the issue, and to continue to develop information on “the full range of existing and potential” ODS alternatives.

This very general decision was matched by a declaration introduced by Denmark and joined by 40 parties. In this statement they:

> 1. Call upon all bodies of the Montreal Protocol not to support the use of transitional substances (HCFCs) where more environmentally friendly alternatives or technologies are available;
> 2. Urge all Parties to the Montreal Protocol to consider all ODS replacement technologies, taking into account their total global-warming potential, so that the use of alternatives with a high contribution to global warming should be discouraged where other, more environmentally friendly, safe and technically and economically feasible alternatives or technologies are available.

As a declaration by a set of Parties and not a MOP decision it has no power within the Montreal Protocol.

During the 24th Excom the representative of Greenpeace made the first link to the Climate convention in the Excom. He pointed out that as HFCs were included in the Kyoto protocol basket of controlled gases, “the dual atmospheric crises of ozone layer depletion and global warming must no longer be treated as separate issues. HFCs should not be regarded as a long-term solution for the replacement of CFCs and HCFCs.”

During the 11th MOP the Greenpeace representative reiterated that HFCs were not a long-term solution and suggested a means of acting upon this: a global cap on HFC production and prohibition of applications with routine releases, save some critical uses like MDIs. In addition there should be preferential consideration of non-global warming gas substitutes for CFCs.

During the same MOP the TEAP reported on its replenishment study that one of the points of investigation had been “Opportunity costs associated with expenditures to favour hydrocarbons in Fund projects.” This was an attempt to quantify any losses due to the 35% cost discount for domestic refrigeration projects using hydrocarbons. The opportunity cost of using HCFCs or HFCs instead of hydrocarbons, accounting for continued ozone and climate damage, and potential second-switch costs, was not assessed—those fall outside the boundary of donor funding responsibilities.

The 12th and 13th MOPs saw continued efforts by NGO observers to draw attention to “the paradox of recommending gases controlled under the Kyoto Protocol as ODS replacements.” Reports on foams and refrigerants during the 13th meeting by the TEAP had a different tone: the new liquid HFCs were becoming available and were expected to “fulfil the need for efficient thermal insulation in space-linked and other demanding applications.” While hydrocarbons were also gaining in popularity “both safety in handling and product fire standards continued to be a problem in some areas.” In refrigeration “The seminal role of HFCs in the phase-out of CFCs and HCFCs was noted, reflected in the significant uptake of HFC-134a initially, with the introduction of more refined brands later to meet the breadth of applications in the sector.”

Ozone meets climate change

Industry always argued that HCFCs and HFCs were a basic part of their acceptance of the Montreal Protocol, and maintained a defensive stance about the ODP and GWP of these substances from the beginning. Without their use in an “orderly transition” from CFCs, argued one 1989 publication (ARCP 1989), among other alarming impacts we could see “shortages or unavailability of some foods and medicines…such as vaccines and transfusable blood.” Alternatives would be a long time in coming: “It is highly unlikely that industry could develop and transition to new products...without at least a 15-year development period.”

Throughout the process of ODS phase-out, “industry has tended to emphasise economic costs and technological feasibility but has understated the potential for innovation”(SEI 1999). So while phase-out is happening more quickly than first foreseen, it happened despite a deep conservatism in the approach to examining options: “in a sense, what users required was a new chemical to fit into an existing ‘technological corridor’; they did not want to have to make major changes in the way that they operated their systems. Of course, it was the chemical companies who had produced CFCs and, given that their knowledge base lay in this direction, it was also in their interests to produce refrigerants of a similar nature” (Glynn 2001).

HFCs and HCFCs seemed to be rising to the occasion when the prospect of HFCs’ inclusion in the Kyoto Protocol threw fluorocarbon enthusiasts into defensive mode. An initial reaction seemed to suggest that they saw an imminent ban on the horizon. It may come as no surprise, given experience of the Montreal Protocol, where “only a total ban has been considered to eventually result in an adequate environmental benefit in the mid to long term...Because of a familiarity with the Protocol mechanisms one often observes a tendency to consider a global ban on HFC consumption which is not consistent or logical under the Framework Convention on Climate Change” (TOC 1998).”

The framework referred to is the Kyoto Protocol’s “basket” of six gases, the aggregate level of which is subject to limitation. This approach “could also involve a certain growth in certain sectors in certain countries (e.g., the HFCs) which would have to be balanced by larger than average reductions in other greenhouse gas emissions” (TOC 1998). The concept of balancing among all six gases gives breathing space for HFC use as ODS substitutes, but puts it into competition with the other 5 gases, requiring justification.

In its report following the joint IPCC/TEAP meeting, the TEAP emphasizes the role of HFCs from the outset, a tone evident throughout most of the document: "Use of HFCs has allowed the rapid phase out of CFCs and halons." "HFC use is also technically and economically necessary for the phase out of HCFCs." "HFCs are currently essential substitutes for some other highly important uses of ODS." "HFC-134a is the only energy efficient substitute endorsed by vehicle manufacturers." "HFCs are necessary for mission-critical military applications," and so on.

In the judgment of TEAP The Kyoto Protocol "need not interfere with the Montreal Protocol," if HFCs are defended: "the Kyoto Protocol need not have adverse implications…provided that implementation by each country allows HFC use…where necessary." Overly restrictive regulations could yield a list of problems: delay CFC phase out and make it more costly; slow phase-out of HCFCs by creating business uncertainty; cancel development of new HFCs, prolonging the use of ODSs or compromising product performance "with the potential for increased energy use."

On the other hand, the Montreal Protocol is unlikely to interfere with Kyoto goals because "HFCs are a very small part of national emission targets." In fact, they can even aid in global warming mitigation where they have an energy efficiency advantage[12].

It is the combination of thorough, professional review of technology options with rhetorical support for HFCs that characterizes the TEAP assessment of its joint meeting with the IPCC. Oberthuer (2001) writes that the report was heavily criticized for going beyond basic information into policy suggestions, and that "it was also suggested that TEAP's findings appeared to be somewhat biased in favour of HFCs."

Examining warming impacts…indirectly

When discussing the harmonisation of ODS phase-out and global warming mitigation, for TEAP, and industry, the discussion boils down to TEWI: the total equivalent warming impact. TEAP (TOC 1998) argues that targeting HFCs is misdirected, when "a more indicative measure of the effect of any technology on global warming is…TEWI. TEWI combines the (direct) effect due to the release of refrigerant into the atmosphere as well as the (indirect) effect of the CO2 produced in generating the energy necessary to run the equipment."

It is argued that indirect CO2 emissions are the most important part of overall emissions—over 90% for unitary equipment (TOC 1998). Obviously, then, the efficiency of the unit bears a more important role in overall emissions. This has led to a fight over calculations of efficiency for HFC versus other systems[13].

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[12] The report notes that indirect emissions through the use of energy are more important that direct emissions "except in locations where electricity is generated form hydropower, nuclear, wind or solar." By way of example, these sources currently combine to 50% of European electricity supply (WEC 1999).

[13] This study focuses on HFCs and its alternatives, but it is important to bear in mind that, independent of comparing efficiencies for technologies associated with a particular working fluid, the opportunity for efficiency

Studies repeatedly show hydrocarbon domestic refrigeration systems using less energy than CFC or HFC systems (early studies are summarized in Maclaine-Cross and Leonardi 1997). For larger systems, some prototype installations using hydrocarbons or ammonia have shown 10-15% lower efficiency by being sub-optimally engineered or installed. Nevertheless, a study from Denmark (Pedersen 1998) showed that even considering slightly increased indirect emissions for a secondary loop system, the direct emissions of HFC from a competing direct expansion (DX) system still yield higher overall warming effect, even when the fuel source for electricity is coal. In Sweden, where there is a decade of experience installing secondary loop refrigeration systems in supermarkets using ammonia, the system efficiency is reported to be equal to or even better than direct expansion with HFCs (Lindborgh 2000). The TEAP (TOC 1998) also recognises that ammonia systems normally give the lowest TEWI for direct systems as well, as in cold storage and processing.

Given near parity of efficiency, direct emissions makes a crucial difference, and because they have negligible direct emissions, only hydrocarbons can achieve the minimum TEWI (GTZ 1997). But where the efficiency benefit is narrow, the direct impacts of HFCs could also be minimized to keep them competitive in TEWI terms. Recognizing that there is increasing evidence of the efficiency benefit from HC-600a, TEAP stresses that “the potential advantage of low GWP “natural refrigerants” is lost if HFC systems are made leak-tight and if industry implements servicing and disposal programs to minimize emissions” (TEAP 1999). Industry, for its part, finds that “mandatory recovery, reclamation, and recycling of HFCs would reduce emissions to very low levels and would provide a better LCCP” (TEAP 1999)

However, containment is most relevant in small unitary devices where hydrocarbons are already showing better efficiency, so that 100% containment of HFCs still couldn’t compete. In larger equipment careful maintenance to avoid releases, and recovery and recycling are particularly necessary due to large charge sizes. Evidence from (H)CFC experience indicates limited success of recovery and recycling efforts, even in countries where it is both required and for which there is a market in recovered substances. In the EU “The available evidence suggests…that R&R schemes in the EU work far from perfectly. Only part of the recoverable ODS are recovered, and it is sometimes unclear what happens to recovered amounts” (Oberthuer 2000).

In developing countries R&R projects for CFCs are heavily promoted through the MLF, but “they may not work the way they were intended to” (Ratnasiri 1999). As an example in Sri Lanka, even in workshops chosen for a special project, where there was adequate training, recovered CFCs were not sent to the processing centre, but were rather refilled directly into other units. The impurities in the

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improvement in general through MLF projects is an absolute top priority. Modern equipment is much more efficient than that of decades past—for example, a current refrigerator-freezer in the US uses one-third the energy of a similar 1972 model (AHA 1997), which is true for many other countries as well (TOC 1998). At least 50% improvement over old equipment should be achievable through better compressor efficiency, heat exchange efficiency, insulation efficiency and construction techniques (TOC 1998).

unprocessed CFCs would be certain to cause reduced system efficiency or even failure of the compressor (Ratnasiri 1999).

“Experience has shown to Ozone officers that there are several difficulties to ensure that refrigerants are effectively recovered and recycled, but specially the lack of incentives for the technicians to do so” (Mosler 1999). Ratnasiri (1999) found that “even in countries where recycling equipment have been supplied by the Multilateral Fund, the progress of the recovery of refrigerants and recycling may be below expectation.” The implication is that “it is unlikely that a recovery and recycling programme for HFCs could be satisfactorily implemented in developing countries.”

TEWI calculations also stipulate comparing like with like, in terms of cost. “In the cases where flammable or toxic refrigerants are applied to these units, the incremental costs required to meet applicable safety standards should be compared to the reduction in TEWI that could be achieved by investing the same amount in efficiency improvement technologies. The designer can then select the approach that provides the greatest consumer benefit.” (TOC 1998)

Pinto et al (1999) recognise that reducing emissions of HFC through awareness training, and recovery and recycling would themselves require more money. This would also have to be included in the TEAP calculation of TEWI based on equivalent system prices, but was not mentioned.

All in all, the uncertainties and specificities surrounding TEWI make its application so problematic, that its use as a guiding, rather than a supporting, concept is questionable. Given site-specific and design objective variables, and uncertainties in TEWI factors, “many assumptions are made in the calculation of the TEWI factor…which will result in a wide range of TEWI factors which are then difficult to use in an absolute sense” (TEAP 1997). Best results are possible under controlled, isolated comparisons, “and when the equipment studied has a TEWI that is relatively insensitive to installation, maintenance, and disposal practices” But as indicated above, much of the defence of HFCs rests on exactly these practices being carried out diligently to the highest standards, not even achieved in years of European experience.

While the TEWI concept is a valid one conceptually, it is merely a truism to say that *if* there were no emissions from manufacturing, no leakage in use, and all HFCs were recovered and recycled then there would be no global warming issue. But there is very little prospect of this occurring.

Bringing climate into ozone policy

Evaluating the options for incorporating natural substances with low global warming potentials (GWPs) into MLF projects now, rather than paying for a second switch away from GHGs in the future, would be in A5 countries’ interest, given the funding currently available for such switches. As pressure on HFCs mounts from the global warming side, “there are good environmental and economic reasons to deal with the phase-out of the main ODS and the problem of

HCFC and HFC use in an integrated manner" (Oberthuer 2000). From the donor point of view, integration may help avoid future friction with A5 countries who may feel that, should future tightening of Kyoto Protocol targets lead to production restrictions of HFCs, "it is the obligation of the Funding Mechanisms of the Kyoto Protocol to meet whatever the incremental costs associated with the second conversion" (Ratnasiri 1999).

To date there is no explicit guidance from MP institutions with side by side comparisons of competing options for a particular application, on the basis of overall global warming impact. And while there is not yet any political decision to address the global warming issue head on within ODS phase-out, it is implicit in certain decisions taken already: Ratnasiri (1999), in noting that HFCs are replacing CFCs at a much higher rate in MLF projects than is the case in Europe, says this could have been avoided if "the Executive Committee took its own guidelines seriously from the beginning." The provision stating that alternatives should be "environmentally sound" was interpreted too narrowly, to mean only in the sense of ozone depletion. "If the global warming factor was also included, hydrocarbons technologies would have received recognition much earlier, thus making Article 5 countries less vulnerable to the impacts of the Kyoto Protocol."

Often the argument is made that because the Kyoto Protocol is not ratified, there is no basis for undertaking efforts to limit emissions of CFC replacing halocarbons. This overlooks the fact that the Climate Convention is an agreed document. In it Parties acknowledge "that change in the Earth's climate and its adverse effects are a common concern of mankind." Article 3 principles include that "Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change…" Article 4 outlines the commitments of Parties to the convention, which include promoting technologies that reduce or prevent greenhouse gas emissions (art. 4.1c), and taking climate change into account in economic and environmental policy (art 4.1f). Developed countries "shall take all practicable steps to promote, facilitate and finance…environmentally sound technologies" in developing countries (art. 4.5). Clearly, MLF projects are *the* major Annex I/A2 financed opportunity to do such technology promotion and take precautionary steps.

Within MLF policy, the (erstwhile) presumption against HCFCs is a logical step, given that they're already planned for phase-out. The situation with HFCs is less straightforward, and development of an HFC policy should follow a logical path. The starting point must be political will to follow up on the commitments already made under the Climate Convention, in the form of a decision to incorporate minimized global warming impact as a goal of MLF projects. Second would come an assessment of which policy would lead to such reductions of total GHG emissions. This is *not* the same as setting a policy of minimizing TEWI per project, but rather evaluating "the TEWI of *policy."* It is essential to recognize that overly cumbersome calculations that may never get made in the real world are far less effective than general guidelines that are easy to follow and will have an impact. Such a policy could range from being less to more anchored in project-specific conditions. Most basic is a flat presumption against HFC[14] on the basis of an overall evaluation that on average GHG emissions would be reduced. Increasing specificity would include determinations by sector, subsector, or project, as feasible.

While some may argue that presumptions against HFCs might appear broad, the TEAP has already made a blanket policy pronouncement: it has repeatedly stated that a combination of containment, recovery and recycling would lead to the lowest TEWI. Given its concurrent analysis of the complexity of TEWI calculations, this assessment cannot be seen as anything but a best guess, or for the fluorocarbon industry's part, wishful thinking. It may *be* the case, but not only is it not backed up with calculations, there is a strong body of empirical and rhetorical evidence that indicates that it is very unlikely to be the case. The full picture will only emerge once the MLF gets the opportunity—the *requirement*—to take climate change seriously.

[14] By this we mean not the kind of presumption against HCFCs that has had no impact, but a presumption where one actively has to fight for the use of HFCs on the basis of critical need, specific evidence of their advantages in certain carefully defined circumstances, etc.