Keeping cool without warming the planet:

Cutting HFCs, PFCs, and SF_6 In Europe

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Climate change presents us with THE challenge of the 21st Century.

To meet this challenge the **Climate Action Network (CAN**) was created, of which **Climate Network Europe** (CNE) is one of several focal points worldwide. CNE was the first Climate Network node and was created in 1989.

The overall **goal of CNE** is to promote action to limit human-induced climate change to ecologically sustainable levels.

Membership is open to all environmental non-governmental organisations that subscribe to the goals of CNE and are active in the field of climate change. Today, Climate Network Europe has over 75 member organisations.

One of CNE's main tasks is to **facilitate co-ordination** of members' climate related work while at the same time co-operating with the other CAN focal points in Africa, South Asia, South East Asia, Latin America, the USA, Canada, Central and Eastern Europe

CNE provides an **information service** on emerging climate change policy developments and recent advances in climate science In addition CNE maintains a library with over 2500 publications related to every aspect of climate change.

Another important task is to raise **public awareness** on the problems and solutions to climate change.

The **European Union** plays a key role in the climate negotiations. CNE monitors and encourages the implementation of policies and measures that combat climate change in the EU as well as working with national NGOs to do the same at the member state level.

CNE closely follows the negotiations on the **UN Framework Convention on Climate Change** (UNFCCC). NGO presence is an integral part of these negotiations in the follow up to the "**Kyoto Protocol**" which was agreed at the Third Conference of the Parties (COP3) in December 1997. CNE is closely involved with the production of **ECO**, the influential NGO newsletter published at the negotiations.

Executive Summary

As the European Union and its member states finally start to develop strategies to reduce emissions of greenhouse gases, the importance of addressing new industrial gases is becoming obvious. These "F-gases," or "FCs" (HFCs, PFCs, and SF_6) have extremely high global warming potentials and are being emitted at a quickly increasing rate--projections indicate emissions could rise 150% between 1995 and 2010. Fortunately they are largely replaceable by commercially available natural compounds like hydrocarbons, ammonia and CO_2, or by alternative technologies and practices. Reducing F-gas emissions could make a major contribution to the greenhouse gas reduction goals Europe accepted under the Kyoto Protocol, at reasonable cost.

The Kyoto protocol's first commitment period is, however, just an important first step. Analyses indicate that we must reduce total greenhouse gas emissions levels by *at least* 50% below 1990 rates within 50 years if we are to avoid dangerous anthropogenic global warming. F-gas emissions are projected to continue growing rapidly beyond 2010, not least because many applications like foams or refrigerants experience most of their emissions upon decommissioning after a long life of use. Left unchecked, HFCs, the most significant of the F-gases, could potentially represent 15% of all CO_2-equivalent greenhouse gas emissions by 2040, and 40% by 2100. It is therefore imperative that policy be immediate in action, and long-term in scope. Further, given that F-gases are synthetic chemicals with inadequately understood human health and local ecosystem impacts, we should invoke the precautionary principle in preventing large concentrations from entering the environment.

As the EU just begins to develop a policy plan, member states are already active. Denmark has a plan to phase out F-gases, the Netherlands will count on 25% of their domestic Kyoto protocol reductions from F-gases, France intends an ecotax on refrigerants, and the United Kingdom has targeted HFCs for strict limitation in its draft climate plan. Several other countries are developing national climate plans with an aggressive approach and the majority of EU countries have restrictions on some of the F-gases. In addition, eight Austrian regions and numerous municipalities, and the city of Berlin are among those committed to phasing out HFCs partially or in full.

Industry proponents of F-gases try to paint alternatives as niche market applications that are too inefficient, unsafe and expensive to use more widely. Each of these arguments has been adequately addressed in broad experience worldwide for most applications. Alternatives are proving often more efficient, safety can be ensured through responsible measures, and costs are rarely significantly higher, and continue to fall with wider market acceptance. Often they are superior products in every respect, not just in terms of climate change concerns. The future belongs to these alternatives, and we should act assertively to ensure they are allowed to fulfil their promise.

Climate Network Europe proposes that the EU reinforce and compliment national measures through several policies, of which the most significant are:

- ***Use "avoidance of dangerous anthropogenic warming" as the guiding principle in policy formation, not just what's easiest for the first commitment period.***
  Ecological reasoning dictates that we need to aim for *at least* a 50% reduction below 1990 emissions levels within 50 years to avoid dangerous global warming. This implies quick action paired with long-term thinking. Because so many F-gas applications work on slow replacement cycles and the processes they're involved in

require time and investment to switch to alternatives, it's imperative that we switch away from F-gases as soon as possible. By moving to natural compounds and other alternatives now, we avoid short- *and* long-term impacts.

- ***Negotiate a cap on production and consumption of F-gases in the EU.***
  1995 emissions of F-gases in the EU contributed about 2% of total GHG emissions. Industry argues that that percentage may only rise to 3% by 2050. Independent studies project the possibility of 15% by 2050 and 40 % by 2100. A cap would provide some security against runaway emissions, and would allow flexibility for actions beneath the capped level.

- ***Declare a presumption against the use of HFCs, PFCs and SF_6; they should be eliminated when technically feasible.***
  Natural substances, not-in-kind substitutes, and alternative practices should be seen as the *standard* for which F-gases are the temporary alternative. Already, in a large proportion of applications F-gases are unnecessary; some industries require some more phase-in time for alternatives, and a small minority are faced with few alternatives, but where emissions can be strongly curtailed. The fluorocarbon industry strives to make F-gases appear indispensable in a range of applications; experience points to the contrary.

- ***Do not enter into EU-level voluntary agreements (VAs)***
  VAs have a poor record of achieving their goals. Where they do work, they are focused in scope, carefully designed and monitored, and supported by a strong legal basis that ensures compliance through reverting to alternative regulations, levying penalties or providing incentives. The EU lacks such a legal basis; entering into VAs would not be constructive and could seriously undermine any attempts to produce significant reductions in GHG emissions.

- ***Introduce an ecotax on the basis of each gas' GWP and overall climate impact.***
  An ecotax would send a price signal throughout the market that influences purchasing decisions, while raising revenue that could be used for research and development, or to assist small businesses in switching to alternatives. Such a tax sped the phase out of CFCs in Denmark through its double impact—changing purchasing patterns and reinvesting revenues. Tax levels should be set so they actually have influence and are based on the danger posed.

Contents

Introduction

Three fluorinated compounds—HFCs, PFCs, and SF_6 (collectively "F-gases" or "FCs")—are the "new industrial gases" of the six-gas basket addressed under the Kyoto Protocol. They are extremely potent greenhouse gases and their use is ballooning—left unchecked, HFCs alone could equal 15% of today's CO_2 emissions levels in the year 2040 (Maté 2000). There are alternatives available for most applications at prices competitive either currently or in the near future, though resistance by F-gas-using industry is strong and policy guidance will have to be proactive to prevent high emissions.

PFCs are mainly an unintended by-product of primary aluminium smelting. The most efficient processes also create the fewest PFCs; releases from this sector will continue to fall in the future through autonomous shifts by industry, though more should be done to ensure use of only the very best technologies (prebaked anodes and eventually inert anodes). The semiconductor industry has also committed to a 10% decrease in F-gas use, primarily PFCs, despite rapid expansion—new processes and substitute gases for etching and cleaning are becoming available. Whether they achieve their promise is an open question.

SF_6 is used to quench arcing in high voltage electrical switches, as a cover gas in magnesium casting, to fill car tires, in sound-reducing window glazing, in sport shoe "air" soles, and in tennis balls. Though SF_6 emissions are predicted to rise, mostly due to release of gas already banked, it is easily replaceable by other gases in the latter applications; for magnesium casting, SO_2, the cover gas used before SF_6, is being reintroduced. Electrical systems have fewer alternatives, particularly in high voltage (>60 kV) switches, but better design and handling should make a major impact in reducing emissions there.

The real battleground lies in HFCs. In replacing ozone-depleting CFCs and HCFCs, HFC use in the EU is ballooning from virtually nothing in 1990 to 37,500 tonnes in 1998 and potentially 129,000 tonnes by 2012 (Maté 2000). They are refrigerants, aerosol propellants, foam blowers, and by-products of HCFC-22 manufacture, among other things. Alternatives include switching to something entirely different—a pump spray instead of an aerosol for instance—or to natural compounds that are far less harmful to the atmosphere, such as hydrocarbons (HCs), air, CO_2, water, and ammonia.

The F-gas industry argues that alternatives are often too dangerous, too inefficient, and too expensive (ICI Klea 1999). In fact, all three issues are being addressed successfully. Proper safety measures in applications like foam blowing and refrigeration with HCs are routinely practised; to date, for example, there are 20 million system-years for domestic HC refrigeration in Germany alone without an accident. Although natural refrigerants themselves are cheaper, safety precautions, sealed systems and secondary loops do increase costs—a supermarket system with a secondary loop (which isolates the primary refrigerant in a back room) may cost 5-10% more than a similar HFC system; costs should fall with larger manufacturing capacity and new technologies. Larger systems with ammonia are already well established. The F-gas industry claims that alternatives cause more harm than good due to higher indirect impact—they are less efficient and use more electricity, thereby increasing GHG emissions. Experience proves otherwise—alternative refrigerants are often inherently more efficient, the variety of options in foams and non-foam alternatives allows choice of efficient insulations, new refrigeration equipment is often more reliable and efficient—alternatives are competitive on this point.

A limited number of NGOs, including Greenpeace and Klima-Bündnis, have been active in taking on F-gases. Greenpeace was responsible for the development of the Greenfreeze HFC-free refrigerator, and found a German manufacturer (Foron) that would make it, while others declined to get involved. Its success induced the rest of the German manufacturers to offer HFC-free models, which dominate the market; several other countries are following suit.

Public pressure and policies in many European countries have shown the degree to which F-gases are largely unnecessary. Restrictions on F-gases are either in place or being introduced right across the continent, and alternatives are increasing in importance, despite resistance from the fluorocarbon industry. Manufacturers produce home air-conditioning units without HFCs, magnesium using SO_2 cover gas, commercial chillers with ammonia, nitrogen to fill sport shoe soles, CO_2-blown polyurethane foam—the list goes on—in short, most applications have an alternative and where policy and public pressure has been outspoken, alternative industries have blossomed (An overview of each gas and alternatives is presented in Annex 1).

Current issues in F-gas control

There are several specific areas that are currently the subject of the majority of the discussion surrounding F-gases; these are addressed here.

Estimating past and current emissions is a problematic exercise

There is a serious lack of data on F-gas emissions. The Kyoto protocol allows a country to choose either 1990 or 1995 as the baseline date, but given the newness of F-gases as an issue, their small quantities, and their emission from specific sources that would require individual monitoring (defying broad estimations), inventories have generally been incomplete or missing. Further, some current figures derived from bottom-up studies (compiling measurements at the source of emissions) don't correspond with atmospheric observations (for SF_6 and HFC-23 for example), though there are some credible explanations that could be tested.

Estimates of current emissions influence the policy process. If they are estimated on the high side, then in the future, abatement actions will appear to be more effective than they really were; low estimations establish a more difficult starting point and make future growth look more dramatic.

Predicting future emissions is even more problematic

Setting a baseline emissions prediction involves complex assumptions that are invariably wrong, but have to be done for the purposes of modelling. High-growth baselines imply that active policy measures will be necessary; low-growth baselines imply the problem will require less active intervention. Industry is forwarding a low growth baseline to help them argue against strong policy measures (see emission projections section on page 27 below).

Setting the proper emissions factor—how much something leaks/emits a gas per year—is built on empirical evidence, but aggregating myriad individual products into general numbers allows a range of possible estimations, with differing implications. If future HFC refrigerators or mobile air conditioning systems are predicted not to leak much, then there will be less pressure to avoid using HFCs. If a foam product is assumed to leak little of the blowing agent, and retains a lot of gas upon end of life, then assuming good recovery and disposal leads to a prediction of low overall emissions. This holds true for refrigerants as well—assuming good collection and disposal from a leak-tight system yields low overall emissions. Industry backs such scenarios, but credible emissions factors may be higher, and collection upon decommissioning probably will be less: the result is significantly higher overall emissions (Johnson 1998).

Estimating costs of abatement options

An economic approach to GHG abatement rationally argues to apply resources in a cost-effective manner—it makes more sense to use a given amount of money where it will do the most good. Studies indicate that addressing the full six-gas basket lowers the cost of an overall GHG reduction strategy compared to just concentrating on CO_2 (Reilly, et al 1999, Gielen and Kram 1998), and the European Commission is currently using economic modelling as a basis to decide among proposed policy measures.

Choosing abatement options on economic grounds necessitates the rank ordering of measures, which is difficult and potentially controversial. First, it relies on the uncertain emissions factors and emissions estimates discussed above. Second, industries are the most knowledgeable about the costs of doing business or making changes to their business, but also have the most incentive to inflate the estimates. The current process therefore depends both on independent, difficult to obtain, assumption-heavy data, and on input from industry sources with motives to be inaccurate.

Rank-ordering has utility but should not inhibit action on items that may be lower on the list: first of all, the ordering may not be accurate—one recent study identified the cost per ton of CO_2-equivalent abated in domestic refrigeration at €400/tonne CO_2 equivalent (March 1998)—another put it at €9/tonne (Ecofys 2000). Secondly, implying that effort in fire extinguishing or domestic refrigeration has been money ill spent overlooks a more complex reality. In fact, there is no single pot of money from which abatement actions take place and there is no single agent deciding how to apportion it. The public has shown willingness to pay for the increased cost of non-HFC refrigerators (regardless of what its cost effectiveness ranking may or may not be), not least because the cost increase is minimal compared to the unit cost. The transactions costs and political infeasibility involved in redirecting that same money away from consumers and addressing an issue higher up on the ranking table would be prohibitive. The economic rankings also tend to ignore non-quantifiable (or not yet quantified) impacts: the local ecology and health impact of HFCs have yet to be thoroughly examined; the corrosive impact of F-gas fire extinguishing substances on costly equipment is not quantified; the importance of activating public participation through the use of natural refrigerants in domestic appliances is intangible; etc.

Issues in Refrigeration

For decades CFC-12 was the standard refrigerant worldwide for most applications. Upon phase-out under the Montreal Protocol, CFC-12 has been largely replaced by HFC-134a. Many substances can be used as refrigerants, however. Ammonia has a long history in larger applications and hydrocarbons have become increasingly important in small systems like domestic refrigeration, especially in Europe. Ammonia and hydrocarbons, along water, CO_2, and air, are expanding their applications from the large and small systems into medium-sized ones, currently dominated by HFCs.

The big market, the big emitter—the middle ground

Medium-sized systems—supermarkets for example—are the main area of contention, the largest market, and the one of the largest potential sources of HFC emissions in future (along with mobile air conditioning). While HFCs in direct expansion (DX) systems are standard, there are numerous systems based on ammonia, especially in Scandinavia, and also many hydrocarbon systems, mostly in the UK. Advances in medium-sized secondary-loop refrigerants like ice slurries show great promise for the near future. Secondary loops allow reduced refrigerant charge amounts because it doesn't circulate around the system—only into the heat exchanger with a secondary refrigerant. This reduces risks and leakage. The fluorocarbon industry seems to be conceding that hydrocarbons will dominate domestic refrigeration, and ammonia industrial, but persists in fighting to retain this largest, middle-ground market by claiming that there are no realistic alternatives, which is clearly not the case.

Safety is not prohibitive

One of the primary arguments voiced by opponents of HC's and ammonia in the medium-size range is that safety is a problem because there are larger quantities of refrigerant than in small systems, but that there is also less careful oversight than at the larger industrial level. Hydrocarbon and ammonia systems certainly benefit from training and safety measures during manufacture and use, but properly designed and installed systems should represent no more likely danger than with other technologies. Probably most relevant is that maintenance personnel should be well aware of the procedures for safe use, which argues for increased training. HFC's, however, also require well-trained personnel and exacting handling in manufacture and servicing, due to the low tolerance for mixing with lubricating oils and the need to capture the fluid properly upon servicing or decommissioning.

Ammonia has a natural built-in alarm—the strong, unpleasant smell, a real benefit from a safety viewpoint. Long before ammonia becomes dangerous, it is too unpleasant to be around. The design of safe HC systems and handling is well within the current technical capability of industry. In addition there are other systems becoming available based on water, air, and CO_2. The safety issue is therefore one that implies sensible care should be taken, but not one that rules out the use of alternatives.

The switch-over from F-gases to alternatives can be done economically

Natural refrigerants themselves are cheaper; extra system costs arise in items like welded connections and an emissions alarm, and for larger systems, secondary loops and other safety measures. Subsequent running costs are often lower than for the systems they replace, making life-cycle costs attractive. At the manufacturing level there are investments in safety measures, redesign and retrofitting of facilities and tools to consider, but which are one-time costs.

An important aspect for equipment prices is volume: it's unrealistic to compare costs of mature-market technologies with those just gaining a foothold—with higher market penetration costs should come down. In those countries where regulatory or market forces have demanded switches from F-gases, replacements have been readily available and innovation has continued to make improvements. The capabilities and costs in these markets are the proper basis for comparison for potential wider commercialisation, not the one-off prototypes built elsewhere.

Natural refrigerant systems can compete on efficiency grounds

Refrigeration and air conditioning's indirect global warming impact through consuming fossil fuel generated electricity is larger than the impact of direct refrigerant leakage. Hence the contention that efficiency is foremost, and that the use of alternative fluids, insulations, and system components must not reduce efficiency.

Industry total equivalent warming impact (TEWI) analyses are pessimistic about the efficiency of alternatives and continually emphasize that indirect emissions increase. However, studies repeatedly show hydrocarbon domestic refrigeration systems using 20% less energy than CFC systems (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 suboptimally 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). In short, the most efficient systems from a TEWI perspective either are already or will soon be natural refrigerant systems.

Energy Savings in Holland
The Vaartland Residence is a pleasant retirement home in the town of Vlaardingen, near Rotterdam in the Netherlands. Faced with a new government policy restricting the state coverage of energy costs for the building, the director initiated a series of energy-saving measures. Among these was retrofitting of the cold storage system in the kitchens, which still used CFCs. Though CFCs are banned for refilling or new installations in Holland, existing systems still contain some 1,200 tons nationwide, leaking steadily. Rather than being switched to HFCs, requiring new equipment, Vaartland's existing CFC system was recharged with a hydrocarbon blend, creating a highly efficient system without ozone or climate damaging substances. Pushing the possibilities further, the waste heat is captured in the dishwashing system's hot water tank. These and other simple measures within the reach of any similar institution yielded a 50% energy saving for the residence this year (Dijkstra 1999).

Foams

The foams sector uses and emits gases in several ways. A compound, like HFC-134a or cyclopentane, is a blowing agent that is mixed with the foam component materials—as the foam is injected in a form or mould or sprayed at a building site, the agent boils, creating a light cell structure. It then acts as insulation when trapped within the closed cells and is emitted slowly over time, a rate largely determined by the foam's thickness and how it is faced, or sealed. There are also spray cans that produce open-cell foam mainly used to fill gaps, where the blowing agent acts as a propellant and is lost upon use.

During the phase-out of CFCs and HCFCs there has been considerable switching to alternative blowing agents like CO_2/water and hydrocarbons, along with a significant share of HFC blowing. Some 25% of all insulating foams in the polyurethane (PU) sector are currently formed with HC blowing agents, a similar amount is blown with CO_2, as are most non-insulating PU foams, and around half of XPS is CO_2-blown (hydrocarbons aren't used in XPS) (IPCC/TEAP 1999). The F-gas industry is holding out promise of new liquid HFCs (HFC 245fa and 365mfc) that will have most of the desirable properties of CFC. The industry sees high-value applications switching to these expensive agents when they become available; this assumption is slowing viable switching to alternatives, even though the actual performance and cost of the liquid HFCs isn't well known.

Costs of conversion and alternatives

At the manufacturing level, conversion to CO_2/water or hydrocarbon foam blowing does require investment, but these are cheaper blowing agents, and conversion has shown pay back periods within 18 months (Prospect 1998). At the consumer level there are some anticipated cost increases, but they are generally minor in context; for example, a 15% increase in the foam price would lead to an increase of only 0.75% on the price of the refrigerator (Prospect 1998). Consumers have responded positively to changes in refrigerators—more than 40 million units with pentane-blown insulation and isobutane refrigerant have been sold worldwide, a rapidly rising figure.

There are approximately 400 SMEs in the EU that produce foam end-products using polyurethane—these range from appliance insulation to dashboards (Jeffs 2000). The estimated cost of conversion measures averages €500,000 per business (Ecofys 2000)—many small businesses that would find this investment to be a considerable sum. While this initial cost may be a barrier, subsequent operating costs will be lower. Therefore, the issue isn't to avoid switching but to overcome the initial cost barrier. SMEs could be supported with loans or grants, perhaps using funds from a global warming potential (GWP) tax (see policy proposal section below); suppliers of foams or foaming equipment could also look to supporting their customers through financing arrangements.

Efficiency is not a reason to downplay alternatives

Supporters of HFC foam blowing argue that they yield better insulators, and because the purpose of foam is to save energy, better insulators yield energy savings and hence fewer CO_2 emissions. The true picture is more complicated. CO_2-blown PU is a poorer insulator, but then a large portion of the CO_2 market isn't used for insulation, but rather for things like seat cushions. CO_2-blown XPS is only a poorer insulator at thicknesses greater than 6 cm; 82% of the market for XPS is 6 cm or less (Boy 2000). Hydrocarbon-blown PU is has slightly lower insulation value than CFCs, but better than HFC-134a (Prospect 1999). Furthermore, the direct warming impact of HFCs released during the production, use, and decommissioning of the foam must be factored in—alternatives lack this disadvantage. The efficiency penalty for alternatives is therefore only true under a combination of factors: where insulation value is the primary issue *and* where direct emissions from HFCs are less significant than indirect emissions saved *and* conditions exist where the alternative is a poorer insulator (due to thickness and/or blowing agent) *and* the foam can't be made thicker to compensate. These factors combine in the small minority of cases currently, and should be resolved in the near future.

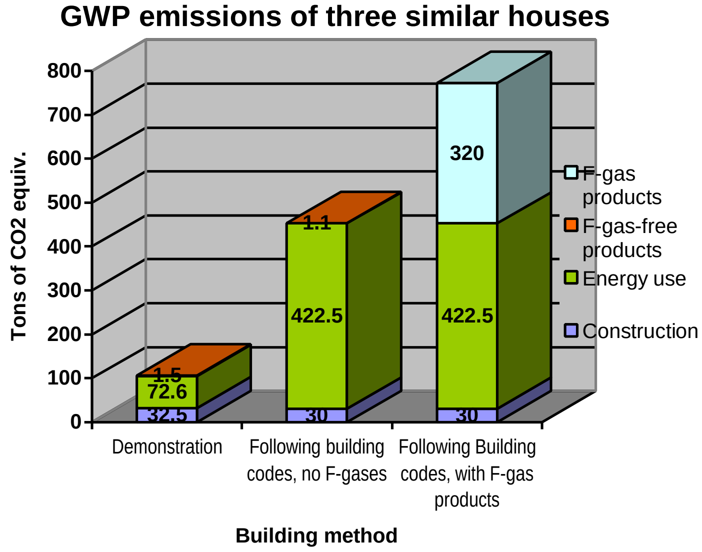
Flammability concerns

Although HCs are flammable, and safety measures are taken during foam blowing, HCs in the cell structure aren't a risk for starting a fire in a building. But fire safety standards in some places for some applications prevent the use of HC-blown foams due to their potentially higher flammability should a fire occur where they are installed. CO_2-blown foams and alternatives like vacuum panels could help address these concerns. Furthermore, safety standards should come under closer external scrutiny--they have a tendency to match closely the interests of the F-gas industry, which is heavily represented on the standards formation bodies.

Fire safety is a hot issue in the use of HFCs for one-component foam spray cans—the kind used primarily to seal gaps around windows and doors. HCs and HFCs propel the foam out of the can and expand it, but is released immediately from the open cell structure. The concern with HCs is that a potentially flammable concentration could be reached in a small room. Most of the EU has a 50g limit on HCs, the rest being made up by HFCs; Scandinavia is exempt from this limit and more HCs are used, because they are cheaper and work just as well—there's a good safety track record in Scandinavia, and in any case a mix of HFC with even 50g of HC renders the blowing agent flammable as well. The potential flammability is a problem that essentially through irresponsible use would be dangerous—certainly the professional users who make up the largest market can be expected to take precautions, as they must do anyway against the toxicity of the vapours. The least-cost switch to alternatives for foams is a shift to hydrocarbons in these cans (Ecofys 2000).

Efficiency without F-gases in Austria

In Austria there are 8 regions with either restrictions on (H)CFCs, HFCs, and SF_6 in construction, or in all uses where practicable. An estimate by Greenpeace Austria indicates that replacing these compounds with alternatives nationwide would yield a 10% reduction in the total greenhouse gas emissions level in Austria. A demonstration house built without F-gas containing projects received the Austrian environmental prize in 1998. It combined the best features of low energy use design with greenhouse-gas-free products. Calculations compared the greenhouse gas emissions of the house with alternative construction methods, including all of the energy inherent construction, materials, and 50 years of use, on a GWP-20 basis for HCFCs and HFCs (Lang 1999):



Reasonable estimates of future emissions

Liquid HFCs (HFC 245fa and HFC 365mfc) are nearing commercialisation, with the promise of coming the closest to the desirable qualities of CFCs. They will likely be high cost and the date of availability remains uncertain. While these factors will naturally limit their market acceptance, industry is counting on them in their assumptions about future emissions and foam characteristics. If liquid HFCs take too long to reach the market, are too expensive, or don't perform as promised then there's the possibility that HFC-134a will be more heavily promoted despite its high GWP and poor performance.

In projecting future emissions from foams, the most significant single factor is decomissioning, as generally 40% of more of the blowing agent still remains in the foam. Assuming recovery and destruction/recycling of the agent from the foam leads to a very low estimate of overall emissions. Since most discussion now is on strategies until 2010, emissions between now and then are estimated to be low, and future decommissioning costs and feasibility are poorly examined. Although the possibility of 50% recovery has been backed by some, "incineration procedures…while technically proven, may not be logistically or economically viable. Accordingly, a target of 25% destruction may be more realistic unless evidence emerges to the contrary. (IPCC/TEAP 1999)"

The case of PVC recycling, also forwarded under pressure to be phased out, is an instructive warning—German industry's touted "global recycling initiative" in fact recycles only 0,25% of PVC consumed, and supposedly recycled window frames have been revealed to be only coloured to give that appearance. In Denmark industry claimed 50% recycling in 1995, which was revealed on closer investigation to be 10-15% (Greenpeace 1999).

Non-foam options, and future developments

Especially for building insulation, foams are just one option of many. The market is in fact dominated by alternatives like mineral wool and fibreglass. While foams are lightweight, low density and versatile, the alternatives may have some environmental advantages, including high recycled content and lack of toxic chemical intermediaries. Although insulations save energy and hence CO_2 emissions through their use, they also consume some energy in their manufacture. At least in comparison with one common foam, Polyisocyanurate (PIR), alternatives are less intensive (see table 1).

Table 1. Embodied energy per insulating unit:

Insulation type	*MJ/ ft² @ R-20**
Cellulose	0.6
Fibreglass	4.8
Mineral Wool	3.1
PIR foam	15.1

* R-20 over one ft^2= RSI 3.52 over 0.093m2

Vacuum panels are already being used in limited degree—they are very effective, allowing much thinner insulation, or much higher insulation values in the same space. While they are higher cost, these costs are reducing, and rising insulation standards may make them more attractive than foams in high-value applications where insulation effectiveness is most important.

While most foam blowing could be done with alternatives now, within ten years it may be possible to meet all insulating needs economically without F-gases at all: applications where insulation value and safety is foremost could be met by vacuum panels, and other traditional or advanced alternatives; hydrocarbon-blown polyurethane could fill a large market segment; those applications where insulation value is less relevant could be met by CO_2-blown polyurethane; and CO_2-blown XPS would supply insulation in the thickness range where it is most effective (Randel 2000). Given this short time frame, it is imperative to avoid allowing HFCs to entrench themselves further in foam blowing—this makes them harder to remove even when unnecessary.

Mobile Air Conditioning (MAC)

HFC-134a supplanted CFC-12 as the refrigerant in automobile air conditioning, and is the current standard. Emissions of HFCs from MAC are projected to account for almost a quarter of all HFC emissions in 2010 (Ecofys & EnvirosMarch 2000). A typical car averages a charge of around 800g of refrigerant. Due to the working conditions, MAC systems have historically leaked 20-30% of their charge per year, and new systems 10-20% (Pedersen 1998b). Industry claims 8-10% for "current" systems, and 4-5% in the future. Annual leakage figures, however, can undercount significant losses during accidents, servicing and repairs. Just averaging a 10% annual loss, or 80g, yields emissions of 120kg CO_2 equivalent, or the same as driving the average European car

650 km. Industry is proposing to address HFC emissions through design changes leading to reduced charges and lower leakage, plus better recovery at maintenance and decommissioning. These measures are inadequate, but industry's resistance to HCs is strong and new CO_2 systems under development are advancing slowly.

The MAC market in Europe is growing

Given the climate in most areas of Europe, AC has not been a feature on most cars. This is changing quickly, however, and it's becoming standard even in Nordic countries (Pedersen 1999b). In Germany, 9.4% of all cars sold in 1992 were equipped with AC; in 1998 the figure was 68%, rising to a predicted 90% in 2001 (Schwarz & Leisewitz 1999). Buyers often don't even have to choice *not* to have AC as it becomes standard equipment. Improvements in leakage reduction can't compete with this trend, a main reason why MAC will be increasingly important in the overall emissions of F-gases. Restoring the option to consumers would be an obvious step.

The safety and efficiency of HCs in Mobile Air Conditioning

The simplest alternative refrigerants in mobile air conditioning (MAC) systems are hydrocarbons—propane or an isobutane/propane blend. In Australia and the United States, auto shops can recharge HFC or old CFC systems with HCs at their customers' request. HCs are cheaper and often more efficient and effective.

The HFC and auto industries cite safety concerns that hinder simply switching to HCs in MAC. Despite evidence from experience to the contrary, they argue that because the air conditioning system is in the forward area of the car (vulnerable to impact), tends to leak (though HCs leak less than HFCs), and isn't designed to handle flammable refrigerants, there's a danger of explosion and/or release into the passenger compartment. But these arguments are rhetorical--risk assessment has indicated that even unmodified systems with HC charges represent a very minor increase in the overall risk associated with driving (Maclaine-cross and Leonardi 1997). In the 20 million system-years of MAC using HCs as a refrigerant there are no known incidents attributable to their flammability (Maclaine 2000).

Further independent assessment of the safety issue could corroborate findings to date and help spur HC use. Despite the evidence of safe HC use and the opportunity for further development in this area, car manufacturers prefer to stick with the status quo, and act as cautious corporations that are highly risk-averse and for whom even the suggestion of possible incidents involving HCs raises the spectre of litigation. Without significant pressure in favour of HCs this option could remain unused in Europe.

CO_2: "the future" of MAC in Europe, delayed

The alternative preferred by European manufacturers for the future is trans-critical CO_2. The system operates at higher pressures and requires a completely different set of components. While some argue that the need to increase thicknesses to tolerate higher pressures will lead to weight increases, and therefore decreased fuel economy, they overlook the fact that the inside dimensions of the components can be made much smaller due to the properties of CO_2, yielding a system of similar weight (Kauffeld 1999). Discussions in the late 1990s between Greenpeace and Mercedes Benz made it clear that CO_2 systems were nearly ready for commercialisation. Now, Daimler Chrysler is claiming commercialisation is at least 5 years away (Lohbeck 2000). Fortunately, recent prototypes are very promising in their cooling effectiveness and impact on efficiency.

Metered Dose Inhalers (MDIs)

MDIs could mostly be replaced

Metered Dose Inhalers propel precise quantities of medication into the lungs of people with conditions like asthma and cardiopulmonary respiratory disease. MDIs have special status as critical uses under the Montreal Protocol, and continue largely to use CFCs. As new formulations with HFCs are developed, these come onto the market. Given the growing use of HFCs and the worldwide increase in respiratory disease, MDIs are becoming a significant source of HFC emissions. A baseline calculation places 2010 HFC emissions from MDIs at 4.1 $MTCO_2$ equivalent (the same as the projected total of Belgium and Denmark's F-gas emissions in that year) (Ecofys 2000).

The inhaler industry plays upon the fear of affecting the quality of medical care to support its position that MDIs with F-gases are a superior product (as in IPAC 1999). In fact, they are currently necessary in the minority of cases. Dry powder inhalers (DPIs) are a proven alternative with no emissions, but which use a new mechanism and have yet to penetrate most markets—which probably goes most of the way to explaining industry reluctance to back them more whole-heartedly, rather than the HFC MDIs they've invested in heavily.

DPIs rely on inhalation by the patient to be activated, while MDIs are self-propelled; self-propelled delivery is crucial for those who are unable to inhale sufficiently—representing possibly 5-10% of the market. There are also patients who are allergic to either the powder or the spray forms. The call at this point therefore isn't to eliminate MDIs, but to increase the market share of DPIs to the 80-90% range, as they are in Scandinavia. A major challenge now is the abundance of cheap generic CFC-propelled MDIs. With the market for CFCs being legislated away, the remaining exempted applications are awash in supply. DPIs also currently use around 10 devices, and aren't a fully mature commercial product. When a standard system emerges and manufacturing benefits from economies of scale, the price difference with MDIs will be much smaller. Also of note is the potential significance of life-cycle analysis on the whole MDI system—MDIs are housed in aluminium, which expends resources to produce, and because it's difficult to tell when an MDI is empty, typically 20% of the content is discarded (Schwarz 2000). DPIs are generally refillable plastic (non-PVC), and the remaining doses are audible when the unit is shaken.

Semiconductors

Emissions and alternatives in a fast-changing industry

The semiconductor industry uses F-gases, mainly PFCs, for cleaning and etching (see table 2). Under a baseline scenario, semiconductors' proportion of overall PFC emissions could nearly double between 1995 and 2010. Cleaning vapour deposition chambers with PFCs accounts for the great majority of current emissions. One reduction possibility is the use of NF_3—it is a higher GWP gas, but its particular properties are advantageous—NF_3 dissociates in the cleaning plasma, and then doesn't re-form afterwards to be evacuated, unlike PFCs. Possibilities for etching include moving to different HFCs—

Table 2. Some F-gases emitted in semiconductor manufacture

Compound	Use
C_2F_6	Etch/chamber clean process gas
CF_4	Etch/chamber clean process gas and/or by-product
SF_6	Etch process gas
CHF_3	Etch process gas and/or by-product
NF_3	Etch/chamber clean process gas
C_3F_8	Chamber clean process gas
C_2HF_5	Etch process gas and/or by-product

Adapted from Mocella 1998

these are generally lower GWP, and some HFCs show more precise etching qualities (Algood 1999). Given the fast-changing technical landscape of the industry, it's very hard to predict which F-gases will be used and how, making current emissions predictions, and investment in control strategies, problematic. Assembling accurate inventories of emissions has also been hindered by industry competition concerns, where releasing relevant information can be considered compromising.

The World Semiconductor Council "voluntary agreement"

The World Semiconductor Council (WSC), which unites regional trade bodies and whose members produce over 90 percent of the world's semiconductors, announced a "voluntary agreement" to reduce member organization emissions of PFCs by 10% below 1995 levels by 2010. They define PFCs to include HFC-23 and NF_3 (but not HFC-134a, which could be increasingly used for etching).

The WSC agreement is essentially internal—it's an agreement among member companies and member regional councils to form one worldwide overall target. A secondary aspect is to link this commitment to agreements with governments. The United States Environmental Protection Agency (USEPA) and the Japanese Ministry of International Trade and Industry are active supporters, though an understanding with the EU has as yet been unworkable. The USEPA's involvement is essentially informational in nature, supplying updates on best practices for industry, gathering monitoring data and rewarding accomplishments.

This voluntary agreement is far from the kind of negotiated agreements that some EU member states use as a public policy device that stands in for or complements other measures like regulation and taxes. The agreement the WSC seeks with governments is essentially recognition of their unilateral promise, and little more. Were they to achieve their goal it would be commendable, but as a policy instrument the agreement is hopelessly weak, offering no meaningful commitments, guarantees or fallback options, coming as it does from the industry and not in negotiation with governments as part of a policy development process related to climate protection goals.

Standards are being unduly influenced by the F-gas industry

Standards impact a number of HFC-containing products, from the fire safety of foams and refrigerants to standards on insulation and pressurised equipment. While they are necessary, they are often self-serving to the industries dominating input into each standards setting process. For example, though the new European standard on refrigerants, EN378, puts in place similar allowances for HCs as in the UK—up to 1.5 kg for small applications, 2.5 kg for medium, and 10 (or more) kg for large systems in off-access areas—it essentially rules out HCs in air conditioning "for human comfort." The implication is that air conditioning in a computer room, for example, would somehow be safer than in an adjoining office. This situation has no basis in technical logic, and may represent an oversight, or a concession to F-gas industry interests.

Putting refrigeration standards into perspective, a cook sweating over the open-flame propane stove in a curb side food stall, with several multiple-kilogram canisters of fuel stacked in the corner ready to do service, would be unable to cool himself off with an air conditioning unit using propane factory-sealed in the unit (such as the popular DeLonghi Pinguino).

It is also irresponsible that the standards committee has examined closely the local environmental hazards of natural refrigerants—flammability, toxicity—but has ignored those reportedly attributable to HFCs or the lubricating oils used with them—toxicity and corrosiveness when burned and adverse impact on the health of maintenance workers—despite evidence for concern.

The reach and influence of if this and other standards in the absence of specific national legislation (which has the power to supersede them) should not be underestimated. While standards are largely viewed uncritically as beneficial (who's against fire safety?), in fact they emerge from a process of considerable debate where vying commercial concerns play a significant role.

European policy development and CNE's proposal

Several European countries are addressing F-gases directly or in the context of climate change action plans. While national plans are imperative, EU-level policy also has an important role. Harmonization of policy will ease competition concerns and help ensure Europe's greenhouse gas reduction goals are met. Currently there are cases where a restriction on an F-gas in one country has helped convert its local industry to alternatives, but they keep producing F-gas products for export to other countries, sometimes because of an opposite restriction on alternatives. This is economically inefficient while permitting continuation of substandard environmental practices.

Both traditional and alternative industry are withholding investment until they are certain their decisions won't be undermined by future policy. If a favourable result is reached for F-gases in the current policy process we'll very likely see them capture a large market. The same is true, however, for alternatives—there are many possible technologies at pre- or early-commercialisation stages whose developers are awaiting guidance before entering more seriously into the market. The result is that potential for alternatives based on activity we see now is seriously underestimated, as are potential F-gas emissions in the near future, depending on the direction policy takes.

Policy Priorities for Europe: CNE's Proposal

The wide variety of niche applications F-gases fill and the technical detail involved in their abatement has allowed the F-gas industry largely to dominate the policy process. Policy makers should recognise that the future clearly belongs to alternatives and that delay will only be costly and harmful to the environment in the long term. They should not allow themselves to be hemmed into lengthy discussion of marginal shifts in process and leakage reduction, which is the thrust of industry's proposals. These are designed to deflect real change. CNE proposes the following priorities for European-level policy:

- *Use avoidance of dangerous anthropogenic warming as the guiding principle in policy formation, not just what's expedient for the first commitment period.*

We need to aim for at least a 50% reduction below 1990 emissions levels within 50 years to avoid dangerous global warming. This implies quick action paired with long-term thinking. Some proposals on the limitation of F-gas emissions look only to 2010, but uses like refrigerants and foams will continue leaking and experience high emissions at end-of-life decommissioning well after 2010, which therefore isn't examined. Because so many F-gas applications work on such slow replacement cycles (refrigerators, gas insulating switches, foams) and the processes they're involved in require time and investment to switch to alternatives (inhaler formulations, foam blowing machinery, compressor design) it's imperative that we switch away from F-gases as soon as possible. By moving to natural agents and alternatives now we avoid short-term impacts *and* long-term problems.

- *There should be a presumption against the use of HFCs, PFCs and SF_6; as undesirable substances, they should be eliminated when technically feasible.*

Natural substances, not-in-kind substitutes, and alternative practices should be seen as the *standard* for which F-gases are the temporary alternative. Already, in a large proportion of applications F-gases are unnecessary; some industries require some more phase-in time for alternatives, and a small minority are faced with few alternatives, but where emissions can be strongly curtailed. The fluorocarbon industry strives to make F-gases appear indispensable in a range of applications; experience points to the contrary.

- *Immediately negotiate a cap on production and consumption of F-gases in the EU.*

1995 emissions of F-gases in the EU contributed about 2% of total GHG emissions. Industry argues that percentage may only rise to 3% by 2050. Independent studies project the possibility of 15% by 2050 and 40 % by 2100. A cap would provide some security against runaway emissions, and would allow flexibility for actions beneath the capped level.

- *Do not enter into EU-level voluntary agreements (VAs)*

VAs have a poor record of achieving their goals. Where they do work, they are focused in scope, carefully designed and monitored, and supported by a strong legal basis that ensures compliance through reverting to alternative regulations, levying penalties or providing incentives (Helby 2000). The EU lacks such a legal basis; entering into VAs would not be constructive and could seriously undermine any attempts at creating real results in reducing GHG emissions.

- *Introduce an ecotax based on the global warming potential (GWP) and overall warming impact of each greenhouse gas.*

An ecotax would send a price signal throughout the market that influences purchasing decisions, while raising revenue that could be used for research and development, or to assist small businesses in switching to alternatives. Tax levels should be set so they actually have influence and are based on the danger posed.

- *Immediately ban non-essential emissive uses of F-gases (such as in klaxons, novelty items, self-chilling cans).*

Such items release comparatively large amounts of F-gases directly into the air upon use. A ban is the most straightforward method to address these applications, as they shouldn't be allowed under any circumstances.

- *Clearly label products containing F-gases; ecolabels should only apply to "F-gas free" products.*

Appliance labelling is a good step for consumer choice, but ecolabels and labels identifying use of F-gases should extend to all relevant products.

- *Strengthen the monitoring and reporting of emissions, with each member state conforming to IPCC standards and future Protocol decisions on inventories.*

Recent reporting has shown inconsistency in method, incompleteness, or even lack of reporting. Accuracy is important when dealing with these high GWP gases. Attention should be paid to agreements with industries on releasing data where there are competition concerns.

- *Support technology transfer of F-gas-free technology to developing countries; remove support for switches to HCFCs and HFCs as part of the Montreal protocol, supporting instead switches to alternatives.*

Experience with natural alternatives to F-gases in the developing world has been positive. In 1998 60% of all refrigerator insulation in China was blown with hydrocarbons; Indonesia, India, Brazil, and other countries are following their example. The fluorocarbon industry is trying to pose climate concerns as being in opposition to ozone depleting substance (ODS) phase-out under the Montreal Protocol in order to protect potential markets in the developing world. Poor countries are being saddled with patented, expensive F-gases and related technologies, while widely available hydrocarbons are being suppressed. Environmental NGOs have long argued against costly double switching from (H)CFCs to HFCs and then to natural compounds, but this is what is being promoted in those countries least able to afford it, and where a second switch will be the longest delayed, allowing high GHG emissions in the meanwhile.

- *Adopt standards for leakage reduction, maintenance and decommissioning, including training and certification of technicians.*

The installed bank of F-gases must be effectively decommissioned, as alternatives expand. Technicians are an important link in the introduction of alternatives—currently they often lack the knowledge necessary to size and install them properly, in addition to being locked into restrictive supply arrangements with traditional suppliers.

- *Increase funding for research, development, and commercialisation of alternatives.*

Although most alternative products are being developed successfully by commercial interests competing on a market basis, additional funding would give an added boost that would help meet policy objectives sooner. One source of funds could be the ecotax.

- *Review relevant standards to remove barriers, such as the unnecessary restrictions on hydrocarbons in air conditioning units in the draft EN378 standard, and low limits on hydrocarbons in foam cans.*

Standards are influenced by special interests, which produce favourable rules that are very influential and viewed as objective, though they aren't. The restriction on hydrocarbons in some air conditioning applications in EN378 is inconsistent with the amounts allowed in other applications, which has no basis in technical logic. For one component foam dispenser cans, most of Europe is limited to 50g of hydrocarbon, with the exception of Scandinavia. The 50g limit should be re-examined. This is a highly emissive use, the safety difference between 50g and higher charges is arguably negligible, and it is the least cost switch away from HFCs.

- *Set a date by which HFC-23 emissions from HCFC-22 manufacture must be thermally oxidized or otherwise eliminated.*

Thermal oxidation of HFC-23 is being practiced in some, but not yet all, facilities. The process eliminates over 90% of the highest GWP HFC, and should be required.

- *Set a target for the market share of dry powder inhalers and other alternatives to MDIs—85% is reasonable.*

This amount is being reached in most of Scandinavia and a consortium of manufacturers working with NGOs and doctors is setting a high target for Germany. Spurring increasing volume of DPI sales will decrease costs, and largely eliminate a growing source of HFC emissions.

Policies already in place around the EU

National Plans

Only four countries in the EU (to date) can be said to have coherent plans for either dealing with F-gases by themselves or addressing them in an overall GHG reduction plan—Denmark, France, the United Kingdom, and the Netherlands (these can be reached through CNE's website: www.climnet.org/links).

The most aggressive approach is found in Denmark. The Danish Environmental Protection Agency (MST 2000) released a detailed plan in January 2000, pursuant to the 1996 announcement by environment minister Svend Auken that F-gases should be phased out by 2006. The plan calls for the great majority of applications to phase out by that date, though certain categories have open targets, to be determined later. Denmark's existing legislation has already precluded F-gases in fire extinguishing and aerosols, and experience with applications like SO_2 cover gases in magnesium foundries and non-HFC foam blowing in district heating pipes has allowed these to face quick phase-out deadlines. Mobile air conditioning is the most significant segment without a deadline, primarily due to the lack of an in-country auto industry. Unfortunately, export of substances banned in Denmark would still be allowed.

France's new national plan addressing climate change includes sections on refrigerants and industry, covering F-gases (CIES 2000). The measures proposed include voluntary agreements, elaborating standards, inspections, spurring recovery, and further research. Most interesting is the extension of the tax on GHGs to cover F-gases. The level is elsewhere set at 500F/tCO_2. Because of F-gas' high GWP, the tax would be significant, for example 180F/Kg of HFC-134a, which sells at 35-50F/Kg. Because of the implications for the industry, the tax was arbitrarily reset at 10F/Kg, or only 5.5% of the level dictated by a uniform consideration of GWP.

The United Kingdom's draft climate change program (DETR 2000) includes the

Phase-out in Denmark

When the Danish draft F-gas phase-out plan became public in January 2000, the European fluorocarbon industry attacked it as a "politically inspired exercise." They were right—it was inspired. It takes leadership to promote environmentally responsible policy in the face of industry lobbying, and Denmark showed its mettle. Environment minister Svend Auken set the goal of eliminating F-gases back in 1996, and the proposed regulation was three years in the making—slowed down not in small part by constant industry lobbying. Though imperfect, it is a solid affirmation that F-gases are largely redundant.

Industry would like to dismiss the contribution of F-gases to Denmark's warming impact as "miniscule." In 1997 the consumption in Denmark had a potential warming impact of 1.6 million tons of CO_2. This is a snapshot of a sharply rising figure—currently around 6% annually at European level, or doubling in 12 years. Denmark's reduction target under the Kyoto protocol is 15 million tons of CO_2 below its 1990 levels. Phasing out F-gases could make a sizeable dent in that goal.

The Danish phase-out plan is divided into numerous market segments, addressing each on the basis of its specific conditions. While it is overly conservative on some points, such as allowing non-insulating flexible foam to use HFCs until 2004, it does reflect a considered balancing of environmental priorities with the needs of industry. The earlier phase-out dates, beginning 2001, come in applications where alternatives are already well established. Denmark has a head start in some respects because of earlier legislation banning F-gases from aerosols and fire extinguishing. It also lacks some challenging industries—no fluorocarbon manufacturers and no automobile manufacturers. As such, it has little influence over imported mobile air conditioning, and it is excluded from the plan. Similarly, export of F-gases and related products would still be allowed. Denmark's influence as a small country only goes so far, but it serves as an important impulse to efforts to limit F-gases in other countries.

promising general principles that HFCs are not a sustainable option and should "only be used where other safe, technically feasible, cost effective and more environmentally acceptable alternatives do not exist." The report acknowledges the inadequacy of the many existing VAs in several industries, stating that they "would not deliver significant reductions in emissions in the short and medium term." The plan lays out measures to strengthen the agreements, such as definitive targets, robust reporting, and a "use list" recommending where HFCs aren't necessary. Further policy measures are limited to requirements in handling and disposal. Given the general principles adopted by the plan, there is clearly room for more proactive policies than the ones proposed.

The Netherlands (VROM 1999) has specified a percentage reduction target to be met from F-gas abatement—at least 23% of their domestic reductions, or 11.5% of overall reductions due to their intention to trade for 50%. The primary vehicles for reductions are "regulations, covenants [VAs], and possible investment support. (VROM 1999)" This means primarily agreements with industry and regulations about leak control, proper maintenance, and recovery at decommissioning.

Only Spain, Portugal and Greece reportedly have no relevant legislation pending or planned. Denmark, Germany, Finland, Ireland, and Belgium are developing coordinated national climate change policy plans. Measures likely to be addressed in these plans include controls over the distribution, recovery, and collection of HFC refrigerants, phasing out HFCs in fire extinguishers, introducing a GWP tax as in the French plan, ecolabelling foam boards, and introducing "manufacturer responsibility" for disposal/reuse of gases (Ecofys & EnvirosMarch 2000).

Legislation

Location	*Measure covers:*
Austria	8 regions and numerous municipalities have adopted a phase-out policy on (H)CFCs and HFCs in products and appliances
Berlin (Germany)	Phase-out policy on (H)CFCs and HFCs in products and appliances in place.
Denmark	F-gas plan (above); comprehensive "refrigeration sector environment scheme;" F-gases banned in aerosols and fire fighting (except for fire departments).
Flanders (Belgium)	Refrigeration inspection; certification/registration of technicians
Finland/ Luxembourg	No specific measures, but general legislation on waste and CFCs can affect F-gases
France	National plan (above); recovery, reuse, destruction where there's >2 Kg refrigerant.
Germany	F-gases banned in solvents
Italy	SF_6 recovery; no HFCs in fire extinguishing from 2009
Netherlands	National plan (above); recovery, reuse, destruction of gases from refrigeration; inspections; leak rates set.
Sweden	Refrigeration system design, maintenance, inspections, training/certification/registration of technicians, recovery, emissions reporting. Design/recovery/handling in fire fighting. No HFCs in polyurethane in construction.
UK	Statutory pollution control reducing F-gases

Sources: Ecofys & EnvirosMarch 2000 (b); Finland 1999; Hanisch 1999

Informational measures

Country	*Measure*
Austria	Ecolabelling foam boards (planned)
Belgium	ODS alternatives advice (in development)
Denmark	F-gases listed as undesirable
Germany	Ecolabelling of refrigerators
Italy	Educating doctors to alternatives to MDIs

Source: Ecofys & EnvirosMarch 2000 (b)

Voluntary Agreements

Industry	*Measure*	*Scope*
Semiconductors	World Semiconductor Council limiting emissions to 10% below 1995 levels	Global
Aluminium	Reduction of PFC emissions from smelting	UK, Germany, France
HFC 23	Incineration of by-product from HCFC 22	UK, Germany
Windows	Phasing out use of SF_6 in double glazing	Austria
Magnesium	Phasing out use of SF_6 in smelting	Austria, France
Electrical Switchgear	Reducing emissions of SF_6 from gas insulated switches	France, Germany, UK
Fluid recovery	Reducing leakage; increasing recycling and recover	Austria, Belgium, Denmark, France, Germany, UK

Source: Ecofys & EnvirosMarch 2000 (b)

Pro F-gas arguments, and responses to them

SF_6

SF_6 in car tires leaks much less slowly than air, maintaining optimum pressure, which has a major impact on fuel efficiency, thereby actually reducing impact on the climate.
Wrong. The direct effect of SF_6 emissions far, far outweighs any indirect saving that would be realized if tire pressure is kept up to best levels. SF_6 will help people avoid filling their tires as often (which isn't often anyway), but nitrogen works nearly as well, for those who are concerned.

The arc-quenching effect of SF_6 is essentially unique—any alternative in electric switchgear would be either much larger, much more expensive, or both.
By all accounts SF_6 is suited to its role in switchgear, but is not irreplaceable, especially in the lower-medium voltage (<60kV) applications, where air insulated switches are an option. Making every effort to limit emissions from use, maintenance and decommissioning are interim steps until alternatives are ready.

No more hot "Air"?
SF_6 is the most destructive greenhouse gas per unit, with a GWP-100 of 23,900. It may come as a surprise then that it is used in some seemingly frivolous applications such as filling car tires, and creating the "air" cushion in sports shoes. Nike, the American sports apparel giant, used some 277 tons of the gas to fill shoe soles in 1997, with a global warming equivalent of 6.6 MT CO_2 equivalent, the same as fuel CO_2 emissions from driving 2.2 million cars for a year at European averages. Nike began a phase-out plan in 1998, with a target date of 2002 for elimination. Projected use for 2000 is 80 tons of SF_6. Though nitrogen air bags are available and "offer the same performance characteristics" as SF_6 bags, "it will take time to incorporate those changes into Nike's product design and manufacturing processes (Severn 1998)." In the interim they are using some of the PFC perfluoropropane (GWP=7000) as a transitional substance, though they promise to eliminate all greenhouse gases from the product by 2002.

SF_6 is the best cover gas for magnesium smelting—the main alternative, SO_2, is toxic and corrosive, and the costs of switching to it are prohibitive.
The world's leading producer of magnesium, Norsk Hydro, thinks otherwise—they're planning to phase out SF_6 by 2001 or 2002 and replace it with SO_2, encouraging any die-casting customers to do likewise—some, in fact, never switched away from SO_2 to SF_6 in the first place. Controls well within the reach of industry are applicable for safe use of SO_2. Nevertheless, a long-term solution without SO_2 or SF_6 is being researched intensively. While there are some conversion costs, running expenses using SO_2 are less than 10% that of the same process with SF_6, leading to long-term cost savings (Gjestand, et al. 1998).

PFCs

Fire extinguishers with F-gases form such a minute source of emissions (<1% of all F-gases) that it's just silly to cause disruption and waste effort regulating them.
As a single source it's small, but there are many small sources, adding up to a significant total. Emissions claims are also drastically underrated by industry—claims are made of 1-3% annual emissions of installed capacity, while they are probably 10% (Laursen 1999). Alternatives are not only available but have several advantages such as non-corrosivity and the ability to do tests, meaning that this is just an obvious application to address.

The aluminium industry is addressing the PFC problem through switching to better technologies—there's no need for intervention.
PFC from aluminium is the still the largest PFC source. Although improvements have been significant, the easiest steps have already been taken, and further improvements will need extra effort to carry out—shutting down non-prebake anode smelters and increasing recycling for example. In addition, aluminium use is rising and new smelters are being built—it's not clear the new capacity is necessary given current supplies and recycling potential. Inert anode technology, yielding zero PFC emissions, would be the next step and should be the goal for the industry. Plant operation methods can vary emissions by a factor of two with the same technology, indicating the need for effort in this area as well.

The World Semiconductor Council has agreed to reduce PFCs 10% below 1995 levels by 2010; they should be applauded, not subject to other conditions.
There is good discussion of technical ways to reduce emissions within the semiconductor industry that may yield real developments. The WSC agreement itself merits close scrutiny—first of all, it is basically an internal agreement among industry and secondarily an agreement with government/regulators; the agreement with government, as in the US, has a strong informational and monitoring component, but no teeth backing it up as in the voluntary (negotiated) agreements some countries, like the Netherlands, use with success. Secondly, the definition of PFCs being used doesn't cover HFCs other than HFC-23. The use of HFC-134a for etching could grow rapidly and be outside of their reduction targets. This may be compensated by improvements to the etching process and in chamber cleaning, but begs the question why all HFCs weren't included in the agreement. A recent industry report indicates the unpredictability of quick-moving technical developments—development of certain films may increase inherent PFC emissions in chamber cleaning—keeping control strategies up with these kinds of shifts may be very difficult (Algood 1999).

HFCs

Industry did its part to phase out CFCs and invested billions of dollars developing HFCs as alternatives, which aren't ozone depleting. Besides, CFCs are also GHGs and we aren't replacing them on anything like a one-to-one basis—we've made great improvements, and environmentalists are exaggerating.
The phaseout of (H)CFCs, in various stages of implementation globally, is indeed an achievement, but not one that absolves all further action on dangerous emissions. It was known that HFC's had high GWPs as they were being introduced, so limiting them shouldn't come as a surprise. The growth of HFCs shouldn't be measured against the decline in CFCs, but rather from the baseline of the best option—non-F-gas alternatives. There are options for reduction and substitution for many if not all applications (some in the longer term), which should be viewed on their merits and encouraged, not avoided and downplayed.

HFCs' global warming impact is offset by their efficiency superiority, which means that a total equivalent warming impact (TEWI) calculation favours HFCs.
For refrigeration and air conditioning systems the efficiency argument actually favours alternatives in most cases. For foams, hydrocarbon-blown polyurethane (PU) is equally or more efficient than that blown with F-gases, and CO_2-blown PU and XPS are sufficient for the majority of applications; where insulation effectiveness is a real concern, vacuum panels should be considered over foams. Estimations of foam efficiency in the future often rest on assumptions about HFCs that are currently not commercialised and likely to be very expensive. When a mandate is given to non-F-gas foam blowing and R&D money is redirected away from other types, we'll see further improvements.

Alternatives are dangerous: hydrocarbons are flammable; ammonia is toxic and flammable, etc.

Many flammable substances are used safely—petrol tanks are in hundreds of millions of cars, homes use gas for heating and cooking, aerosol cans have flammable propellants... The amount of HC in the domestic Greenfreeze refrigerator is equivalent to that in two cigarette lighters—people are quite used to using these amounts in daily life. Ammonia systems have a long track record and can be well sealed, in secondary cycles, separated from people for extra safety. Furthermore its pungent scent acts as an effective early warning signal. In addition, alternatives like water and air are yet more benign. Safety measures are necessary but are consistent with proper practice routinely carried out around a host of substances.

HFC elimination is unrealistic—on the contrary, HFC's are important for CFC and HCFC replacement.

Environmental NGO's have long recognized that relying on HFCs as an ODS replacement would mean an unnecessarily long two-step phase-out from (H)CFCs to HFCs and then finally to non global warming technologies. HFCs are the heavily-promoted replacement for many technologies, but are by no means the default choice. Many other options exist that are only less "obvious" because they are less desirable to certain industry groups, who have invested heavily in HFCs; other industries recognize the validity of the replacements. Now is the time to offer policy guidance to phase out HFCs—just because it hasn't happened doesn't indicate that it was for good reason—on the contrary.

F-gases are so minor in their global warming impact compared to CO_2, (a percent or two) that they shouldn't be such a target.

In some countries, including ones with reduction targets under the Kyoto protocol, F-gases represent sometimes over 5% of CO_2-equivalent emissions. Given the rapid growth of F-gases at a time when attempts are being made to control CO_2, these will become proportionally more and more important in the future. In any case, many individual sources can claim to be only a percent or two of warming, adding up to the whole picture (even the automobile industry uses the same argument)—none can be ignored; they all have to be addressed on the basis of the suitability of replacements or mitigation. F-gases can be cut back or eliminated in a broad variety of applications at low cost. Furthermore, they have other undesirable environmental properties that argue for their elimination. F-gases are entirely man-made, and as such are within our reach and responsibility to control. Doing so indicates not only a country and industry's serious intent in curbing global warming, it is also a matter of a consistent and comprehensive approach to eliminating undesirable compounds from our environment.

HFCs are manufactured to strict standards in state of the art facilities—nothing could be more environmentally safe.

This statement intends to distract, and is essentially irrelevant. Monitoring shows atmospheric emissions not just of errant HFCs but also of the carcinogens vinyl chloride and ethylene dichloride, as well as the potential for dioxins and chromium in liquid catalyst wastes from these facilities (Banks 1996). Manufacturing a ton of HFCs also indirectly yields 38.8 tons of CO_2 emissions, 160 times the amount produced by making a similar amount of isobutane (McCulloch and Campbell 1998, cited in Calor 1999).

The impacts of HFC breakdown products like Trifluoroacetic Acid (TFA) have been thoroughly studied and found to be a non-issue.

Several of the most significant studies were done by, or in close cooperation with, the same companies that manufacture the chemicals in question, raising questions about impartiality (AFEAS 1998, Boutonnet et al. 1999). The effects found on, for example, zooplankton and marine plants, are matters of degree, where the "no impact" finding rests heavily on assumptions about future emissions levels and complicated, speculative sets of circumstances that may or may not lead to high concentrations in organisms. Tromp (1995) did find potential impacts. In any case, if we've learned anything from the numerous nasty environmental surprises attributable to synthetic chemicals in the past few decades, it is that there is very likely to be a big difference between an forward-projected risk assessment backed by companies with a bias to disprove impacts, and an after-the-fact impact study 30 years from now that uncovers the real effects HFCs have had. Given, further, that TFA is just one of many environmental stresses, the precautionary principle dictates that we should take measures to avoid adding this toxic burden to the environment.

Consumers should be allowed to weigh the safety risks and make a responsible choice.

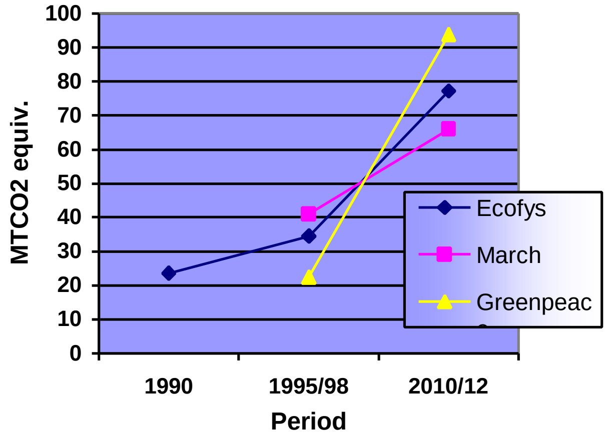
People want a well-functioning economical device; they are also concerned about climate change. Alternatives to HFCs address all of these things. The "consumer choice" argument is a standard industry smokescreen. As long as replacements are safe and perform well, as has been demonstrated for many applications, then it is irresponsible for government to imply that HFCs are equivalently acceptable by failing to take action on their control or elimination. Ensuring collective welfare through restrictions on undesirable substances is a legitimate role of regulation. Furthermore, consumers have shown enthusiasm for alternatives, as evidenced by among other things the millions of F-gas-free refrigerators sold worldwide.

Metered dose inhalers (MDIs) are delivering critically needed medication to millions of asthma and respiratory disease sufferers worldwide; F-gases are critical to MDIs. Respiratory problems are a growing worldwide problem.

If dry powder inhalers (DPIs) are good enough for 80% of the inhalers Swedes buy, it will work for 80% (or even more) of any population. In that minority of applications where F-gases are indispensable for reasons of medical effectiveness (patients who need self-propelled delivery) there should be exceptions to phase-out while alternatives are being developed. Some studies link growing rates of respiratory problems to pollution—treating the symptoms with a polluting substance (albeit of a different sort) is ironic, to say the least.

European emissions estimates and projections

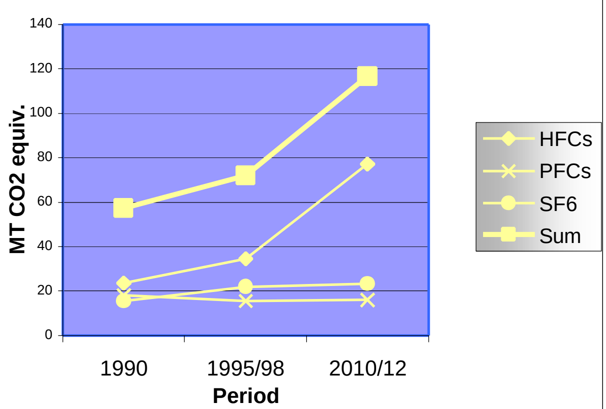
Figure 1. HFC emissions growth



Two recent reports prepared for the European Commission attempted to quantify emissions of F-gases in Europe. These are compared (figure 1) with HFC estimates from a report commissioned by Greenpeace (in Maté 2000). It is clear from the HFC estimates that not only future emissions levels, but also current and past ones are contentious. EnvirosMarch Consultants' baseline starts high and doesn't rise fast—40.7 Mtonnes CO2 equivalent in 1995 rising to 66 Mtonnes CO2 equivalent in 2010, an increase of 55% (EnvirosMarch 1999). The Greenpeace analysis of their assumptions and estimations yields different numbers—rising from 31.1 Mtonnes CO2 equiv to 80.0 Mtonnes CO2 equivalent—an increase of over 150%. Ecofys Consulting's estimates fall between the two, but are based on a different methodology with more general assumptions (Ecofys 2000).

Ecofys generated projections combining all three gases (figure 2), using conservative estimates. HFCs are clearly the most important, growing source of emissions. Total emissions of the three gases rise from 73 $MtCO_2$ equivalent in 1995 to 116 $MTCO_2$ equivalent.

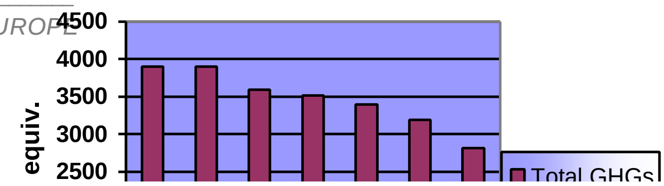
Figure 2. F-gas emissions



Greenpeace (Maté 2000) has made projections of possible emissions beyond 2010. Because HFCs are rather recently introduced and growing quickly, their emissions will certainly continue to rise significantly beyond 2010. They find that "HFCs could represent 15% of all greenhouse gases by 2040, " and "by the year 2100 in a low emission scenario HFC/PFC greenhouse gas contribution would be 20-30% of 1990 CO2 emission levels, in a high emission scenario 55-85%, and in a best estimate scenario 40% (plus or minus 10%)."

If we allow F-gases to escape our attention, given some assumptions about the growth of F-gas emissions over the next fifty years (4% annually—currently it's 6%) and moderate reductions in overall GHG emissions (nothing like those dictated by ecological considerations), we see (figure 3) that F-gases could potentially grow to nearly 25% of all GHG emissions by 2050. Achieving overall reductions while HFCs rise would furthermore mean a greatly increased burden on limiting emissions from other GHGs.

Figure 3. Growing proportion of F-gases



Annex 1: F-gas facts

HFCs

HFCs are primarily replacements for ozone depleting substances (ODSs) like CFCs and HCFCs. There is recent, sharp growth in their use and high anticipated growth through the next decades.

Main uses, emissions sources, and alternatives:

Emission of HFC-23 from the production of HCFC-22: from 1.5-3% of the product is HFC-23, which is still sometimes vented. HCFC-22 is used as a refrigerant and as a feedstock for fluoro-organics like PTFE.
Alternatives: capture and thermal oxidation can reduce 98% of emissions; reducing the HCFC-22 market.

Refrigeration and air conditioning (stationary and mobile): historic annual leakage of around 1% for a domestic refrigerator, 10% for chillers, 25% for commercial systems, 30% for refrigerated transport and mobile air conditioning, plus the loss at end of life if not recovered (historically the case).
Alternatives: natural refrigerants like ammonia, hydrocarbons, CO2 water, and air; systems like absorption, stirling cycle, and thermoelectric refrigeration; leak reduction combined with reduction in the charge of refrigerant, most significantly through an indirect, secondary loop system; elimination of the need for cooling through passive design, ambient cooling.

Foams: emitted directly to the atmosphere when used as blowing agent to make the foam, released over time from within the cell structure, and emitted upon destruction at end of life.
Alternatives: CO2 and water, hydrocarbons; NIK insulations like mineral wool, fibreglass, cellulose.

Metered dose inhalers (MDIs): emitted directly to the atmosphere while propelling medication into the lungs.
Alternatives: dry powder inhalers (DPIs) require inhalation effort, but could serve over 90% of the market; nebulisers; oral treatments (pills).

General aerosol propellants: released directly to atmosphere from a spray can; not very common now compared to the role CFCs used to play, but has potential to grow.
Alternatives: HCs, DME, pumps, roll-ons.

Fire extinguishing substance: annual leakage, unintended and intended release account for up to 10% a year of installed amount.
Alternatives: fixed systems: inert gas extinguishers, NIK—better fire detection, water; portable: CO2, foam, water.

Solvents: as used for precision cleaning, electronics cleaning, and metal cleaning.
Alternatives: no-clean technologies, aqueous cleaning, semi-aqueous cleaning (HCs then water)

PFCs

Used or unintentionally emitted in a wide variety of industrial applications.

Main uses, emissions sources, and alternatives:

Aluminium smelting: The main source is as an unintended by-product of aluminium smelting due to the “anode effect,” which is itself undesirable for the smelting process. Alternatives: currently there is an overall decline in PFC emissions from aluminium due to autonomous shifts in industry to superior technologies like pointfeeders and, much better yet, prebaked anodes. Inert anodes are the next step, and promise zero PFC emissions.

Solvents and etching: mainly in the semiconductor industry, along with SF_6 and NF3, for cleaning vapour deposition (CVD) chambers and etching semiconductors. Alternatives: recapture and destruction or recycling; switch to other gases that yield lower releases—potentially NF3 in CVDs, switch to a lower-GWP HFC for etching.

Refrigerants: as a drop in replacement for CFCs.
Alternatives: as above.

SF_6

SF_6 is emitted in relatively small amounts but has large banked quantities and the highest GWP of all measured F-gases.

Main uses, emissions sources, and alternatives:

Gas insulated switchgear/large scale electrical equipment: 80% of SF_6 sales. Remains banked for long periods within the units.
Alternatives: air-insulated switches (require more space) for lower voltages; recapture on decommissioning, careful maintenance, leak prevention.

Magnesium casting and production: as a cover gas to avoid flammable contact with air
Alternatives: return to the old cover gas—SO2, reduce quantities, recapture.

Sound insulating double glass: released in filling and destruction; has little impact on sound insulation in fact; quite significant in Germany.
Alternatives: larger gap between double glazing, with no SF_6.

Sport shoe soles: Nike “Air” soles; quantities hard to determine, large bank probably still existing.
Alternatives: being discontinued and replaced by nitrogen.

Car tires: used instead of air because it leaks more slowly; costly and not widely used.
Alternatives: air, nitrogen

Annex 2: Global warming potentials

Different substances have different impacts on climate, due to their inherent physical properties and the length of time the stay in the atmosphere. The global warming potential (GWP) is a metric devised to compare substances' impact, where that of CO_2 is set equal to 1. The GWP is defined over a set time horizon—the impact relative to that of CO_2 over a 100 year period (GWP-100) or a 20 year period (GWP-20) are often used. GWP-100 is the most common metric, and the one used in most documentation. GWP estimates change, however, and the table below reflects the most recent updates to HFC-245fa (up from 820 to 1040), HFC-365mfc (up from 810 to 910) and HFC-134a (up from 1300 to 1600) (WMO 1999). In other words, with the new figures HFC-134a is estimated to have an additional 38 times more warming potential that an equivalent amount of isobutane (GWP-100 = 8) (chart sources: IPCC 1995; WMO 1999)

GWP-100 values of the fluorinated compounds (F-gases)

Substance	Empirical formula or composition	Name	GWP 100
Perfluorocarbons (PFCs)			
	CF_4	14	6500
	C_2F_6	116	9200
	C_3F_8	218	7000
Hydrofluorocarbons (HFCs)			
	CHF_3	23	11700
	CH_2F_2	32	650
	C_2HF_5	125	2800
	$C_2H_2F_4$	134a	1300
	$C_2H_3F_3$	143a	3800
	$C_2H_4F_2$	152a	140
	C_3HF_7	227	2900
	$C_3H_2F_6$	236fa	6300
	$C_3H_3F_5$	245fa	1040
	$C_4H_5F_5$	365mfc	910
	$C_5H_2F_{10}$	43-10mee	1600
HFC blends			
	143a/125/134a (52/44/4)	404A	3260
	32/125/134a (23/25/52)	407C	1525.5
	32/125 (50/50)	410A	1725
	125/143a (50/50)	507	3300
	404A/507 (80/20)	404A/507	3268
Others			
	SF_6		23900
	NF_3		8000
	$C_4F_9OCH_3$	HFE 7100	500

Sectoral GWP-100s

Application	*GWP*
HFC-manufacture and distribution	1,300
HFC-23	11,700
XPS-foams	1,180
PU/PIR-foams	815
Domestic refrigeration	1,300
Commercial and transp. refrig.	2,700
Food and agric and general indus.	2,200
A/C with water chilling	2,600
Mobile AC	1,300
Aerosols	1,300
MDIs	2,500
Solvents	810
Fire-fighting	2,900
SF_6	23,900
PFC	6,500

(Ecofys 2000)

Annex 3: Glossary of terms and acronyms

CFCs: chlorofluorocarbons—the most important ODSs are CFC-11 and CFC-12, used worldwide for refrigeration, foam blowing and other applications, though now being phased out.
COPD/CRD: cardiopulmonary respiratory disease. People with CRD are common users of inhalers like MDIs and DPIs.
Direct Expansion (DX): a cooling system where the refrigerant itself flows through the entire cycle—for example in a supermarket--from the equipment room to the display cases and back, through potentially kilometres of piping. DX systems are characterized by high leakage.
DME: dimethyl ether—an aerosol propellant
DPIs: dry powder inhalers—an option for administering medication in exact doses directly to the lung through inhaling, as done by asthmatics. MDIs, using F-gas propellants, dominate the market, though where DPIs have been promoted they've taken up to 90% of the market (as in Finland). This fact belies the medical industry's claims that DPIs are only appropriate for few people.
GWP: global warming potential—a standard measure that compares the global warming effect of a substance relative to CO2, which is set at 1. GWP-100 is the relative effect as seen over a 100-year time horizon, and is the measure adopted by the IPCC as the standard. GWP-20 is also used sometimes, and can be quite different. In general the GWP is a rough guide, ignoring significant complexities that can't be reduced to one number.
HFCs: hydrofluorocarbons; non-ODS but high GWP. Promoted by the F-gas industry as the successor to CFCs and HCFCs because they retain many of the good qualities of CFCs, as well being patented and expensive.
HCFCs: halocarbons, another ODS being phased out, on a slower schedule than the more damaging CFCs.
IPCC: Intergovernmental Panel on Climate Change.
MDIs: metered dose inhalers—as used by asthmatics and others to administer medicine to the lungs. The propellant is emitted directly to the atmosphere and as such constitutes a rather high percentage of overall F-gas emissions. DPIs are an alternative for the great majority of patients—those who can't inhale enough to activate a DPI will need a propelled MDI system, barring developing of other new alternatives.
MTCO_2 equivalent: million tonnes of carbon dioxide equivalent emissions. F-gas emissions are converted to this equivalent using the GWP multipliers.
NIK: Not in kind—an option that is completely out of the category, such as replacing HFC-blown foam not by one blown with HC, but with mineral wool insulation.
ODS: ozone-depleting substances (such as CFCs and HCFCs), which are now regulated under the Montreal Protocol and are being phased out.
RAC: refrigeration and air conditioning
Secondary Loop: as opposed to DX, these systems have refrigerant confined to a space with the machinery, where heat is exchanged with a secondary refrigerant that then flows through the rest of the system. Leakage of refrigerant is thus dramatically reduced because only climate-benign secondary refrigerant like flo-ice or glycol flow through the long piping network.
TEWI: total equivalent warming impact**:** a measure that incorporates not just a process or product's direct emissions, but the indirect ones induced by the process where direct emissions occur; for example the release of HFC leaking from a refrigerator is a direct emission, while the CO2 released from coal burnt to power the refrigerator is indirect. The TEWI for the refrigerator incorporates both. It is less complete than an LCC (life-

cycle cost) that would add the impact of making the refrigerator and the refrigerant, transporting it to the site of use, etc.

UNFCCC: United Nations Framework Convention on Climate Change

VA: voluntary agreement—an agreement by industry with government to meet a target without the need for regulation. They are often unsuccessful, mostly when seen as unilateral promises, and not as part of a well thought-out plan with an alternative regulation ready to be put in place.

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Resources on the Web

NGOs, networks, and academic:

www.climnet.org *Climate Network Europe*
www.greenpeace.org/~climate/greenfreeze/index.html *Greenpeace Greenfreeze*
www.ecozone.nl/ *Climate-safe cooling in the Netherlands*
www.greenchill.org *Alternative cooling in Australia*
ctan.unsw.edu.au/pub/archive/HC/papers/HCpapers.html *Studies on hydrocarbons*

International Governmental Bodies:

www.unfccc.de/program/wam *UNFCCC ways and means of reducing f-gas emissions*
www.teap.org/ *Technology and Economic Assessment Panel of the Montreal Protocol*
www.ipcc-nggip.iges.or.jp/public/public.htm *IPCC GHG inventory practices*
europa.eu.int/comm/environment/enveco/studies2.htm *European Commission studies*

Government Plans:

www.mst.dk *Danish EPA's plan to phase out F-gases*
www.vrom.nl/environment/climate_policy/ *The Netherlands' climate plan*
www.environment.detr.gov.uk/climatechange/draft/index.htm *UK plan*
www.premier-ministre.gouv.fr/FOCUS/CLIMAT/SOMMAIRE.HTM *French Plan*

Businesses:

www.energ-ice.com *Integral Energietechnik*
www.earthcareproducts.co.uk *Alternative cooling products*
www.care-refrigerants.co.uk/html/index.asp *Calor gas refrigerants (CARE)*
www.hychill.com *Hydrocarbon refrigerants*
www.duracool.com.au *Hydrocarbon refrigerants*
www.york.com *Manufacturer of cooling equipment*
www.grasso.com *Manufacturer of cooling equipment*
www.delonghi.it *Manufacturer of cooling equipment*
www.hennecke.com/ *Polyurethane products*
www.dupont.com/zyron/techinfo/ *Semiconductor/F-gas information from Dupont*