TOTAL EQUIVALENT GLOBAL WARMING IMPACT: COMBINING ENERGY AND FLUOROCARBON EMISSION EFFECTS*

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INTRODUCTION

At the 1990 International CFC Conference a year ago, an announcement was made by AFEAS (Alternative Fluorocarbons Environmental Acceptability Study, a consortium of the world's leading chemical companies) of a study to be undertaken by ORNL and Arthur D. Little on energy and global warming. Many of you were involved in initial meetings of CFC user industry experts here in Baltimore last year and/or in the follow-up data input and draft review iterations that took place through this past year. For your valuable input, feedback, and time, we thank you!

The study has been completed. This paper reviews selected results of this study and highlights the major findings and conclusions.

Background: Basis for Systems Approach to Global Warming Assessment

To date, most of the atmospheric scientist and environmental policymakers' attention has been placed on the DIRECT contribution to global warming of CFCs and their fluorocarbon alternatives, HCFCs and HFCs, as greenhouse gases. This DIRECT effect is characterized by a so-called GWP (global warming potential) value for the particular compound. However, this value alone does not account for the total potential global warming impact, since it excludes the INDIRECT carbon dioxide (CO_2) greenhouse gas emissions effect due to the energy consumption of the system in which the CFC is used (to meet some societal need).

For convenience in combining these effects in this study, the DIRECT (chemical emission) effect is expressed as equivalent carbon dioxide, consistent with the Global Warming Potential (GWP) indexing approach of Intergovernment Panel on Climate Change [IPCC, 1990]. This equivalent CO_2 DIRECT effect can readily be combined with the INDIRECT (energy-related) CO_2 emissions. For electric systems, end-use energy is referenced back to the power plant for purposes of estimating CO_2 emissions. The combined or total effect is termed the Total Equivalent Warming Impact or TEWI.

This concept is illustrated in Fig. 1 for replacement of CFCs in a household refrigerator/freezer. The pie chart on the left represents the TEWI for a 20 ft^3 automatic defrost refrigerator/freezer using CFC-11 blown polyurethane insulation and CFC-12 as the refrigerant. Eighty percent of the TEWI is a consequence of CO_2 emissions from generating electricity to operate the refrigerator for the assumed 15 year useful life. The balance of the impact on global warming comes from emissions of the blowing agent and the refrigerant. The pie chart on the right represents the calculated TEWI for a refrigerator/freezer using HCFC-123 and HFC-134a using actual foam insulation thermal conductivities and measured refrigerator performance. In this example, the total equivalent warming impact (TEWI), represented by the comparative area of the two "pies," is reduced by about 18% in the transition from CFCs to the HCFC and HFC alternatives. This improvement is due to the reduction in DIRECT impact (from 20% to 2%) combined with no change in INDIRECT (energy-related) impact. An evaluation of this combined impact for the various alternatives to CFCs in a number of specific end-use applications was undertaken in this study.

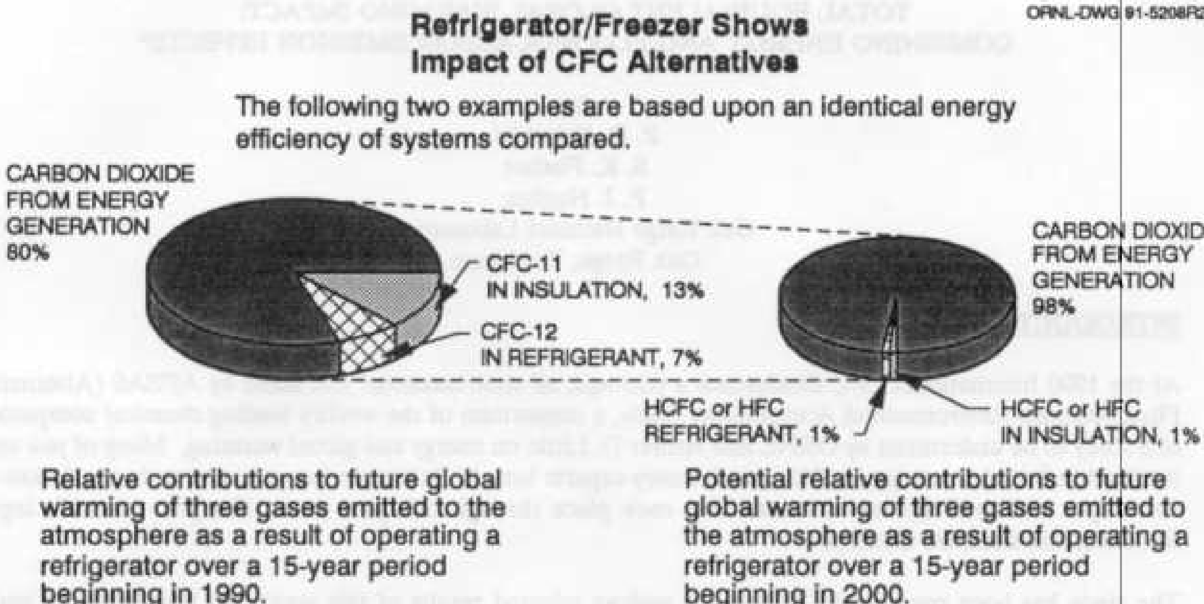

Fig. 1. Example of Total Equivalent Warming Impact from replacing CFCs with alternative fluorocarbons.

SCOPE AND METHODOLOGY

The primary objective of this study is to develop representative indications of the relative energy use, associated CO_2 emissions, and total equivalent warming impact (TEWI) of viable options to replace CFCs in their major energy-related application areas. The study is international in scope and takes into account significant differences in present CFC end-use practices, sources of energy, and other societal factors between Europe, Japan, and North America.

The analysis addresses alternative chemicals and technology alternatives to CFCs in uses such as refrigeration, foam insulation, and metal and electronic cleaning and drying processes. The major refrigerant applications covered in the analysis include:

- household refrigerators/freezers
- commercial refrigeration
- chillers (water-cooled, air-cooled)
- unitary space conditioning equipment
- automotive air-conditioning

The major applications of foam insulation include:

- commercial building roofs and walls
- residential wall sheathing
- insulation for household refrigerators

The major applications of solvents include:

- in-line and batch electronics cleaning processes
- in-line and batch metal cleaning processes

Table 1 lists the alternatives considered for each of these applications.

Household Refrigeration		Commercial Refrigeration	Air-Conditioning Chillers, and Heat Pumps	Automotive Air-Conditioning	Residential and Commercial Building Insulation Materials	Metal and Electronic Cleaning/Drying
Insulation Blowing Agent or Alternative Technology	Refrigerant or Alternative Cycle	Refrigerant or Alternative Cycle	Refrigerant or Alternative Cycle	Refrigerant or Alternative Cycle	Insulation Blowing Agent or Alternative Technology	Solvent or Alternative Process
			Chillers		*PIR/PUR*	
CFC-11	CFC-12	CFC-12	CFC-11	CFC-12	CFC-11	CFC-113
CO_2/CFC-11 (part water blown)	HFC-134a	R-502	CFC-12	HFC-134a	HCFC-123	1,1,1, TCA
HCFC-123	Ternary blend	HCFC-22	HCFC-22	Ternary blend	HCFC-141b	Trichloroethylene
					Isopropylchloride	
HCFC-141b	Absorption	Two-stage multi-plexed HCFC-22	HCFC-123	HFC-152a	*Extruded Polystyrene*	Semi-aqueous
Isopropylchloride or 2-Chloropropane	HCFC-22/ HCFC-142b dual evaporator	HFC-134a	HFC-134a	Propane	CFC-12	Aqueous
					HCFC-142b	
CO_2 w/additive perfluoroalkane cell modifiers)	HFC-152a	Ammonia vapor compression	Absorption (LiBr-water)	Brayton cycle	HFC-134a	HCFC-123
					HCFC-124	
100% CO_2 (water-blown)	Stirling Cycle (freezers only)	HFC-32 blend	Ammonia vapor compression	Stirling cycle	*Alt. Bldg. Insulation Materials*	HCFC-141b
Evacuated (vacuum) panels			*Unitary*		Glass fiber	No-clean
					Mineral fiber	
Perfluoroalkanes (blowing agent)			HCFC-22		Expanded polystyrene beadboard	HCFC-225ca/cb
			HFC-134a			
			Absorption (ammonia water)			

Table 1: Matrix of Applications and Alternatives Considered in the Study

The study involved experts from industry, government, and academia around the world in the above applications to characterize existing CFC practices or baseline technology and to identify the technology options for the various applications and geographic regions. The focus of the technical analysis is on energy use comparisons of the technology options and associated per lifetime equivalent CO_2 emissions, together with estimated emissions of the refrigerant, blowing agent, or cleaning solvent, all on a per unit basis.

The general methodology employed in all cases consisted of the following steps:

- Development of appropriate engineering parameters to characterize the baseline technology and algorithms for calculating energy use in each application
- Identification of alternatives to replace the use of CFCs in the existing applications
- Collection and compilation of user industry data on comparative engineering parameters and physical properties to characterize the technology option(s)
- Calculation of energy use and calculation of estimated lifetime equivalent carbon dioxide (CO_2) emissions (INDIRECT effect) from unit lifetime estimates and regional fuel utilization or electric power generation mix
  - for solvent these calculations were done on the bases of unit throughput
- Calculation of equivalent CO_2 emission of greenhouse gas content or loss (DIRECT effect), if applicable, for each option using the greenhouse warming potential (GWP) index values.
- Combination of the INDIRECT and DIRECT global warming effects and comparison of the total equivalent global warming impact (TEWI) among technology options

"Current Generation" and "Next Generation" Alternative Technologies

New systems, materials, and processes that represent potential CFC replacement technologies are being rapidly developed. Technology options already available or identified by the user industries as their primary development focus for first generation replacement of CFCs, whether fluorocarbon or not-in-kind (non-fluorocarbon) alternatives, were given first consideration with regard to quantitative analysis of their DIRECT and INDIRECT effects and their TEWI. These are referred to as "current generation" alternative technologies in this study and are distinguished from "next generation" alternative technologies.

SELECTED RESULTS AND MAJOR FINDINGS

The results of the quantitative analyses conducted for each of the applications are illustrated in a series of summary bar graph figures (Figures 2-5). These figures show the changes in Total Equivalent Warming Impact or TEWI of the various CFC alternatives relative to the baseline CFC technology for a range of representative refrigerant, insulation, and cleaning applications. The relative proportions of the DIRECT and INDIRECT effects on the TEWI for each of the various alternatives or technical options are also illustrated.

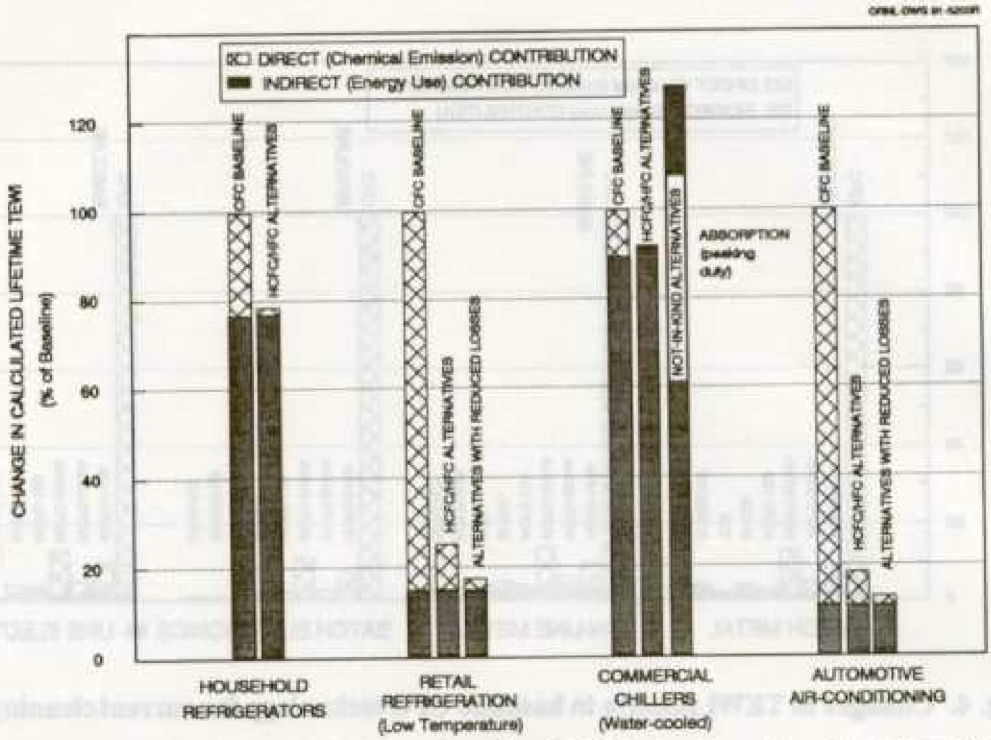

Fig. 2. Changes in TEWI relative to baseline CFC technology for selected refrigeration and air-conditioning applications.

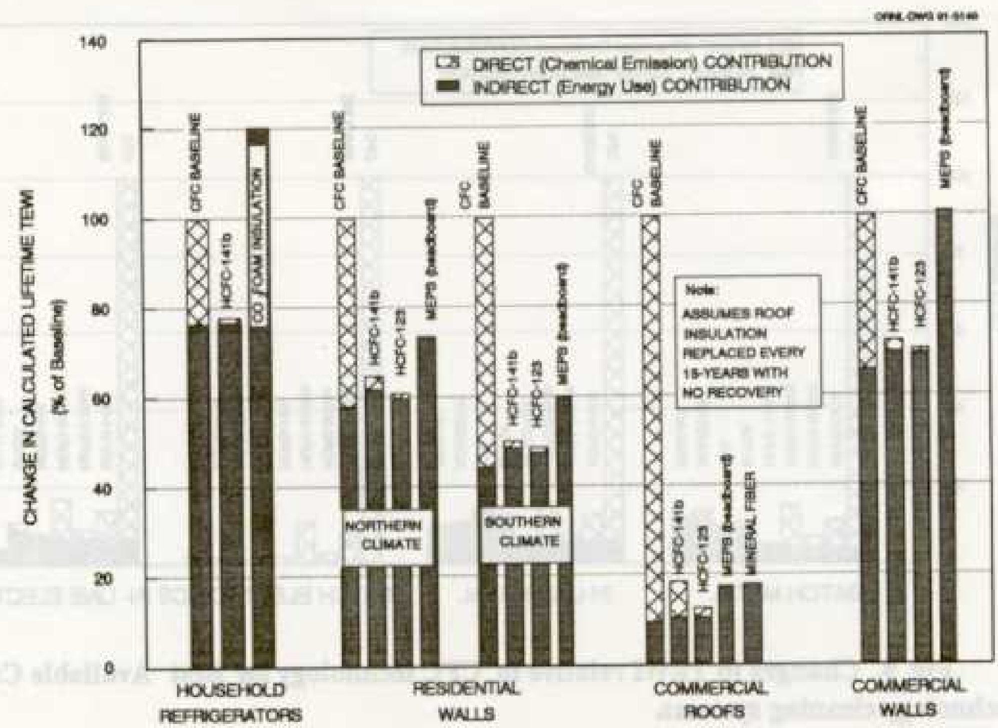

Fig. 3. Changes in TEWI relative to baseline CFC technology for selected insulation applications.

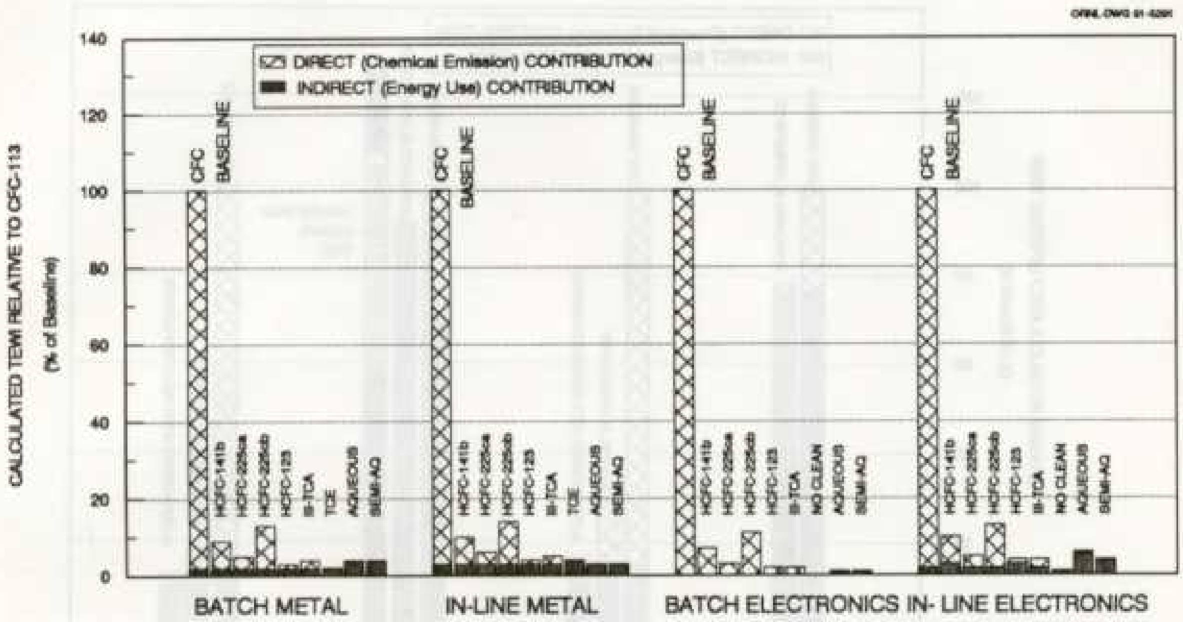

Fig. 4. Changes in TEWI relative to baseline CFC technology for current cleaning systems.

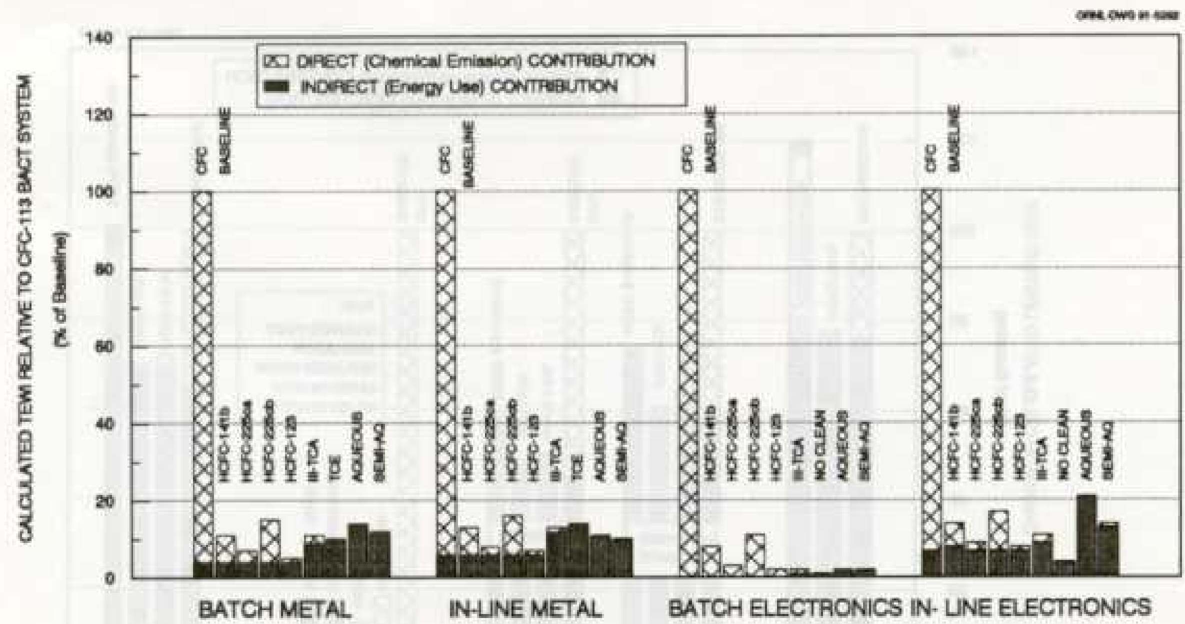

Fig. 5. Changes in TEWI relative to CFC technology for Best Available Current Technology cleaning systems.

Some of the major (common) findings that address all three major application areas include the following:

- Replacement of CFCs with suitable HCFCs or HFCs yields a dramatic benefit in reducing Total Equivalent Warming Impact (TEWI) for all CFC end-use applications considered; reductions in TEWI range from 10% to 98%, depending on application.
- There is a wide variation among applications with regard to the relative importance of the INDIRECT (energy use) effect and the DIRECT (chemical emission) effect of the HCFC/HFC alternatives
- Several alternative not-in-kind (NIK) technologies were evaluated or considered in each of the three major application areas, with results for some also showing reduced TEWI benefits.
  - Aqueous and semi-aqueous cleaning technologies are examples of NIK alternatives already in widespread use which exhibit a substantial reduction in TEWI relative to the baseline CFC cleaning technology (as shown in Figs. 4 and 5).
- Energy use for most of the available or current generation NIK options was found to be greater than for the HCFC/HFC technologies, as illustrated for insulation options (Fig. 3) and chillers* (Fig. 2). However, some next-generation NIK options such as evacuated vacuum panel insulation for appliances and "no-clean soldering" technology in the electronics sector show promise for future energy savings. Technical issues must still be successfully resolved before these options can be widely adopted.

SPECIAL NOTE: The TEWI comparisons shown in Figs. 2-5 are valid only for different technology options within the same application. Different applications are combined on these figures only as a convenience in summarizing the results. It is important not to make comparisons between different applications; e.g., commercial roof insulation options should not be compared with household refrigerator insulation options with regard to TEWI differences.

Other major findings shown in these figures are application-specific, for instance:

CFC Refrigerant Alternatives

- Energy efficiency/energy use differences are small between CFC baseline refrigerants and HCFC or HFC alternatives (Fig. 2).
  - Early published test data indicate small penalties for substitutes, but recent industry data show near equal refrigerant performance as achievable, especially in CFC-12 applications (with new lubricants and optimized engineering design)
- The small differences in lifetime energy use projections and associated INDIRECT CO_2 contributions among the HCFC and HFC options do not allow a meaningful ranking of the options at this time.

* NOTE: Absorption chiller results shown in Fig. 2 are representative of peaking duty for direct-fired double-effect equipment and are not directly comparable to the adjacent results for baseload duty of the CFC and HCFC/HFC chillers.

CFC Blowing Agents or Insulation Alternatives

- Differences between "aged" thermal conductivity values for CFC-blown and HCFC-blown polyisocyanurate/polyurethane foam insulation materials suggest that any increase in energy use and INDIRECT CO_2 emission should be relatively minor (Fig. 3).

- Energy use and TEWI for non-fluorocarbon foam insulation or fiber insulation is generally greater than for HCFC-blown foam insulation (exception in commercial roofs, where the TEWI's are essentially equal, due to DIRECT effect of longer-lived HCFC's).

CFC Alternatives for Metal and Electronic Cleaning and Drying [ADL, 1990]

- Unless solvent losses from the cleaning equipment are carefully controlled, the DIRECT impact of solvents with the longer atmospheric lifetimes will be the predominant factor in the total equivalent warming impacts (Fig. 4).

- Technologies are available but not widely practiced as yet to reduce the TEWI of both solvent systems and aqueous or semi-aqueous systems.

A conservative estimate of the impacts of systems using the "best available current technology" (BACT) is shown in Fig. 5.

Another way of viewing the results is to eliminate the baseline CFC technology and to focus only on the alternatives. This perspective can help identify opportunities for further future reductions in the TEWI by emphasizing the relative importance of the INDIRECT and DIRECT effects. Figure 6, for example, addresses only the fluorocarbon (HCFC and HFC) *refrigerant alternatives* and illustrates the relative contribution of their INDIRECT and DIRECT effects. It should be recognized that most of the alternative technologies are still being optimized and, thus, the currently available data are not likely to represent the lowest cost effective energy consumption or the lowest losses/emissions achievable. As Fig. 6 illustrates:

- For applications dominated by INDIRECT effects (i.e., chillers, household refrigerators, unitary space conditioning), a change of only 2-5% in efficiency would have a greater impact on TEWI than completely eliminating the DIRECT (chemical emission) effect.

- Applications in which DIRECT effects of alternatives are a substantial proportion of the TEWI (e.g., automotive air conditioning and retail refrigeration) represent important target opportunities for improved containment and "not-in-kind" technology options,

  – though energy efficiency can play a major role in future TEWI reductions in these applications also.

CONCLUDING REMARKS

Recent progress in improving energy efficiency with the HCFC and HFC alternatives represents an encouraging and important trend. Results of the earlier CFC phaseout assessment indicated the potential for more serious energy consequences. However, the energy-intensive user industries have responded strongly to this challenge in the past 2-3 years.

The replacement of CFCs is probably the most important single near-term step that can be taken toward reducing the total global warming impact. The contribution of CFCs to global warming in the last decade, estimated at 24% of the total by the IPCC, is second only to CO_2 (at 55% of the total). And simply replacing CFCs with HCFC and HFC alternatives (in the refrigerant, insulation blowing agent, and solvent cleaning applications studied) would result in a nominal 90% reduction in that DIRECT global warming impact.

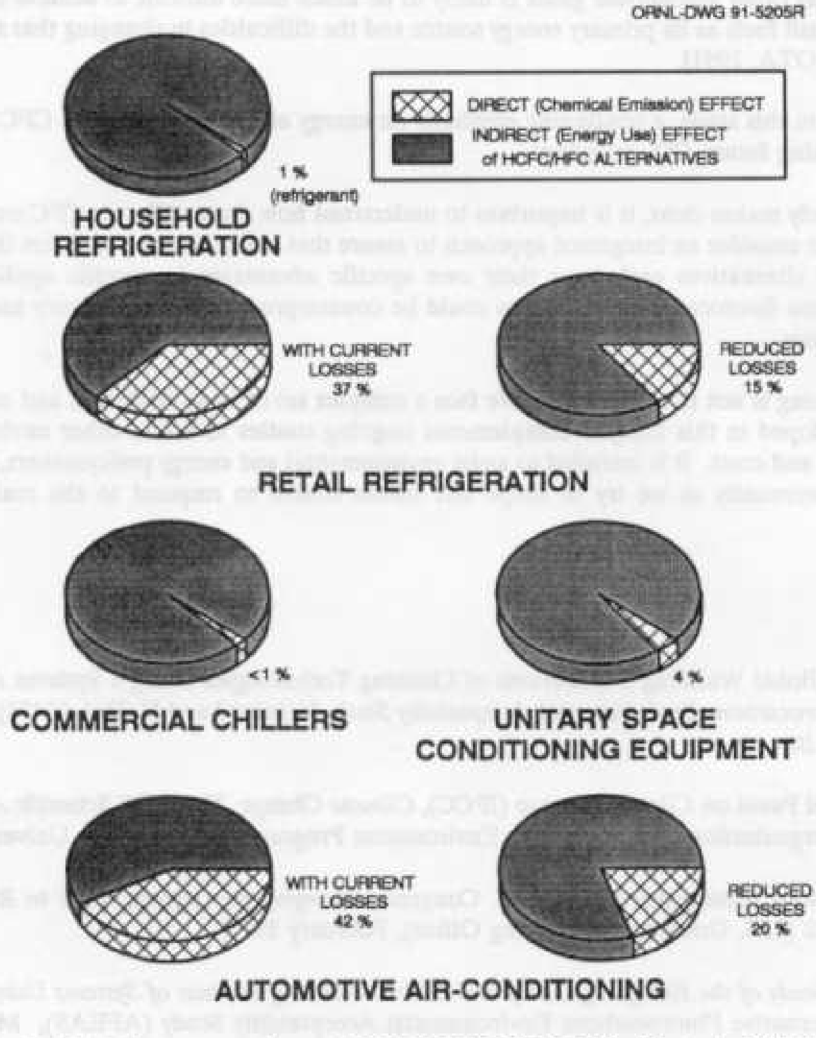

Fig. 6. Relative proportion of DIRECT/INDIRECT effects to TEWI for selected refrigeration and air-conditioning applications of HCFC and HFC alternatives.

Reducing CO_2 and other greenhouse gases is likely to be much more difficult to achieve due to the world's dependence on fossil fuels as its primary energy source and the difficulties in changing that significantly in the next 20-30 years [OTA, 1991].

As demonstrated in this study, a continuing emphasis on energy efficiency during the CFC transition will be important in limiting future CO_2 emissions.

Finally, as this study makes clear, it is important to understand how these different CFC transition issues are interrelated and to consider an integrated approach to assure that a decision or policy has the intended effect. HCFC and HFC alternatives each have their own specific advantages in specific applications. Further constraints on these fluorocarbon alternatives could be counterproductive to efficiency and global warming in many applications.

Also, global warming is not the only issue. We face a complex set of issue trade-offs and compromises. The information developed in this analysis complements ongoing studies to assess other environmental effects, safety, toxicology, and costs. It is intended to assist environmental and energy policymakers, industry, utilities, and the R&D community as we try to shape our future course to respond to the realities of the CFC transition.

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