

**تكلفة حماية طبقة الأوزون الستراتوسفيرية  
في جمهورية مصر العربية**

**Costs to Egypt of Protecting  
the Stratospheric Ozone Layer**

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**جهاز شئون البيئة المصري  
بالتعاون مع  
وكالة حماية البيئة الأمريكية**

**Egyptian Environment Affairs Agency**

**in cooperation with**

**United States Environmental Protection Agency**

## **ACKNOWLEDGEMENTS**

The Egyptian Environment Affairs Agency and the United States Environmental Protection Agency would like to thank the following individuals, organizations, and corporations for their assistance in the preparation of this study:

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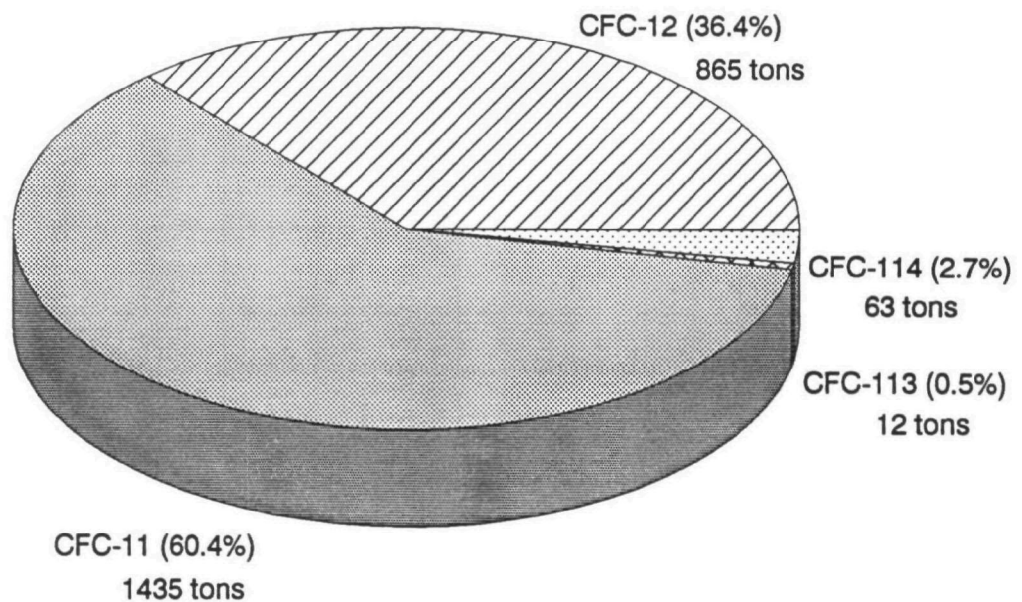
## **EXECUTIVE SUMMARY**

Since the world became aware of the problem of ozone depletion, Egypt has played a leading role in the international effort to protect the stratospheric ozone layer. Ambassador Essam Hawas of Egypt played a pivotal role in the preparation of the Vienna Convention. Dr. El-Mohamady Eid, Chairman of the Egyptian Environment Affairs Agency, was active in designing and drafting the Montreal Protocol on Substances that Deplete the Ozone Layer. Egypt was the seventh country to sign and ratify the Protocol and has been working aggressively to reduce its consumption of chlorofluorocarbons (CFCs). In the early part of the last decade, before the Vienna Convention was drafted, public-sector companies (state-owned enterprises) manufacturing pesticide aerosol products made a complete switch from CFCs to hydrocarbons in response to worldwide concern over ozone depletion. This switch led to a significant decline in CFC usage in Egypt between 1982 and 1986. In addition, the Ministry of Industry issued a decree on November 8, 1989, that banned the use of CFCs in aerosols starting in January 1991.

Egypt does not produce any of the Group I controlled substances (CFCs) addressed by the Montreal Protocol. Demand is met completely through importation. Egypt consumed a total of 2,375 metric tons of CFCs in 1989. Exhibit ES-1 presents the 1989 CFC consumption pattern for Egypt. The Egyptian Environment Affairs Agency forecasts that in the absence of Protocol restrictions CFC use could grow at 5 percent annually through the year 2000.

## Exhibit ES-1

### Egypt: Distribution of CFC Consumption (Based on Actual Tons Consumed in 1989)



**Total: 2,375 MT**

**Source: EEAA 1990b,c**



Egypt also does not produce any of the Group II controlled substances (halons) addressed by the Montreal Protocol. The total consumption of 1,000 metric tons in 1989 was met through importation. Exhibit ES-2 presents the halons consumption pattern in Egypt. In addition to the Group I and Group II controlled substances, Egypt also consumes limited quantities of methyl chloroform and carbon tetrachloride. These ozone-depleting substances are likely to be regulated under the amended Protocol.

Two scenarios, which assume a different annual increase in CFC use (in the absence of Protocol restrictions) and different costs of implementing alternatives, were used to calculate the costs to Egypt of phasing out the use of CFCs:

- **Scenario 1: Likely Growth Rate - Likely Cost.** CFC use grows at an annual rate of 5 percent in the period 1990-2000 and at 2.5 percent per year in the period 2001-2010 in the absence of Protocol restrictions; the costs of implementing the substitute technologies and using alternative chemicals is 5 percent higher in Egypt compared to the U.S.
- **Scenario 2: Likely Growth Rate - High Cost.** CFC use grows at an annual rate of 5 percent in the period 1990-2000 and at 2.5 percent per year in the period 2001-2010 in the absence of Protocol restrictions; the costs of implementing the substitute technologies and using alternative chemicals is 30 percent higher in Egypt compared to the U.S..

The costs of implementing options could be higher in Egypt than in the United States.

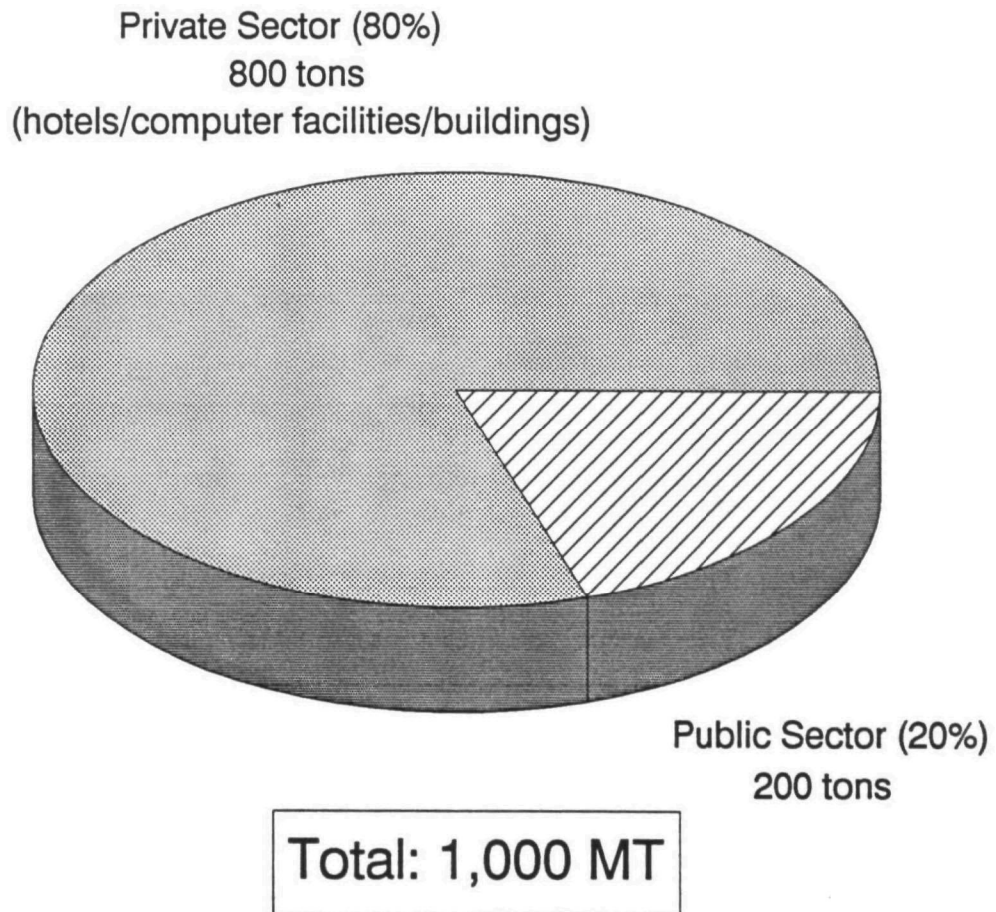
Associated costs would include the following:

- transportation costs for imported equipment;
- maintenance and servicing costs for the new technologies;
- incremental infrastructure development costs;
- costs due to exchange rate variations;
- technology transfer costs; and
- costs due to smaller economies of scale.

## Exhibit ES-2

### Egypt: Halon Consumption by End Use

(Based on Actual Tons Consumed in 1989)



Source: EEAA 1990c

The estimated cost to Egypt to phase out the consumption of CFCs ranges from \$30.52 million to \$37.76 million. Exhibit ES-3 presents the distribution of costs by end use for the period 1990-2010.

At least a 50 percent reduction in the use of Halon-1211 and Halon-1301 can be achieved at zero net cost by using existing dry and foam chemical alternatives and by eliminating unnecessary emissions from testing, training, and accidental discharges.

Egypt demonstrated her commitment to the protection of the global environment by being one of the first countries to significantly reduce the use of CFCs in aerosol products in the early 1980s. Egypt has played a leading role over the last ten years in establishing an international framework for protecting the ozone layer. Egypt will continue to be a leader in global efforts to protect and preserve the environment.

**Exhibit ES-3. Costs to Egypt of Phasing Out CFC Consumption**  
(millions of U.S. dollars)

Compound	End Use	Scenario 1		Scenario 2	
		Likely Growth Rate/ Likely Cost (1990-2010)		Likely Growth Rate/ High Cost (1990-2010)	
CFC-11	Aerosols	0.0		0.0	
	Refrigeration	8.75		10.87	
	Foams	<u>21.11</u>		<u>26.07</u>	
	Subtotal	24.86		36.94	
CFC-12	Aerosols	0.0		0.0	
	Refrigeration	<u>0.31</u>		<u>0.39</u>	
	Subtotal	0.31		0.39	
CFC-113	Solvents	0.03	0.03	0.03	0.03
CFC-114	Aerosols	0.0		0.0	
	Refrigeration	<u>0.32</u>		<u>0.40</u>	
	Subtotal	<u>0.32</u>		<u>0.40</u>	
TOTAL		30.52		37.76	

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## **I. INTRODUCTION**

### **A. Background**

From the moment the world became aware of the problem of ozone depletion, The Arab Republic of Egypt<sup>1</sup> has played a leading role in the international effort to protect the stratospheric ozone layer. Egypt was the seventh country to sign and ratify the Montreal Protocol. Ambassador Essam Hawas of Egypt played a pivotal role in the preparation of the Vienna Convention<sup>2</sup>. Dr. El-Mohamady Eid, Chairman, Egyptian Environment Affairs Agency (EEAA) was an active participant in the discussions leading to the drafting of the "Montreal Protocol on Substances that Deplete the Ozone Layer."

On February 23, 1981, the Egyptian Ministry of Industry (MOI) received an alert from the U.S. Environmental Protection Agency (EPA) via the Embassy of Egypt in Washington, D.C., regarding the harmful human health and environmental impacts resulting from the depletion of the stratospheric ozone layer. In response to this alert, the MOI appointed an ad hoc committee (Decree, MOI-638/81) that included representatives of the CFC consumer industries such as the refrigeration and air conditioning, aerosols, and plastics industries. The committee was reconstituted (Decree MOI - 446/86, Ahmed Amin 1987), and expanded to include other concerned bodies such as the Federation of Industry, the Ministry of Health, EEAA, and the General Organization for Standardization. Dr. Ahmed Amin Ibrahim, at that time Undersecretary of State, Ministry of Industry, acted as the technical rapporteur to this committee.

The committee performed a number of technical and economic studies, which resulted in the following recommendations:

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<sup>1</sup> Referred to in the rest of this report as 'Egypt.'

<sup>2</sup> His Excellency Mr. Essam Hawas is currently the Ambassador of the Arab Republic of Egypt to Qatar.

- No new permits or licenses should be given to projects that shall use CFCs in their production process;
- No extension permits should be given to existing facilities using CFCs;
- Introduction of CFC substitutes that are locally available or abundant and easy to produce should be encouraged;
- The possibility of introducing legislation banning the use of CFCs in such end uses where substitutes are readily available and cost effective should be studied;
- The possibility of imposing taxes on CFC importation and providing incentives for substitutes should be considered; and
- A procedure for the disposal of salvaged equipment containing CFCs (e.g., refrigeration equipment) should be developed.

In addition, the Ministry of Industry issued a decree banning the use of CFCs in aerosols beginning January 1991 (see Appendix A).

The Egyptian Environment Affairs Agency (EEAA) and the U.S. Environmental Protection Agency (EPA), in cooperation with Egyptian industry, jointly undertook a national case study whose purpose was threefold:

- (1) to estimate current and future demand for CFCs, halons and other ozone-depleting substances, including methyl chloroform and carbon tetrachloride;
- (2) to analyze the specific uses of these substances; and
- (3) to evaluate controls options and costs of reducing the use of these substances in Egypt.

This report, which represents the results of this case study, describes the technical and financial needs of Egypt as Egypt takes action in phasing out CFCs and halons. At least seven other case studies are being undertaken. The U.S. EPA is also collaborating with Mexico and Brazil. The United Kingdom is cooperating with India; Canada with Malaysia, Finland with China (through the United Nations Development Programme), Sweden with Kenya, and Venezuela is conducting its own case study.



This report is divided into six sections:

Section I, the Introduction, describes the role of CFCs and halons in stratospheric ozone depletion, presents some background on the Montreal Protocol and subsequent developments, and describes Egypt's policy regarding protection of the stratospheric ozone;

Section II describes the consumption of CFCs and other ozone-depleting substances in Egypt;

Section III characterizes current end-use consumption of CFCs and halons in Egypt;

Section IV describes the practices, technologies, and substitute chemicals and products that can be used to reduce CFC and halon consumption in each end-use area;

Section V describes cost-effective measures Egypt can adopt to reduce CFC consumption immediately; and

Section VI describes the costs to Egypt of reducing consumption of ozone-depleting substances.

## **B. The Role of Chlorofluorocarbons and Halons in Stratospheric Ozone Depletion**

Stratospheric ozone shields the earth from harmful ultraviolet (UV) radiation. Increasing concentrations of man-made chemicals, including chlorofluorocarbons (CFCs) and halons, as well as methyl chloroform, carbon tetrachloride, and HCFCs, destroy stratospheric ozone. A significant reduction in stratospheric ozone could result in long-term increases in skin cancer and cataracts, suppress the human immune system, damage crops, aquatic organisms and natural ecosystems, and contribute to global warming. Increased ultraviolet radiation also contributes to increased ground-level ozone (smog).

CFCs, and particularly halons, are potent ozone depleters. CFCs consist of chlorine, fluorine, and carbon. They were first developed in the 1930s as efficient, safe refrigerants for home use. The physical properties of CFCs made them ideal for a wide variety of applications – they are nonflammable, efficient, inexpensive and low in toxicity. These properties helped increase demand for CFCs and led to their use as foam-blowing agents, refrigerants for cooling applications, cleaners for electrical and metallic parts, aerosol

propellants, and in other applications. Halons, containing bromine, are used as fire-extinguishing agents. They are preferred in many applications due to their excellent flame-extinguishing properties, low toxicity, lack of electrical conductivity, and lack of corrosivity and residue.

Because CFCs and halons are chemically inert, they are virtually unreactive in the lower atmosphere. As a result, CFCs and halons slowly migrate to the upper atmosphere where higher energy radiation strikes them, releasing chlorine and bromine atoms. Once released, the chlorine and bromine acts as a catalyst, repeatedly combining with and breaking apart stratospheric ozone molecules. A single chlorine atom can destroy over 100,000 ozone molecules.

### **C. The Montreal Protocol and Subsequent Developments**

In September 1987, 56 nations and the European Economic Community participated in negotiations that led to an agreement in Montreal to reduce the use of CFCs and halons. The Protocol on Substances that Deplete the Ozone Layer was signed in Montreal, Canada, on September 16, 1987, and entered into force on January 1, 1989.

#### **1. The Montreal Protocol**

The chemicals controlled by the Montreal Protocol have been subdivided into two groups.

**"Group I" - Fully-Halogenated Chlorofluorocarbons:**

CFC-11 Trichlorofluoromethane  
CFC-12 Dichlorodifluoromethane  
CFC-113 Trichlorotrifluoroethane  
CFC-114 Dichlorotetrafluoroethane  
CFC-115 Chloropentafluoroethane

**"Group II" - Halons:**

Halon-1211 Bromochlorodifluoromethane

Halon-1301 Bromotrifluoromethane  
Halon-2402 Dibromotetrafluoroethane

The Protocol control provisions became effective July 1, 1989, with a freeze on Group I CFCs at 1986 consumption levels. Reductions of 20 percent from 1986 production levels are required by July 1, 1993, and reductions of 50 percent from 1986 consumption levels are required by July 1, 1998. Group II halons will be frozen at 1986 consumption levels in 1992. The Protocol allows developing countries a 10-year grace period.

Exhibit I-1 presents the Ozone Depletion Potential (ODP) and the Global Warming Potential (GWP) for the regulated CFCs, halons, and other ozone-depleting substances.

The Montreal Protocol contains a number of provisions to encourage the participation of developing countries. It requires Parties to the Protocol to transfer environmentally safe alternative substances and technologies bilaterally and multilaterally to developing countries. Furthermore, it calls for all signatories to undertake to facilitate bilaterally or multilaterally the provision of subsidies, aid, credits, guarantees, or insurance programs to assist developing countries who are signatories to the Protocol in their efforts to use alternative technology and effect product substitution.

## **2. Subsequent Developments**

The Montreal Protocol provides a mechanism to review the adequacy of control measures and adjust them where, and when, appropriate based on new scientific, technical, economic, and environmental information.

Increasing evidence suggests that ozone depletion is more severe than originally estimated during negotiations in 1987. Since 1987 scientists have concluded that Antarctica's springtime ozone depletion of approximately 50 percent is caused by CFCs and other ozone-depleting substances. The Ozone Trends Panel, consisting of over 100 of the world's leading atmospheric scientists, examined both global ozone changes and evidence concerning the

**Exhibit I-1. Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) of CFCs and Halons**

Substance		ODP Relative to CFC-11*	GWP Relative to CFC-11* (Mass Basis)
<b>Controlled by the Current Montreal Protocol</b>			
<u>Group I Substances:</u>			
CFC-11	Trichlorofluoromethane	1.00	1.00
CFC-12	Dichlorodifluoromethane	1.00	2.67
CFC-113	1,1,2-Trichloro-1,2,2-trifluoroethane	0.82	1.09
CFC-114	1,2-Dichlorotetrafluoroethane	0.76	2.89
CFC-115	Chloropentafluoroethane	0.43	9.69
<u>Group II Substances:</u>			
Halon-1211	Bromochlorodifluoromethane	3.0	—
Halon-1301	Bromotrifluoromethane	10.0	2.12
Halon-2402	Dibromotetrafluoroethane	6.0	—
<b>Other Substances of Concern not Controlled by the Current Protocol</b>			
CCl <sub>4</sub>	Carbon Tetrachloride (tetrachloromethane)	1.11	0.39
MCF	Methyl Chloroform (1,1,1-Trichloroethane)	0.11	0.02

Source: UNEP Technology 1989.

\* Factors governing the relative efficiency of these compounds to destroy ozone include: (1) rate of release of the compound into the atmosphere; (2) rate of removal of the compound in the troposphere and its persistence in the stratosphere; and (3) efficiency of the compound in destroying ozone in the stratosphere.

Ozone depletion potential (ODP) is defined (Fisher *et al.*) as the model-calculated ozone depletions under steady state conditions. More specifically, it is defined as the ratio of calculated ozone column change for each mass unit of a gas emitted into the atmosphere relative to the calculated depletion for the reference gas CFC-11. ODP provides a useful yardstick for estimating the relative destruction potential of various chemicals.

The ability of a compound to absorb infrared radiation characterizes global warming potential. Global warming potential (GWP) is defined as the ratio of calculated warming for each unit mass of a gas emitted into the atmosphere relative to the calculated warming for a mass unit of reference gas CFC-11.

Both ODP and GWP estimate the relative adverse environmental impacts of alternative substitute chemicals on two global environmental problems. Both need to be taken into account when judging the environmental acceptability of chemicals.

cause of the Antarctic ozone hole. The Panel reported that total column ozone in northern hemisphere mid-latitudes had decreased by 1.7 to 3.0 percent between 1969 and 1986 (NASA 1988). Based on their analysis of ground-based and satellite data, the panel concluded that the actual depletion of total column ozone was two to three times greater than the original projections of depletion developed using atmospheric models. The panel also concluded that the weight of evidence supported the theory that formation of the Antarctic ozone hole during the springtime was the result of man-made chlorine- and bromine-containing compounds being released into the atmosphere. Furthermore, new evidence indicates that ozone loss is not confined to the South Pole. Recent measurements show downward trends in total column ozone of up to 6 percent from 1970 to 1986 over the Northern Hemisphere during winter (NASA 1988).

In the spring of 1988, EPA's study of future chlorine and bromine levels in the atmosphere (EPA 1988) estimated that complete phase-out in emissions of CFCs and halons, with additional stringent controls on the chlorine-containing compounds methyl chloroform and carbon tetrachloride, would be necessary to stabilize the levels of chlorine and bromine in the stratosphere.

As a result of this new evidence, international discussions concerning a complete phase-out of CFCs and non-essential halons and restrictions on other chlorinated compounds began. In April 1989, 70 nations met in Helsinki at the First Meeting of the Parties to the Montreal Protocol and agreed to a non-binding resolution known as the Helsinki Declaration on the Protection of the Ozone Layer (Exhibit I-2).

Since the Helsinki declaration, a working group under the Montreal Protocol has proposed amendments to the Protocol for adoption during the next meeting of the Parties in June 1990 in London. It is likely that the Protocol will be amended to require a complete phase-out of CFCs and the non-essential uses of halons by the year 2000, allowing

## **Exhibit I-2. Helsinki Declaration on the Protection of the Ozone Layer**

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**The Governments and the European Communities represented at the First Meetings of the Parties to the Vienna Convention and the Montreal Protocol**

**Aware of the wide agreement among scientists that depletion of the ozone layer will threaten present and future generations unless more stringent control measures are adopted**

**Mindful that some ozone-depleting substances are powerful greenhouse gases leading to global warming**

**Aware also of the extensive and rapid technological development of environmentally acceptable substitutes for the substances that deplete the ozone layer and the urgent need to facilitate the transfer of technologies of such substitutes especially to developing countries**

**ENCOURAGE all states that have not done so to join the Vienna Convention for the Protection of the Ozone Layer and its Montreal Protocol**

**AGREE to phase out the production and consumption of CFCs controlled by the Montreal Protocol as soon as possible but not later than the year 2000 and for that purpose to tighten the timetable agreed upon in the Montreal Protocol taking into account the special situation of developing countries**

**AGREE to both phase out halons and control and reduce other ozone-depleting substances which contribute significantly to ozone depletion as soon as feasible**

**AGREE to commit themselves, in proportion to their means and resources, to accelerate the development of environmentally acceptable substituting chemicals, products, and technologies**

**AGREE to facilitate the access of developing countries to relevant scientific information, research results, and training and to seek to develop appropriate funding mechanisms to facilitate the transfer of technology and replacement of equipment at minimum cost to developing countries.**

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developing countries a 10-year grace period for compliance. It is also likely that methyl chloroform and carbon tetrachloride will be added to this list of controlled ozone-depleting substances.

#### **D. The Revised Montreal Protocol and Egypt's Policy on Stratospheric Ozone Protection**

Exhibit I-3 shows the historical and projected consumption of CFC-11, CFC-12, CFC-113, and CFC-114 in Egypt,<sup>3</sup> assuming no controls were imposed (upper line) and a reduction schedule (stepped line), which represents the likely schedule for complying with the Montreal Protocol.<sup>4</sup> CFC consumption dropped between 1982 and 1985 because manufacturers of aerosol products switched to alternative propellants such as liquified petroleum gas (LPG). CFC consumption rose after 1985 because of an increase in demand for CFCs for foam-blowing applications. Industry sources predict that CFC consumption will grow at an annual rate of 5 percent between 1990 and the year 2000.

This analysis is based on the assumption that Egypt will comply with the Montreal Protocol by:

- (a) freezing 1999 CFC consumption<sup>5</sup> at 1996 consumption levels;
- (b) reducing CFC consumption by 20 percent by the year 2003;
- (c) reducing CFC consumption by an additional 30 percent by the year 2008; and
- (d) phasing out CFC consumption by the year 2010.

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<sup>3</sup> Egypt does not produce or import CFC-115.

<sup>4</sup> The revised Protocol may utilize stepped reductions or other phase-out schedules. The schedule shown in Exhibit I-4 is an example based on the current Protocol design.

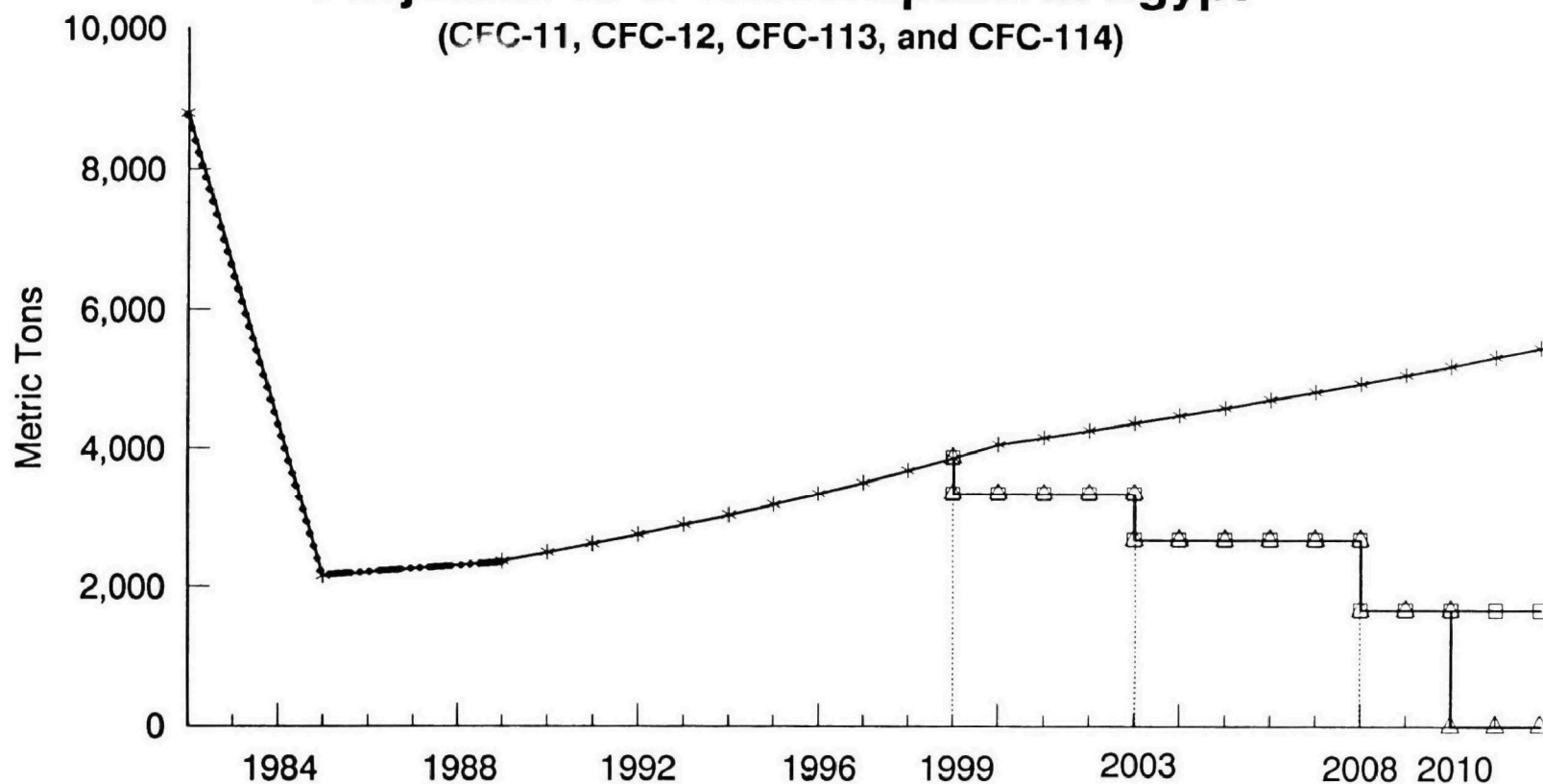
<sup>5</sup> The Montreal Protocol restricts production and consumption of these substances. See Montreal Protocol at paragraphs 1 and 2 of Article 2: Control Measures. Consumption is defined as production plus imports minus exports of controlled substances.

In addition, the revised Montreal Protocol is likely to include a phase-out of carbon tetrachloride (for non-feedstock uses) and non-essential halons, as well as controls on methyl chloroform consumption. Egypt consumes a limited quantity of both these ozone-depleting substances. No information was available on the exact quantities consumed.

Egypt consumes less than 0.3 kilograms of CFCs per capita and thus should qualify as a low-use developing country under the Protocol definitions (Article 5). Under these provisions, as shown in Exhibit I-3, Egypt could increase CFC use for as long as 10 years before beginning reductions in use.



# **Exhibit I-3** **Projected CFC Consumption in Egypt** (CFC-11, CFC-12, CFC-113, and CFC-114)



No Controls    Current Montreal Protocol    Revised Montreal Protocol

- ..... CFC use reduced due to switch away from CFCs in Aerosol Products
- ..... CFC use increased due to increasing use in Foam Products

Source: EEAA 1990b



## **II. CONSUMPTION OF CHLOROFLUOROCARBONS AND OTHER OZONE-DEPLETING COMPOUNDS IN EGYPT**

This section describes the consumption in Egypt of Group I and Group II controlled substances<sup>6</sup>. Egypt does not produce any CFCs and halons; its local demand is met via importation. Exhibit II-1 presents the distribution of CFC-11, CFC-12, CFC-113, and CFC-114 consumed in Egypt. Exhibits II-2 and II-3 show total CFC consumption by end use. Egypt consumed 2,375 metric tons of CFCs in 1989 (EEAA 1990b and 1990c). Refrigeration accounted for the largest use of CFCs, 38.6 percent; followed by foam, 35.8 percent; aerosols, 25.1 percent; and solvents, 0.5 percent.

Exhibit II-4 shows the distribution of halon consumption in Egypt in 1989 by end use. It is estimated that in 1989 Egypt consumed 1,000 metric tons of halons. The public sector accounted for approximately 20 percent of consumption, and the private sector (hotels, computer facilities, and buildings) accounted for the remaining 80 percent. Exhibit II-5 presents price data for CFCs and halons consumed in Egypt. These prices include a 7 percent import tariff.

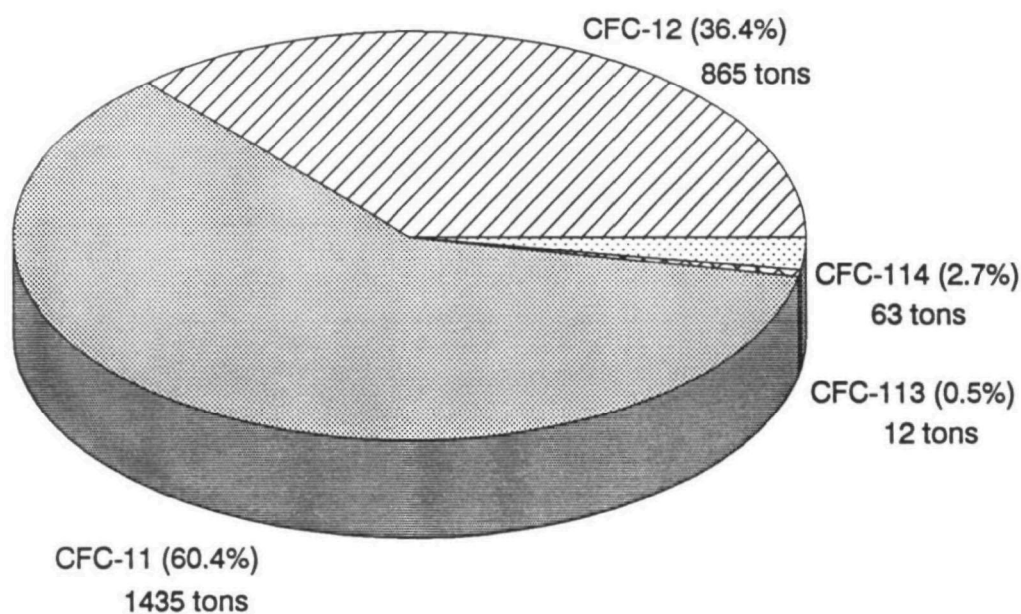
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<sup>6</sup> No data was available on the consumption of methyl chloroform and carbon tetrachloride in Egypt.

## Exhibit II-1

### Egypt: Distribution of CFC Consumption

(Based on Actual Tons Consumed in 1989)



**Total: 2,375 MT**

**Source: EEAA 1990b,c**

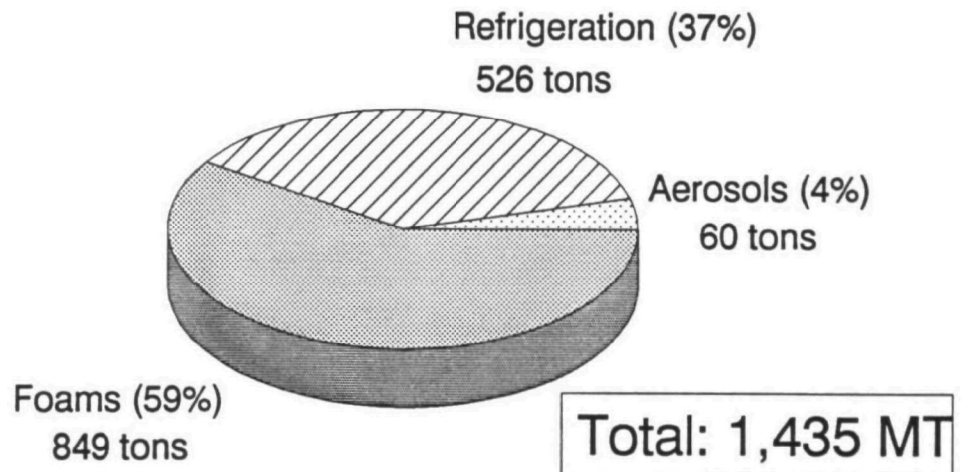
**Exhibit II-2. Distribution of CFC Consumption in Egypt in 1989  
(metric tons)**

End Use	CFC-11	CFC-12	CFC-113	CFC-114	All CFCs Combined
Aerosols	60 (4%)	486 (56%)	-	50 (79%)	596 (25%)
Refrigeration	526 (37%)	379 (44%)	-	13 (21%)	918 (39%)
Foams	849 (59%)	-	-	-	849 (36%)
Solvents	-	-	12 (100%)	-	12 (<1%)
<b>TOTAL</b>	<b>1,435</b>	<b>865</b>	<b>12</b>	<b>63</b>	<b>2,375</b>

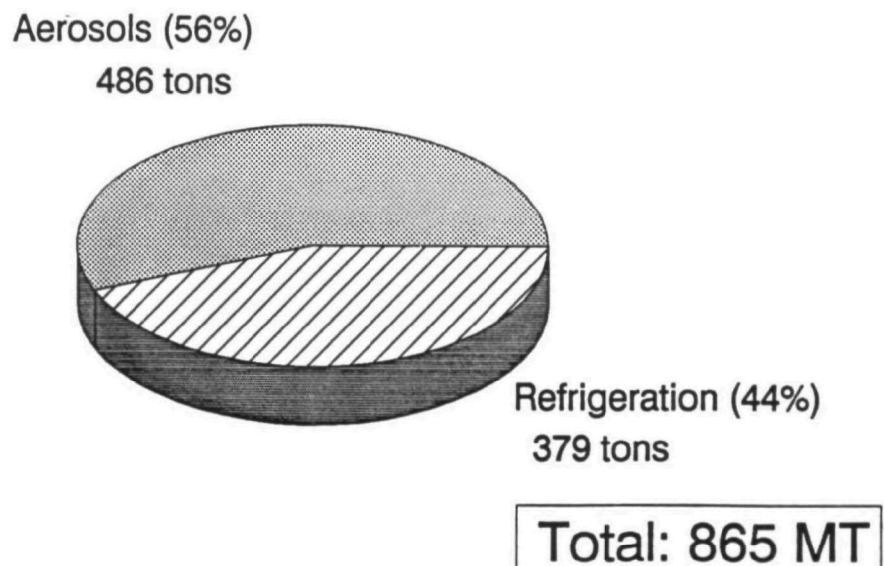
Source: EEAA 1990b and 1990c.

## Exhibit II-3

### Egypt: CFC-11 Consumption by End Use (Based on Actual Tons Consumed in 1989)



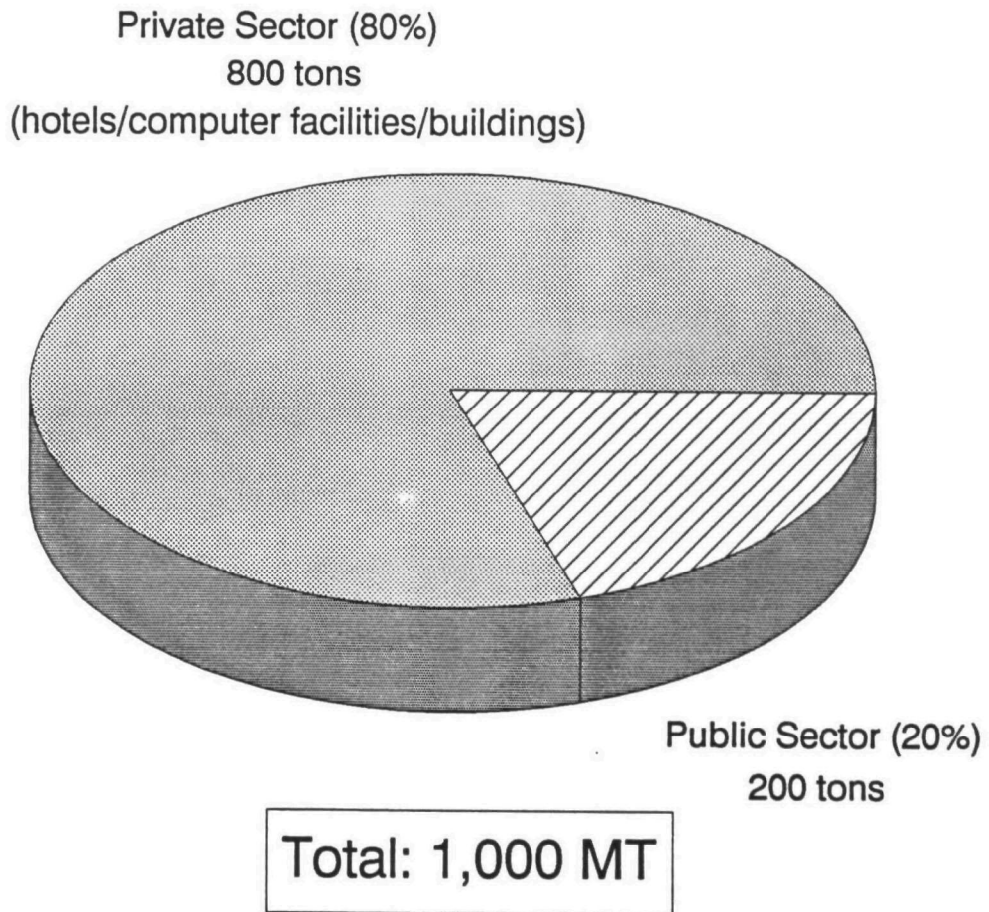
### Egypt: CFC-12 Consumption by End Use (Based on Actual Tons Consumed in 1989)



Source: EEAA 1990b

## Exhibit II-4

### Egypt: Halon Consumption by End Use (Based on Actual Tons Consumed in 1989)



Source: EEAA 1990c

**Exhibit II-5. Purchase and Selling Prices for Imported CFCs and Halons**

Compound	Selling Price (£E per kg)	Purchase Price <sup>a</sup> (£E per kg)	Corresponding <sup>b</sup> Purchase Price (US \$ per kg)
CFC-11	£E 5.0	£E 4.25	\$1.60
CFC-12	£E 7.0	£E 5.95	\$2.25
CFC-113	£E 14.0	£E 11.90	\$4.49
CFC-114	£E 12.0	£E 10.20	\$3.85
Halon	£E 45.0	£E 38.25	\$14.43

<sup>a</sup> Custom Duties of 7 percent inclusive.

<sup>b</sup> Exchange rate: \$1.00 U.S. is approximately equal to £E 2.65.

Source: EEAA 1990c.



### **III. TECHNOLOGY AND EQUIPMENT CHARACTERISTICS IN CURRENT END USES**

Many different industries and applications use CFCs, halons, and other ozone-depleting substances in Egypt:

- Commercial and Residential Refrigeration,
- Air Conditioning,
- Aerosols,
- Sterilization,
- Solvent Cleaning,
- Foams, and
- Halon Fire-Extinguishing Agents.

Chapter II showed the distribution of CFC and halon consumption in Egypt by end use. This chapter describes the different applications in which CFCs or halons are used.

#### **A. Commercial and Residential Refrigeration and Air Conditioning**

Egypt began using CFCs in refrigeration applications around the 1930s. At that time most of the common household refrigerators operated with pre-prepared ice blocks, which were produced in ice plants using ammonia as a refrigerant. These types of refrigerators still exist in rural villages in Egypt.

Modern refrigerators that use CFCs were first introduced in Egypt in 1962 by the Ideal Company (a public sector company). The Ideal Company produces refrigerators and window air conditioning units. In 1989 in Egypt approximately 918 metric tons of all types of CFCs were used in refrigeration and air conditioning units (EEAA 1990b).

##### **1. Commercial Refrigeration**

CFCs are used as refrigerants in the following kinds of commercial systems in Egypt:

- Retail food storage, used to refrigerate food and beverages in grocery and convenience stores;
- Chillers, air conditioning systems in large commercial and industrial buildings, including office buildings, hospitals, schools, and factories; and
- Cold storage, refrigerated spaces such as warehouses that are used to store meat, produce, dairy products, and other perishable goods.

The stock of chiller units operating in Egypt is estimated at 5,000 units; yearly production capacity is 50 units. CFCs are released from refrigeration systems and air conditioners during (1) manufacturing (during leak testing, reworking, and shipping); (2) installation; (3) use and servicing on-site; and (4) product disposal. CFC emissions that occur during use, servicing, and disposal far exceed emissions that occur during manufacturing and installation.

## **2. Residential Refrigeration**

Residential refrigeration includes home refrigerators, freezers, and other small refrigerated appliances such as ice machines and dehumidifiers. There are seven major refrigerator manufacturers in Egypt with a total production capacity of one million units. Refrigerators produced in Egypt come in several sizes: 5, 8, 10, 12, and 14 cubic-foot capacity. Exhibit III-1 shows the major manufacturers of refrigerators in Egypt. Ideal Company accounts for about 75 percent of the market (EEAA 1990b).

## **3. Air Conditioning**

### **a. Comfort Air Conditioning Units**

The use of window air conditioning units in Egypt has increased rapidly in the last 10 years. Window air conditioning units use HCFC-22 as the refrigerant. It is estimated that the total number of window air conditioning units installed per year is 130,000 units; there are about 475,000 units in operation. Koldair Company is the main public-sector company producing these units. Other private-sector companies that are joint ventures with

**Exhibit III-1. Major Manufacturers of Household Refrigerators in Egypt**

<b>Manufacturer<sup>a</sup></b>	<b>Production Capacity (units)</b>	
	<b>Refrigerators</b>	<b>Freezers</b>
Ideal Company	750,000	--
El-Dowlya Company	45,000	15,000
El-Alamyia Company	32,000	48,000
Kriazy Company	40,000	--
El-Islamia	32,000	8,000
Super Bbosh	--	20,000
<b>TOTAL</b>	<b>899,000</b>	<b>91,000</b>

<sup>a</sup> There are a number of small-scale manufacturers that produce custom-made refrigeration units. The use of CFCs by these smaller manufacturers is estimated to be minor.

Source: EEAA 1990b.

SAS, Carrier, and Mitsubishi include Miraco Company and El-Dalia Refrigeration company. The Montreal Protocol does not control the use of HCFCs. This sector, therefore, is unlikely to be affected by Protocol restrictions.

#### **b. Mobile Air Conditioners**

CFC-12 is used as the refrigerant in mobile air conditioners to cool the passenger compartments of automobiles, trucks, buses, and railway wagons used in Egypt. Of the 1 million automobiles operating in Egypt, only about 10,000 (or 1 percent) have factory-installed air conditioners. In addition, 2,000 tourist buses, 1,000 large railway wagons, and 10,000 small railway wagons use mobile air conditioners (EEAA 1990c).

### **B. Foams**

Egypt uses CFC-11 as a blowing agent to produce rigid and flexible polyurethane foam and rigid polystyrene foams. Exhibit III-2 shows the types of foams produced in Egypt. Flexible polyurethane foam is used in furniture, bedding, carpet underlays, automotive interiors, and in other transportation seating applications. Rigid polyurethane foam is used for insulation in refrigerators, freezers, buildings, tanks, pipes, and doors and in packaging. Rigid polystyrene foam is used for insulation in buildings and refrigeration units and in packaging used for food and agriculture products.

There are 31 facilities producing foams in Egypt (EEAA 1990b). CFC producers sell blowing agents and CFCs to formulators who, in most cases, mix them with other raw materials to create a pre-mixed reactant product. System formulators sell their pre-mixed reactant products to either Original Equipment Manufacturers (OEM) foam users or to applicators. OEM foam users employ the pre-mixed reactants and other raw materials (such as catalysts, water, and other additives) to create a chemical reaction that yields various foam products. For example, a household refrigerator manufacturing firm is an OEM foam user

**Exhibit III-2. Structure of the Foam Plastic Industry in Egypt**

<b>Product</b>	<b>Major Applications</b>	<b>No. of Existing Factories</b>
<b>Polyurethane</b>		
<b>Flexible</b>	Mattresses, furniture, packaging	4
	Mattresses, furniture, chair seats	6
<b>Rigid</b>	Heat insulation, packaging, seats, and supports	2
	Heat insulation for walls, cooling units (refrigeration)	3
<b>Rigid Polystyrene</b>	Heat insulation for buildings and cooling units, packaging	6
	Packaging for fragile items, food, and agricultural products	7
	Linings for ceilings, walls, and floorings; decorations; packaging	3
<b>TOTAL FACTORIES</b>		<b>31</b>

Source: EEAA 1990b.

because it uses pre-mixed reactants (containing CFCs) to create a chemical reaction within pre-assembled refrigerator walls. Construction contractors spray foam products on-site to insulate refrigeration chambers and refrigerated transportation equipment.

### **C. Aerosols**

Aerosols using CFCs as propellants and solvents were introduced in Egypt in the 1960s in various products, including insecticides, cosmetics, paints, etc. Economic growth and increased consumer demand resulted in a surge in aerosol manufacturing facilities. The two main subsectors of the Egyptian aerosols industry are the pesticides and cosmetics industries.

#### **1. Pesticides**

The Egyptian pesticide aerosols industry has a production capacity of 55 million units. The common can sizes in Egypt are 12, 14, and 16 ounces. Currently, all public-sector companies use liquified petroleum gas (LPG) instead of CFCs to manufacture pesticide aerosols products. Exhibit III-3 lists the major manufacturers of pesticide aerosols in Egypt and the production capacity of each. El-Nasr Intermediate Company, the largest pesticide aerosol manufacturer, also produces some personal care products. This company, which has a production capacity of 15 million units per year, uses LPG instead of CFCs in all of their pesticide aerosols. Appendix B describes the steps El-Nasr Chemical undertook to convert from CFC-based aerosols to LPG-based aerosols (EEAA 1990b).

Kafr El Zayat Company (KZ) is also a major manufacturer of pesticide aerosols, with production capacity of about 8 million units per year. KZ was the first company to switch to LPG in 1984. Appendix C describes the costs incurred by Kafr El Zayat when converting from CFC-based aerosols to products propelled by LPG.

**Exhibit III-3. Major Manufacturers of Pesticide Aerosols in Egypt**

<b>Company</b>	<b>Annual Production Capacity<sup>a</sup> (million units)</b>
El-Nasr Intermediate	15
Kafr El Zayat	8
Johnson Wax-Egypt	--
Dexan	--
Sox	--
Giza Chemical	--
El Shark	6
El Watanya	--
Gelica	--
<b>TOTAL</b>	<b>55</b>

<sup>a</sup> Although no information on production capacity was available for six of the nine major manufacturers of pesticide aerosols, total capacity for all manufacturers is known to be about 55 million units per year.

Source: EEAA 1990b.

The Johnson Wax-Egypt Company's facility, which began aerosol production in the 1980s, was designed and built to manufacture aerosol products propelled with LPG. The design of the facility incorporates all the important elements necessary to manufacture LPG-based aerosol products, such as safety and fire hazard features, and can be used as a "model" for facilities of this kind.

There are a number of other small- and medium-sized pesticide aerosol manufacturers such as Dexan, Sox, Giza Chemical, El Shark, El Watanya, and Gelica. Some of these companies use CFCs in the manufacture of their aerosol products (EEAA 1990b).

## **2. Cosmetics**

Egyptian manufacturers of aerosols use greater amounts of CFCs than do manufacturers of pesticide aerosols. The United Trading and Agency Corporation, a subsidiary of El Beleidy Company, a private-sector enterprise, is the major producer of cosmetics aerosols products, with an 85 percent market share. The company manufactures cosmetics under license from a variety of European manufacturers which specify the formulation. Most of the critical ingredients are imported and formulated at the company's facilities in Cairo, which are undergoing major expansion.

United Trading and Agency Corporation is also a major exporter of cosmetics aerosol products. The main export market, accounting for 50 percent of aerosol production and 70 percent of all cosmetics products manufactured by the company, is the Soviet Union. The Soviet importers have informed the company that starting in January 1991 they will not accept any aerosol products that contain CFCs. The company, therefore, has been advised by its licensors to switch to hydrocarbons-based propellants (EEAA 1990c).



Other manufacturers of cosmetics aerosols include the Sugar and Refinery Company, Shabrawishy Company, Lafayette Company, Wella Company, Yasmina, New Farm, Lactuel, and Parafico (EEAA 1990b and 1990c)<sup>7</sup>.

#### **D. Solvents**

There is a limited amount of CFC-113 used for solvent cleaning applications in Egypt. CFC-113-based solvents are mainly used for metal-cleaning and electronics-cleaning applications. Chlorinated solvents are also used in Egypt. No data is currently available on the amounts and types of chlorinated solvents used.

#### **E. Halons**

About 1,000 metric tons of halons are used in Egypt each year (EEAA 1990c). Most of the halon consumed (80 percent) is used for fire protection in central systems in buildings, computer facilities, chemical plants, etc. The public sector accounts for the remaining 20 percent of the use. No information is available on the breakdown of halon use for public sector applications.

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<sup>7</sup> No data is available on the production capacity of these facilities.



#### **IV. METHODS FOR REDUCING CHLOROFLUOROCARBON USE: RECYCLING, CHEMICAL ALTERNATIVES, ALTERNATIVE TECHNOLOGIES, AND PRODUCT SUBSTITUTES**

Methods for reducing chlorofluorocarbon use fall into four general categories: recycling and adoption of other conservation practices, use of chemical alternatives, use of alternative technologies, and product substitution. This chapter reviews existing and emerging reduction measures specific to each category, and Exhibit IV-1 lists the options available in each category.

##### **A. Recycling and Other Conservation Practices**

Recycling and other conservation practices are technically and economically feasible methods to immediately reduce and eliminate unnecessary emissions of ozone-depleting chemicals in various end-use sectors. Recycling also ensures a reserve of recycled CFCs and halons, which industry can use to service existing capital equipment and other essential uses. The use of recycled CFCs and halons prevents additional ozone depletion and eases the problems associated with early retirement or costly retrofit of existing capital equipment. In Egypt, the primary sectors to target for recycling and conservation practices are refrigeration and foams. Conservation in the solvents and sterilization sectors is also discussed.

##### **1. Refrigeration**

Refrigeration accounts for 38.6 percent of total CFC use in Egypt. Recycled CFCs can replace the demand for virgin CFCs in the after market and can provide immediate reductions in CFC use in residential refrigeration, industrial/commercial refrigeration, and automobile air conditioning.

**EXHIBIT IV-1  
OPTIONS TO REDUCE CFC USE**

<u>End Use</u>	<u>Recycling and Conservation</u>	<u>Chemical Alternatives</u>	<u>Alternative Technologies</u>	<u>Product Substitutes</u>
<b>Refrigeration (CFC-11, CFC-12, CFC-114, CFC-115)</b>	<b>Refrigerant Reclamation and Recycling Units (on-site)</b>  <b>Central Recycling Facility (off-site)</b>	<b>HFC-152a HFC-134a Ternary Blends* NARMS Ammonia HCFC-123 HCFC-22 CFC-500, CFC-502</b>	<b>Two Evaporators Thicker Walls Vacuum Insulation</b>	
<b>Foams (CFC-11)</b>	<b>Carbon Adsorption</b>	<b>HCFC-123/HCFC- 141b</b>  <b>HCFC-142b/HCFC-22 HCFC-22 Methylene Chloride</b>	<b>Increased Water Substitution</b>  <b>AB Process CO<sub>2</sub> Foam Blowing New Polyols</b>	<b>Natural &amp; Synthetic Fiber Materials</b>  <b>Vacuum Panels</b>
<b>Solvent Cleaning (CFC-113)</b>	<b>Improved Operating Practices Engineering Controls On-site Recycling Systems Off-site Recycling Systems</b>	<b>Organic solvents (e.g., alcohols)</b>  <b>HCFC-225ca HCFC-225ab HCFC-141b/HCFC- 123/methanol Blend</b>  <b>Isopropanol Azeo- tropes</b>	<b>Aqueous Cleaning Low solids/"no clean" Flux</b>  <b>Inert Gas Wave Soldering</b>  <b>Terpene Cleaning</b>	
<b>Aerosols (CFC-11, CFC-12, CFC-113)</b>		<b>Hydrocarbon Propellants</b>  <b>HCFC-142b/HFC- 152a/HCFC-22</b>  <b>HCFC-22/HCFC-123</b>		<b>Pumps Mechanical Pressure Dispensers</b>  <b>Solid sticks Roll-ons</b>
<b>Sterilization</b>	<b>Cryogenic Recovery</b>	<b>Compressed Gases CO<sub>2</sub>/EO HCFC Blend/EO</b>	<b>Steam Sterilization Off-site Central Facilities</b>	

\* One of the promising ternary blends has the following composition: HCFC-22 (40%), HFC-152a (40%), and HFC-124 (20%).

#### **a. Residential, Commercial, and Industrial Refrigeration**

Recycling technologies for applications using large quantities of CFC refrigerants, such as commercial buildings and industrial facilities, have existed for many years. Recycling in these applications can be done either on-site or off-site.

Many industrial facilities employ a stationary receiver tank that temporarily stores refrigerant when the system is being repaired. Receiver tanks act to prevent venting of the refrigerant to the atmosphere and collect refrigerant for reclamation. Captured refrigerant can then be transferred to proper holding tanks and shipped to off-site facilities for recycling and reclamation. Off-site reclamation is generally the most efficient means of recycling refrigerant from large systems (Omega 1989).

On-site recycling, however, is becoming more technically and economically feasible. In response to restrictions on CFC production, equipment manufacturers are developing effective on-site refrigerant recycling equipment. Major benefits of this equipment are that it reduces CFC emissions to the atmosphere, provides a safe and economical method of storing refrigerant during servicing, and it has an extended lifetime.

A recycling machine has been developed to service chillers and other large systems with capacities of 500-5,000 pounds (Refrigerant Reclamation Systems 1989). The unit can be dedicated to one machine full time or mobilized to service multiple systems. The machine could be adapted to many other refrigeration systems. In addition, a large appliance manufacturer has developed a refrigerant recovery system to prevent release of CFC refrigerant during routine servicing of centrifugal chillers (Carrier 1990). The transfer pumping system and storage tank of this unit is capable of holding 1500 or 3300 pounds of CFC-11, depending on the tank size. It is capable of recycling the refrigerant while the chiller is in operation, as well as when it is being serviced and during all downtime. Excess oil and water in the refrigerant are removed by means of a distillation/separation system. The recycled

refrigerant is then returned to the system, recharging the chiller for optimum efficiency. The recovery system can be used with any manufacturer's CFC-11 chiller. Price will vary depending on the model size, number of units in the order, and the installation requirements.

Portable recycling units for systems with 1- to 100-pound charge sizes, are also currently on the market. Portable units are appropriate for office building chillers, retail food refrigeration systems, refrigerated transport, and home air conditioning systems.

One of the most innovative developments for small-capacity systems is the plastic recovery bag. Developed by Whirlpool Corporation, a large appliance manufacturer, it is a seven-layer plastic refrigerant recovery bag for household refrigerators and freezers. The recovery bag can be hooked up to a refrigerator or freezer prior to the unit's servicing to catch and hold the refrigerant. Following servicing, a service technician can take the old refrigerant to a recovery center for transfer to a pressurized tank. In turn, the tank is shipped to a reprocessor. The 28-ounce capacity of the bag allows it to be used for two or three jobs before being emptied. The plastic material is durable enough to be filled and emptied up to four times, after which it should be cut up and discarded properly along with other plastic waste. One side of the bag has been left clear so that the technician can visually check exhausted refrigerant to determine whether damage has been done to the appliance's sealed system.

#### **b. Mobile Air Conditioning**

Established methods are available to recapture CFCs in automotive air conditioners that would normally be vented to the atmosphere during servicing. Underwriters Laboratories (UL)<sup>8</sup> has announced the first certifications on recovery/recycling equipment that will properly recycle the refrigerant found in automotive air conditioners. To date, UL has

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<sup>8</sup> Underwriters Laboratories (UL) is a not-for-profit laboratory that has been certifying products for over 95 years to reduce safety and health risks to consumers.

certified the recycling equipment of six manufacturers. The certified equipment complies with UL Standard 1963 for safety of refrigerant recovery/recycling equipment and the Society of Automotive Engineers' (SAE) J1991 Standard for purity of recycled refrigerants. UL Standard 1963 provides safety and performance guidelines for the certification of automobile air conditioning recovery/recycling equipment and specifies the SAE J1991 Standard. SAE J1991 is the published voluntary industry standard of purity for recycled refrigerant. SAE has also published recommended practices for service procedures for containment of CFC-12 (J1989) and for extraction and recycle equipment for mobile air conditioning systems.

Several automobile manufacturers worldwide are voluntarily taking additional steps to promote refrigerant recycling. Ford, General Motors, Nissan, Toyota, and Volvo will sell recycling equipment to their dealers this year. Additionally, Ford, General Motors, Nissan, and Volvo will require their dealers to use UL-certified recycling equipment by 1991.

## **2. Foams**

Foam products represent the second greatest use of CFCs in Egypt, accounting for 35.8 percent of total consumption. The primary end uses across this sector are polyurethane and polystyrene foams. CFCs are released from foam products at different rates depending on the type of foam and the molecular weight of the blowing agent. CFCs are released from most open-cell foams during the manufacturing process. Closed-cell foams gradually release CFCs over the life of the product and at product disposal. At present, recovery and recycling of CFCs in the foaming sector may only be technically and economically feasible in flexible slabstock production (UNEP Foams 1989). Carbon adsorption technology is available to successfully capture CFC-11 emissions in this application. Carbon adsorption is an efficient recovery/recycling method for those manufacturing processes with high CFC emission rates. Carbon adsorption is a process by which CFC-11 from process exhaust streams is absorbed onto activated carbon. Producers

can then easily desorb the CFC-11 and recover it for reuse. Carbon adsorption is especially effective at recovering CFC-11 emitted from flexible slabstock manufacturing processes. In one full-scale, conventional slabstock plant in Europe, a recovery rate of approximately 40 percent was achieved using carbon adsorption (U.S. EPA 1990a).

Greater recovery of CFCs may be achieved by including the curing area, a major source of CFC-11 emissions in the manufacturing process, in the recovery process. An example of recovery technology that encloses the curing area is a foam production machine, developed by a European foam manufacturer, that contains an active carbon recycling unit to capture CFC-11 released in the manufacturing process (Unifoam 1989). The process design permits higher CFC recovery rates than are currently possible in conventional pouring and curing operations. Although CFC-11 recovered with carbon adsorption units is clean enough to be reused without further purification, the costs associated with this process can be substantial and are highly plant specific. To be economically efficient, a carbon adsorption unit must recover and return a quantity of CFC-11 sufficient to offset the annual costs of operation (U.S. EPA 1990a).

### **3. Solvents**

The solvents sector accounts for 0.5 percent of total CFC consumption in Egypt. The largest application areas within this sector are electronics and metal cleaning.

A first step to significantly reduce consumption and eliminate unnecessary emissions of CFC solvents is to implement conservation and recovery practices. This is especially important in the near-term while processes and equipment are redesigned or other production changes are made to eliminate CFC use altogether.

#### **a. Electronics**

Conservation and recovery practices can dramatically reduce CFC-113 consumption in electronics applications. Specific recommended operating practices include



reducing air currents (particularly around the degreaser), optimizing manufacturing schedules to minimize work being processed on an intermittent basis, positioning work to minimize drag-out, ensuring that the speed of work entry and exit does not disrupt the vapor blanket, and locating and repairing all leaks (UNEP Solvents 1989). Greater attention to improved storage and handling procedures will also minimize CFC solvent releases.

Engineering controls also contribute greatly to CFC-113 conservation. Controls for batch degreasers include retrofitting or redesigning with increased freeboard height, retrofitting automatic hoists and programming them for proper entry and exit speeds, and adding degreaser lids or covers that automatically close when the assembly is removed (U.S. EPA 1990b). For in-line cleaners, specific controls include increased freeboard height, increased compressor capacity, extra cooling coils on inlets and outlets, and rationalization of cleaners to handle output from two or more soldering machines (UNEP Solvents 1989).

Recovery technology is well established in the solvent user industry. Solvents can be recycled on-site by users or at off-site commercial recycling facilities. Solvent recovery systems conserve solvent and minimize fresh solvent use. One of the most successful methods in use today is carbon adsorption. A two-stage carbon adsorption steam-regenerated solvent scrubber can effectively capture and reclaim CFC-113 losses due to evaporation. However, the benefits of converting to other alternative cleaning methods should be considered in relation to the increased costs of maintenance and operation of carbon adsorption equipment and the quantity of solvent recovered. The payback period on a carbon adsorption system is estimated to be 2 years (UNEP Solvents 1989). The higher the losses through escaped solvent exhaust, the greater the payback with this system.

#### **b. Metal Cleaning**

A range of options exist for conserving or recycling CFC-113 in metal-cleaning applications. Specific engineering controls include adding additional filtration

equipment, modifying the cleaning and assembly sequence to reduce cleaner use, wrapping parts between assembly steps, or wearing gloves while handling parts to eliminate the need for manual cleaning. Suggested improvements in operating procedures include physically removing large contaminants prior to degreasing and centrally locating systems for removing heavy contaminants to decrease the amount of cleaner used (UNEP Solvents 1989).

As in the electronics sector, recovery techniques for metal-cleaning processes have existed for a number of years. Three examples are gravity separators, water adsorption, and single-plate distillation. Gravity separators operate on the principle that water and solvent separate into two distinct phases provided there is sufficient residence time. Once separated, the heavier solvent phase will be purified further or returned to the solvent-boiling still. Gravity separators are commercially available and can be adapted to any existing degreaser.

Water adsorption is another effective moisture control technique. In this process, trace amounts of water are removed from the solvent by passing the solvent through molecular sieves or similar desiccants. This control maintains the cleaning performance of the solvent and minimizes hydrolysis.

The single-plate distillation process, combined with product filtration and desiccation, produces a virgin-quality solvent that can be reused. This process combines and concentrates still bottoms and transfers them to a reclaiming still. The distillate is then returned to the degreaser or to a storage reservoir. Single-plate distillation is economical for plants generating approximately 30 liters per day of solvent waste (UNEP Solvents 1989).

Both the electronics and metal-cleaning sectors can utilize off-site recycling facilities to recycle solvent generated from degreaser bottoms left over after cleaning operations or from still bottoms with high contamination levels left over after on-site recycling. Most off-site facilities in the U.S. are owned and operated independently, but some CFC solvents manufacturers also provide recycling facilities to their customers. Solvents recycled off-site

can be sent back to the user that generated the spent solvent or placed on the open market as recycled solvent and sold to a wide variety of users.

#### **4. Sterilization**

Add-on engineering systems are available for recycling CFC-12 and ethylene oxide (EO). These systems require handling of pure EO (with the necessary safety precautions) to replace lost amounts. All of the CFC could be reclaimed using a cryogenic system. This could be cost effective on a large scale (UNEP Aerosols 1989).

### **B. Chemical Alternatives**

The timely development and adoption of substitute chemicals for CFCs is important for stratospheric ozone protection. In addition to being environmentally sound, CFC alternatives must be technically and economically feasible. Reviewed below are the current and emerging chemical substitutes under consideration for the major end uses applicable to Egypt. The "alternative technologies" (i.e., alternative methods which involve new processes in each of the CFC application areas) are presented in Section C.

#### **1. Refrigeration**

##### **a. Residential Refrigeration**

For residential refrigeration, near- and medium-term alternatives include ternary blends, HFC-152a, non-azeotropic refrigerant mixtures (NARMs), and CFC-500.

A promising option for domestic refrigeration is a ternary blend of HCFC-22 (40 percent), HFC-152a (40 percent), and HCFC-124 (20 percent). The ternary blend has thermodynamic properties that match CFC-12 very closely. Other advantages include approximately 3 percent better energy efficiency consumption compared to CFC-12 and an ODP of 0.03 (UNEP Refrigeration 1989). The ternary blend is expected to become available worldwide by 1993.

Combinations of commercially available and acceptable fluids in NARMs may be used as CFC substitutes. Today's refrigerators use a single refrigerant, CFC-12, which boils at 30°C. Most early discussions of replacing CFC-12 focused on finding a single "drop-in" replacement.<sup>9</sup> However, certain mixtures (non-azeotropic) of non-CFC refrigerants, such as the HCFC-22/HCFC-142b mixture, exhibit the property of boiling over a range of temperatures, which provides a number of thermodynamic advantages in designing a refrigeration system (Hoffman and Kwartin 1990). Some NARMs have ODP values below 0.05 and have properties very similar to CFC-12, so they could be phased in quickly.

HFC-152a<sup>10</sup> is available as an alternative refrigerant and has proved to be a possible replacement for CFCs. HFC-152a is moderately flammable but has excellent thermodynamic characteristics. Recent tests demonstrate that HFC-152a would improve refrigerator energy efficiency by at least 7 percent, which makes HFC-152a an attractive near-term option. Since the amount of refrigerant used in refrigerators is only about 0.2 kg, it is possible that engineers will design units that can use HFC-152a.

CFC-500 is the azeotropic mixture of 73.8 percent CFC-12 and 26.2 percent HFC-152a. CFC-500 is compatible with existing CFC-12 systems and no equipment modifications are necessary. Further advantages of CFC-500 include increased cooling capacity and an ODP that is 25 percent less than that of CFC-12.

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<sup>9</sup> A "drop-in" substitute can replace CFCs in existing equipment without requiring conversion or retrofitting of the equipment.

<sup>10</sup> HFC-152a contains no chlorine and therefore does not deplete ozone.

## **b. Industrial and Commercial Refrigeration**

For industrial and commercial applications, possible alternative refrigerants include ammonia, HCFC-123, HCFC-22, the ternary blend of HCFC-22/HFC-152a/HCFC-124 already discussed, CFC-500, and CFC-502.

Ammonia is already used with existing equipment in many industrial and commercial applications such as cold storage and food processing. It biodegrades quickly and does not deplete the ozone layer. It is, however, toxic to humans in concentrations above 110 parts per million (ppm) and after 8 hours of exposure, and flammable in concentrations of 16 to 25 percent by volume in air (UNEP Technology 1989). However, because of its pungent odor, it is easy to recognize so that personnel can be evacuated and leaks repaired soon after a leak occurs.

HCFC-123 is being considered as a substitute refrigerant for CFC-11 for commercial chillers. HCFC-123 is likely to be a near drop-in substitute for CFC-11 and has an ODP of 0.02. A manufacturing plant has been built in the U.S. to produce this new refrigerant, with commercial quantities expected by late 1990. Two manufacturers (Trane and York) have developed chillers that are fully compatible with both CFC-11 and HCFC-123. This makes a transition to HCFC-123 easy because HCFC-123 is completely miscible with CFC-11, eliminating the need for changes in bulk facilities. Existing models of the new chiller can be converted from CFC-11 to HCFC-123. There will be instances, however, where chiller equipment may have to be adjusted or replaced to allow for the change in refrigerants.

HCFC-22 has an ODP of 0.05 compared to that of CFC-12. Alone or in a blend, it can be used in both medium- and low-temperature systems, as found in cold storage or retail food applications, as a replacement for CFC-12 and CFC-502. In certain applications, system redesign and compressor modification will be required to permit HCFC-22 use.

CFC-500 and CFC-502 are two chemical substitutes that can replace CFC-12 use in the short term. CFC-502 is presently used in some retail and cold storage/food processing applications. CFC-502 is an azeotropic mixture composed of HCFC-22 (49 percent) and CFC-115 (51 percent) with an ODP of 0.3. Both CFC-500 and CFC-502 can replace CFC-12 in new equipment for most applications in the industrial sector (UNEP Refrigeration 1989).

### **c. Mobile Air Conditioning**

The most viable candidate to replace CFC-12 in mobile air conditioning is HFC-134a. A non-ozone-depleting chemical<sup>11</sup>, HFC-134a's thermodynamic properties are similar to those of CFC-12. HFC-134a is not a drop-in replacement; system changes are necessary for a successful conversion to this alternate refrigerant.

Many car manufacturers worldwide are preparing to produce cars with HFC-134a air conditioning systems in the near future. Volvo has committed itself to offer HFC-134a-based systems on all models of their cars by the end of the 1994 calendar year. Nissan will install HFC-134a systems on new vehicles beginning in 1993, with all models equipped by the mid-1990s. General Motors will introduce a new air conditioning system dependent on HFC-134a starting in the 1994 model year.

## **2. Foams**

HCFC-123 and HCFC-141b are possible substitutes for some applications presently using CFC-11. Both exhibit physical properties similar to those of CFC-11 (boiling point, vapor thermal conductivity, and heat of vaporization), and both have significantly lower atmospheric lifetimes and lower ozone depletion potentials than CFC-11 (0.13 and 0.69 respectively). HCFC-123 results in a slight decline in thermal performance, somewhat decreased blowing efficiency, and increased solvency (UNEP Foams 1989). HCFC-141b, a

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<sup>11</sup> HFC-134a contains no chlorine and therefore does not deplete ozone.

more efficient blowing agent than CFC-11, is flammable and may require plant modifications to accommodate its use (UNEP Foams 1989).

A blend of HCFC-123 and HCFC-141b is currently being evaluated by two major chemical manufacturers. The HCFC-141b/HCFC-123 blend appears to be one of the most promising future substitutes for insulation and flexible applications. Commercial quantities are expected to be produced by 1993.

In the near term, HCFCs are considered the most viable substitutes for CFCs as blowing agents, provided they are environmentally acceptable. The immediate substitution of currently available HCFCs such as HCFC-142b and HCFC-22 in the polystyrene, polyethylene, and some polyurethane industries can achieve almost one third of total global reductions (UNEP Foams 1989). Blends of CFC-12/HCFC-22, HCFC-22/hydrocarbons, and HCFC-142b/HCFC-22 are also immediately feasible options offering a reduced ODP. In slabstock applications, methylene chloride is also immediately available to replace CFC-11.

Alone or in combination with HCFC-22, HCFC-142b is a blowing agent/insulation gas alternative to CFC-12. With an ODP of 0.06 and proven low toxicity, HCFC-142b differs little from CFC-12 with respect to permeability and product quality. HCFC-142b is commercially produced in North America, Europe, and Japan, and capacity is expected to meet global demand by 1990-91 (UNEP Foams 1989).

HCFC-22 can be substituted for CFC-12 in the manufacture of some extruded polystyrene products. HCFC-22 has a far lower ODP than CFC-12, is non-flammable, low in toxicity, and has high chemical and thermal stability. In most applications, the quality of products made using HCFC-22 is acceptable and comparable to that of products using CFC-12 (UNEP Foams 1989).

The use of CFC-11 and CFC-12 for food service foam products can be reduced or eliminated by switching to HCFC-22 as an alternative blowing agent. The American

Foodservice and Packaging Institute (FPI) has published the technical details of the food packaging plant conversions and they are available for distribution worldwide (FPI 1988).

Another option that foam manufacturers have explored is the use of hydrocarbons such as n-pentane, butane, isopentane and isobutane for polystyrene foam applications. These hydrocarbons are readily available petroleum byproducts that can be used alone or in combination with carbon dioxide or HCFC-22.

In slabstock production, the substitution of methylene chloride for CFC-11 is a technically feasible and commercially available immediate option. Methylene chloride has a very short atmospheric lifetime and a negligible ODP. Methylene chloride can technically eliminate 80 to 100 percent of CFC-11 usage in slabstock production (UNEP Foams 1989). Its toxicity and the associated precautions for industrial use should be considered when evaluating its potential as a substitute for CFC-11 in foam applications.

### **3. Aerosols**

CFCs used as aerosol propellants accounted for 25.1 percent of total CFC consumption in Egypt (data for 1982). A wide variety of alternative propellants exist for CFCs used in aerosol applications. The suitability of a particular alternative varies with the product to be produced. The optimal choice is a function of matching product requirements with alternative propellant characteristics.

The most common substitutes for CFCs are the flammable hydrocarbons liquified petroleum gas, propane, butane and sometimes n-pentane. A substantial portion of the Egypt aerosol industry has already made the switch from CFC propellants to the more cost-effective hydrocarbon-based technology. Hydrocarbons are flammable and, as such, special filling and storage precautions must be taken. As a result, filling and storage facilities must be equipped with fire-detection equipment, sprinklers, and other related systems in the event of an emergency. Gassing stations should be located in an explosion-tolerant facility well



away from the main building and any populated areas. The station should be fitted with a blow-out wall, grounded equipment, and explosion-proof electrical systems. Other additional requirements, depending on local codes and regulations, could include gas-detection equipment, standard and emergency ventilation at floor level, and explosion-suppression systems.

Dimethyl ether is another flammable alternative propellant. Due to its high water solubility, dimethyl ether is primarily used in those applications where special properties such as water solubility are required. The cost of dimethyl ether is higher than the cost of hydrocarbons, but equal or less than the cost of CFCs. Due to its flammability, capital costs are similar to those for hydrocarbons, except that a more sophisticated explosion-proof electrical system is needed (UNEP Aerosols 1989).

Two other existing flammable alternatives are HCFC-142b and HFC-152a. More costly than CFCs and the other alternatives covered thus far, they are used primarily in instances where the ability to enhance product performance is of greater importance than the price of the propellant used.

The non-flammable alternatives currently available include HCFC-22, blends of HCFC-22/HCFC-142b and HCFC-22/HFC-152a, HCFC-22 and HCFC-123, and compressed gases such as carbon dioxide and nitrogen. These options are currently being evaluated for certain specialty products such as electronic cleaners and mold releases.

In those applications where medium to coarse sprays are acceptable, carbon dioxide and nitrogen with current valve designs can be substituted effectively for CFCs. Compressed gases are used in 7 to 9 percent of aerosols worldwide and may increase their market share as valve and package designs are improved to compensate for the decreasing can pressure during product use (UNEP Aerosols 1989).

#### **4. Solvents**

This section discusses chemical alternatives for CFC solvents used in electronics and metal cleaning. Process modifications, such as aqueous cleaning, are discussed under Section C, Alternatives Technologies.

##### **a. Electronics**

There is no single substitute for the many uses of CFC-113. Every application area, however, has one or more options that can be adopted. Substitute solvents for CFC-113 in electronics industry applications that provide equal or better cleaning performance at equal cost include terpenes (a solvent derived from orange peels), organic and alcohol-based solvents, and HCFC solvent blends.

Hydrocarbon/surfactant-based solvents such as terpene blends are viable alternatives for cleaning rosin flux residue from both wave-soldered and reflow-soldered assemblies (UNEP Solvents 1989). Terpenes are generally isoprene oligomers, but may include derivatives such as alcohols, aldehydes, and esters. Terpenes display a number of characteristics that make them attractive cleaning alternatives. For example, they can be used to clean closely spaced components, which is particularly important for cleaning surface-mount devices; they work well at room or slightly higher temperatures; they are noncorrosive, have low viscosity, and are low foaming; and they remove both polar and non-polar contaminants (U.S. EPA 1990b). The waste solvent or wastewater of the terpene blends must be treated effectively and disposed of properly. From the outset, care should be taken to ensure that both the rinse waters and the surfactant used in the blend are environmentally acceptable.

Organic solvents such as ketones, aromatics, aliphatics (mineral spirits), and alcohols are effective at removing solder fluxes and many polar contaminants (UNEP Solvents 1989).

In general, they are volatile and flammable. Organic solvents are primarily used in small quantities in well-vented areas or under inert atmospheric conditions.

Methyl chloroform and carbon tetrachloride are capable of replacing CFC-113 in certain cleaning applications. Methyl chloroform's ODP is 0.11 and carbon tetrachloride's ODP is 1.11; both are consumed in large quantities worldwide (UNEP Technology 1989).

Five other organic solvents and HCFCs have been proposed as possible CFC-113 substitutes: pentafluoropropanol, isopropanol, HCFC-225ca, HCFC-225cb, and an HCFC-141b/HCFC-123/methanol blend. Preliminary data suggest that these solvents have good cleaning performance. In fact, experiments indicate that isopropanol is about twice as effective as CFC-113 azeotrope blends and distills for longer periods before its effective quality drops. (UNEP Solvents 1989)

Pure CFC-113 and chlorocarbon solvents, when blended with alcohols such as ethanol and methanol, effectively remove fluxes when used properly (UNEP Solvents 1989). A number of CFC-producing companies have developed a variety of solvent blends with significantly reduced CFC-113. These blends, however, are viable options for the near term only, however, because of the high ozone-depletion potential of the CFC-113 in the blends.

One blend that is likely to be available commercially in the next 1-3 years relies on neither CFC-113 nor methyl chloroform. The blend is an azeotrope-like mixture of HCFC-123, HCFC-141b, alcohol (methanol), and stabilizers suitable for use in vapor degreasing operations to clean printed circuit boards. It has an ODP of 0.08 and is capable of cleaning as well as or better than CFC-113.

#### **b. Metal Cleaning**

In metal-cleaning applications, a substantial short-term reduction in the use of CFC-113 is possible by substituting other cleaners. The process modifications related to

these applications, such as aqueous cleaning, are outlined in the alternative technologies section of this report.

For large industrial vapor degreasers, alternative solvent blends include CFC/113 azeotropes and new azeotropic blends of HCFCs and chlorinated solvents. Due to the ozone depletion factors associated with these substitutes, their use is primarily viewed to be short term until non-ozone- depleting alternatives are developed (UNEP Solvents 1989).

For manual cleaning, commercial solvent blends are available. These products are mixtures of aliphatic and aromatic hydrocarbons (naphtha, toluene, xylene) and oxygenated solvents (ketones, esters, and alcohols). Many of these blends are flammable and some have relatively low threshold limit values. In the U.S., industrial use of these volatile organic compounds is discouraged and closely regulated because of their effect on tropospheric ozone formation (smog).

Solvent blends of aliphatic naphtha with perchloroethylene and/or methylene chloride are viable substitutes for CFC-113 in manual or immersion cleaning of heavy soils and greases where hydrocarbon residue from naphtha is not a problem and volatile organic compounds can be controlled (UNEP Solvents 1989).

## **5. Sterilization**

Sterilization of instruments and equipment by hospitals, medical equipment suppliers, and contract sterilization firms plays a vital role in protecting human health.

Ethylene oxide (EO) is currently widely used for gas sterilization of medical equipment and devices. EO is especially useful for sterilizing heat-sensitive products. However EO is toxic, mutagenic, a suspected carcinogen, flammable, and explosive. In order to reduce flammability and explosion risks, EO is diluted with CFC-12 to a mixture of 12 percent EO and 88 percent CFC-12 (by weight). This mixture is commonly known as "12/88". Most industrial and commercial users of "12/88" could switch to pure EO (UNEP Aerosols 1989). Existing

"12/88" sterilization chambers can be used, but extensive retrofitting for safety would be required. Cost savings would be realized, however, because CFC-12 or its potential replacement chemicals would not have to be purchased (UNEP Aerosols 1989). Small- and medium-sized industrial and commercial facilities may find it easier to convert to a mixture of 10 percent EO and 90 percent carbon dioxide. The overall investment costs for a switch to "10/90" would be lower than switching to pure EO, unless existing equipment is unable to operate at the higher pressures required (UNEP Aerosols 1989).

For the future, the most promising alternative is an HCFC-based proprietary blend. This blend can serve as a near drop-in for existing "12/88" equipment and could also be used in "10/90" equipment with minimal changes. Testing of the new blend's performance characteristics have been encouraging.

## **C. Alternative Technologies**

### **1. Refrigeration**

The standard refrigerator/freezer has its evaporator in the freezer where a fan blows air over it. This cools the air below the freezing point of water, which removes moisture from the airstream. The cold, dry air circulates through the freezer and then into the refrigerator, where the absence of moisture dehydrates the vegetables and other foods. The Lorenz cycle, first proposed by an East German scientist in 1975, would use a (non-azeotropic refrigerant mixture (NARM) and have two evaporators (one in the refrigerator, one in the freezer). Each compartment would be designed to chill to the correct temperature and to maintain humidity in the refrigeration section. This process could reduce electricity consumption by 20-23 percent, and provide a "vegetable friendly" refrigerator section (Hoffman and Kwartin 1990).

Other possible design technologies include machines with totally independent refrigerator and freezer loops and two-loop, two-compressor configurations with one compressor motor.

## **2. Foams**

The foaming agents proposed as replacements for CFC-11 are likely to produce slightly poorer foam insulation properties. To compensate, refrigerator walls could be thickened to increase insulation. One process change that the polyurethane industry can implement to achieve immediate CFC reductions is to increase the substitution of water for CFC-11. Water reacts with isocyanate to generate carbon dioxide as a blowing agent. The actual amount of water substituted in the process will depend on the initial energy performance of the foam, the isocyanate base used to manufacture the foam, and on physical property requirements (UNEP Technology 1989). Increased water substitution has been adopted in Japan, the United States, and Western Europe. To partially offset the effect of the changed gas composition due to the increased use of water, some manufacturers have reduced cell size. The result is a reduction in thermal conductivity from heat transfer (UNEP Foams 1989). Other changes that compensate for the increased substitution of water for CFC-11 include modifications to pumps, pipes, filters and mixing head equipment.

The AB process reduces the need for inert blowing agents such as CFC-11. Based on using the reaction of formic acid with an isocyanate in addition to the water/isocyanate reaction normally used to generate gas for the expansion of foam, the AB Process doubles the quantity of gas generated (UNEP Foams 1989). The foams produced by this process are softer than all water-blown foams. Capital investment in process equipment, protective equipment for the workers, environmental controls, and increased ventilation might be necessary depending upon the existing facilities (UNEP Foams 1989). Providing protective

equipment and improved ventilation is especially important since carbon monoxide is emitted as a result of the AB Process.

An insulation technology currently under development as a long-term option is a total carbon-dioxide-blown foam used in combination with vacuum panels. Extensive research is still needed to determine the overall commercial potential for this technology. This technology could eliminate CFCs from polyurethane foam insulation and potentially provide significant increases in energy efficiency.

Another alternative that should be considered is new polyol technology. Using new polyol technology in combination with new chemical systems can produce an expanded range of grades of polyurethane foam with reduced CFC-11 use (UNEP Foams 1989). Polyols have been targeted to significantly reduce or eliminate the need for CFCs and other auxiliary blowing agents for higher-density foams. New polyols can be used with existing foam machinery. Conventional formulations relying on auxiliary blowing agents will still have to be relied upon for lower-density foams.

A different approach that may work is vacuum insulation. Vacuum insulation has far superior insulating properties even compared with CFC-11 foam, but manufacturers have not yet perfected a technique for making vacuum panels that will last for 30 years. One European manufacturer produces a commercially-available vacuum insulation that, if durable enough to last the full life of a refrigerator, could reduce electricity consumption.

### **3. Solvents**

#### **a. Electronics**

There are a number of alternative cleaning processes available for the electronics industry. It is important, however, that customer requirements are closely examined before implementing any alternative technology.

Water is an excellent solvent for removing ionic contaminants and water-soluble fluxes. Water, in combination with a saponifier, can remove non-polar substances such as oil and rosin fluxes. Aqueous cleaning systems generally consist of a washing, rinsing, and a drying stage. Aqueous cleaning is most effective when combined with high-pressure and/or high-volume sprays normally used in batch cleaners and in-line conveyors. Aqueous cleaning offers several potential advantages: it can be used to remove water-soluble fluxes, and, in conjunction with saponifiers, rosin fluxes; it is suitable for cleaning through-hole and surface-mount assemblies; no distillation equipment is required to recycle the solvent; there are no costs to dispose of spent solvents; and pretreatment costs can be reduced if water treatment (e.g., distillation, reverse osmosis, heating, etc.) is not required (U.S. EPA 1990b).

Most newly designed aqueous cleaning systems are based on a closed-loop recirculating wash and rinse stage, as opposed to a continuous discharge system. The wash- and rinsewater is continuously used for weeks or months without being discharged. This reduces the amount of wastewater being used, therefore reducing energy and disposal costs. "Zero-discharge" aqueous cleaning equipment, closed-loop recycling systems that minimize the discharge of process water, is available for systems that use water-soluble fluxes. Such systems reduce water, energy, and disposal costs significantly (UNEP Solvents 1989).

Digital Equipment Corporation recently announced the development of a new technology to clean sophisticated printed circuit boards used in electronic products. Digital will allow manufacturers worldwide to use this technology free of charge as part of its corporate commitment to protect the ozone layer. Digital's Microdroplet Aqueous Module Cleaning Process is different from other aqueous-based cleaning systems in the industry. The key process parameters identified are related to water droplet size and angle of impingement of the water for effectively cleaning rigid leaded surface-mount components.



An alternative to cleaning is the low-solids flux/"no clean" assembly. By carefully evaluating and selecting components and assembly processes, low-solids fluxes can be used to eliminate cleaning in some instances. Traditionally, the electronics industry has used, and is still using, rosin fluxes containing between 15 to 35 percent solids content for wave soldering electronics assemblies (through-hole, single-sided, and double-sided printed circuit boards) (U.S. EPA 1990b). Numerous low-solids fluxes containing 1 to 10 percent rosin (or resin, or both) have been formulated and tested. The advantages of the low-solids fluxes include the possibility that "bed of nails" testing on printed circuit board assemblies can be carried out immediately after wave soldering without the problems created by the presence of rosin residues and without defluxing (U.S. EPA 1990b). Depending on the solder mask or resist and the low-solids flux used, little or no visible residue remains on the boards after soldering. The remaining residues, if any, dry and rapidly harden. Automatic testing can be done without cleaning the boards. Because low-solids fluxes are generally considered non-corrosive and have high insulation resistance, it is unnecessary to remove them, in most cases, even for cosmetic reasons. Commercial spray fluxes are now available in foam, wave, and spray application. Wave application of low-solids flux presents minimal cost and retrofit difficulties (UNEP Solvents 1989). As these processes all utilize low-solids fluxes diluted with isopropanol, adequate ventilation and fire-suppression systems must be considered.

A new soldering process, controlled atmosphere wave soldering, operates under a nitrogen atmosphere and applies finely divided activators via ultrasonic injection. The carboxylic acid activators include formic acid, acetic acid, citric acid, and adipic acid. Other processes being developed function on the same principle, except that soldering is carried out in vacuum instead of in a nitrogen atmosphere.

The particular features that make this process preferable to the method of soldering under atmospheric conditions (i.e., in the presence of oxygen) are that soldering takes place

with metallically pure solder; oxide formation is greatly reduced on the printed circuit boards both before and after soldering; the system operates without conventional rosin or resin fluxes; and it eliminates for many applications the post-cleaning required for assemblies that are wave soldered on existing equipment that uses conventional fluxes (U.S. EPA 1990b).

Inert gas wave soldering has been tested by a large West German electronics manufacturer with numerous conventional wave soldering systems in operation. Preliminary test results show no significant differences in the quality of solder joints (UNEP Solvents 1990). Boards tested by a large telecommunications company after inert gas wave soldering found better solderability (Brox 1989). These preliminary tests showed an order-of-magnitude decrease in solder defects. In addition, several European and North American companies will soon be using the inert gas process to wave solder both through-hole and surface-mounted assemblies. Results are preliminary and tests are underway to further quantify the process.

Equipment specifically designed for terpene cleaning is necessary because of material compatibility, combustibility, and odor concerns associated with terpenes (UNEP Solvents 1989). Because of the low closed-cup flash point (47°C) and potential room temperature flammability associated with spray mist, cleaning machines using terpene solvents must be purged with inert gas such as nitrogen to be safely operated. A final point to consider is that terpenes are considered volatile organic compounds (VOCs), which contribute to tropospheric smog. Therefore, adequate containment of terpene mist and vapors should be provided to control odor and minimize material losses.

Machines designed for the use of flammable solvents are commercially available; the range of equipment includes cold solvent cleaners with brush option, hot solvent cleaners with ultrasonic option, vapor-phase batch cleaners with ultrasonic option, and in-line continuous cleaners with spray and ultrasonic options (U.S. EPA 1990b). Ancillary equipment for solvent recycling is also available.

A large European electronics manufacturer currently operates a modified conveyORIZED in-line alcohol cleaner. The machine cleans both through-hole and surface-mounted assemblies. The equipment has an on-line still for recycling and the system is explosion proof. For a production rate of 100,000 printed circuit boards per year, consumption of isopropanol is reduced to one-half that of CFC-113, and costs of solvents are reduced by 10 percent (UNEP Solvents 1989).

#### **b. Metal Cleaning**

A number of alternative cleaning processes are also currently available for metal-cleaning applications. Aqueous cleaning processes include ultrasonic cleaning, immersion cleaning, and spray cleaning. Common active ingredients in aqueous cleaning chemical formulations include alkyl benzene sulphonates and other anionic surfactants. Corrosion inhibitors have been added to minimize the effect of the cleaners on the metal surface. Hundreds of aqueous cleaning formulations are commercially available and have been used successfully in blends and pilot-scale testing for numerous metal-cleaning applications by the aerospace industry. The equipment differs in design features and in the optimal equipment included. Options include solution heaters, dryers, automated parts handling equipment, solution filtration, and solution recycle and treatment equipment (U.S. EPA 1990b).

Ultrasonic cleaning effectively cleans intricate parts and contaminants that are difficult to remove, such as carbon and buffing compounds. Ultrasonic machines can clean numerous types and sizes of parts, from small metal components to large fabricated metal parts. The electrical power requirements for tanks of several thousand gallon capacity or more become prohibitively expensive (UNEP Solvents 1989). Ultrasonic equipment tends to be expensive because of the machinery used. It also uses more electricity than agitation immersion cleaners of similar size. Aqueous ultrasonic cleaning equipment can be configured with other

cleaning stages featuring parts and/or fluid agitation, or may be used as a step in a spray machine.

Aqueous immersion cleaning generally combines the cleaning action of a water-based solution with mechanical cleaning action. Immersion cleaning consists of four major steps: cleaning, rinsing, drying, and wastewater treatment. The simplest aqueous immersion cleaning machine configuration consists of a single wash tank. However, the demands of most cleaning jobs will require more complex configurations.

Spray cleaning equipment washes the parts by spraying them with an aqueous cleaner. Depending on the resilience of the surface to be cleaned, high-velocity sprays can be used to physically displace soils. Spray washers are of three general types: batch, conveyor, and rotary. While the mechanical action of spray cleaning equipment is spray action, custom spray machines can combine spray action with the mechanical action used in immersion equipment.

Batch spray equipment consists of a tank to hold the cleaning solution and a spray chamber with a door. These machines can be used for maintenance or manufacturing applications, but generally do not clean as thoroughly as multiple-stage machines.

Conveyorized spray cleaning equipment consists of a tank to hold the cleaning solution, a spray chamber, and a conveyor to feed the parts. Conveyorized equipment is usually used in manufacturing applications with high throughput requirements where parts have flat, even, controlled surfaces. The advantages of this process are high throughput, automated parts handling, the ability to clean all sizes of parts from a variety of industries, and a reduction in the amount of wash- and rinsewater required. Rotary equipment, similar to conveyorized equipment except for the manner in which parts are handled, is also available.

Metal-cleaning applications can also employ no-clean alternatives. A number of companies are beginning to market water-soluble and emulsifiable machining and metal-

forming lubricants, some of which are non-chlorinated. Emulsion cleaning is an effective cleaning method for metal parts using techniques such as ultrasonics or fluid circulation. In emulsion cleaning, a water-immiscible solvent is dispersed in the form of tiny droplets in the water phase using surfactants and emulsifiers. Emulsified solvents have a low vapor pressure, low evaporative loss, low flammability and flashpoint, and potentially lower solvent purchase cost than CFC-113 (UNEP Solvents 1989). One promising group of emulsion cleaners are terpenes.

Other products that offer the potential for eliminating the need for degreasing are "dry" lubricants and thin polymer sheeting that can be peeled away after the metal-forming process.

#### **4. Sterilization**

For non heat-sensitive products, steam sterilization is widely used both in hospitals and by manufacturers because it is non-toxic, economical, safe, and well accepted. Greater use of outside contractors who utilize steam sterilization can lead to further reductions in CFC use in this sector (UNEP Aerosols 1989).

Off-site, centralized facilities can also be equipped to use radiation technology to sterilize. Radiation facilities tend to be costly to build and operate, but in some instances the cost to convert medical products to be amenable to a radiative sterilization process may be less than the cost to retrofit existing facilities (UNEP Aerosols 1989).

Pre-sterilized, disposable products are another possible alternative to enable hospitals to reduce their dependence on CFC-12.

#### **D. Product Substitutes**

One of the surest methods to eliminate the use of CFCs and other ozone-depleting substances is product substitution. Those sectors in Egypt in which product substitution could occur are foams and aerosols.

##### **1. Foams**

Non-CFC-containing product substitutes currently compete in some subsectors of the foam market, with the possible exception of appliance insulation. Alternative materials are available that provide low-density cushioning (natural and synthetic fiber materials), packaging protection, and insulation value. The availability and viability of product substitutes is highly dependent upon the category of foam and its specific application (UNEP Foams 1989).

Foam insulation has high energy efficiency combined with other physical properties, including excellent fire-test performance, waterproof characteristics, low density, thin profile, and ease of handling. Other insulating products, such as expanded polystyrene bead board, fiberboard and gypsum board, perlite board, fiber glass (mineral fiber), and cellular glass, have some of these properties and have always been available. Non-CFC-containing products offer some of the properties of laminated foams. Alternative materials generally have higher thermal conductivity per unit thickness and will not insulate as efficiently as CFC-blown foam of equal thickness (UNEP Foams 1989). It is necessary to increase the thickness of the alternatives to achieve the same insulating values.

In certain flexible slabstock uses, notably the outer layers of furniture cushions and mattress upholstery backing, fiberfill materials such as polyester batting and natural latex foams are competitive in the market. These materials can replace at least some portion of slabstock use, particularly the supersoft foams. Other products such as paper, cardboard, and expanded polystyrene can be used in many packaging applications.

A possible future replacement for polyurethane foams used as insulation in the appliance industry involves the concept of combining 100 percent carbon-dioxide-blown foam with advanced insulation, such as the highly energy-efficient vacuum panels (UNEP Foams 1989). The successful development of vacuum panels could provide substantial energy efficiency gains in appliances. However, considerable research and development is required to determine a cost-effective way to commercialize this technology and develop long-term panel reliability.

## **2. Aerosols**

Non-aerosol alternatives can be used to apply or administer products that currently use CFCs. These include other spray dispensers such as finger pumps, trigger pumps, and mechanical pressure dispensers, as well as non-spray applicators such as solid sticks, roll-ons, brushes, powders, and others. In many countries, the switch to non-CFC aerosol products is well underway.

Finger-pump and trigger-pump applicators consist of a bottle and a pump valve attached to the bottle. Pumps normally provide a wet spray. As air is admitted to replace the liquid, oxidation may take place. Trigger pumps are similar in principle to finger pumps, the difference being that they are filled with a trigger mechanism. Pumps are not suitable when a fine spray is desired or where introduction of micro-organisms may have harmful effects.

Filling is performed on a liquid filling line and needs no special machinery. The cost of the package for a pump is highly dependent on the style of the bottle, degree of construction, order quantity, and local supply and economic conditions.

Two-compartment aerosols separate the product and propellant inside the aerosol package by means of piston, an inner bag containing the product, or an expanding bag containing propellant. This device can be used with liquids to provide a propellant-free spray. Although the propellant will eventually be released to the atmosphere, only small quantities

are required, and fluorocarbons, hydrocarbons, or compressed air can be used. The quality of the spray will be similar to that of a pump, except that the spray will be continuous, and the device can be used at any angle and will not permit air ingress (UNEP Aerosols 1989).

Mechanical pressure dispenser systems are also available. These systems provide spray either by manual pressurization of the container or by contraction of an inner bag that was expanded when the product was filled. The spray is continuous and no propellant is used.

Examples of non-spray dispensers are the solid-stick dispenser for deodorant or antiperspirant and the roll-on, ball-type dispenser. These applications are well established in the market. Solid-stick filling equipment is generally three times the investment cost for a CFC aerosol line. Packaging costs vary depending on the sophistication of the package. The use of CFCs in medical products, as explained earlier, is the most difficult to substitute for. However, new powder inhalant administration methods have been developed and are already on the market (UNEP Aerosols 1989).



## **V. COST-EFFECTIVE MEASURES FOR REDUCING CONSUMPTION OF OZONE-DEPLETING SUBSTANCES**

Egypt can reduce consumption of ozone-depleting substances as mandated by the Montreal Protocol by implementing a number of alternative technologies starting in 1999. Contingent on the availability of international funding, Egypt has the option of accelerating its program to achieve these reductions.

Early financing of alternative technologies results in a net reduction in the costs to Egypt of pursuing its CFC reduction program. Two factors explain this reduction in costs: (1) significant immediate reductions can be achieved with cost-effective conservation and recycling technologies; and (2) the amount of CFCs and halons recovered by recycling can be allocated to service existing equipment and for other essential uses. Also, early reductions contribute to a decrease in emissions of ozone-depleting substances, which is important to stabilize chlorine concentrations in the stratosphere and thus protect the ozone layer.

The Egyptian Case Study project team has identified several CFC reduction measures that can be implemented immediately in Egypt<sup>12</sup>. These measures satisfy the following criteria: technologies are commercially available and the measures are cost effective, environmentally sound, energy efficient, and represent viable long-term solutions. These measures and associated capital costs are listed below. Total capital costs if all measures are implemented is around \$4 million. Cost estimates do not incorporate the operating cost savings that would result if these measures are adopted.

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<sup>12</sup> It is important to note that the projects discussed do not represent the complete list of measures that could be taken to achieve long-term reductions.

<b>1. Hold workshop on CFC Free Technologies</b>	<b>\$ 50,000 - \$100,000</b>
<b>2. Demonstrate Recycling of CFC-12 in auto Air Conditioners</b>	<b>\$115,000 - \$130,000</b>
<b>3. Recycle CFC-11 In Chillers</b>	<b>\$ 60,000</b>
<b>4. Substitute Water-Blown Foam for CFC-11-Blown Foam</b>	<b>\$200,000 - \$300,000</b>
<b>5. Reduce CFC-12 Charge in Domestic Refrigerators</b>	<b>\$350,000</b>
<b>6. Substitute Hydrocarbons for CFCs in Aerosols</b>	<b>\$2,000,000</b>
<b>7. Build Ice Plants for Transport of Perishables</b>	<b><u>\$1,200,000</u></b>
<b>TOTAL</b>	<b>\$3,975,000 - \$4,140,000</b>

#### **1. Hold Workshop on Technologies to Reduce and Eliminate CFC Use**

This 2- to 3-day workshop will enable Egyptian industry representatives to discuss alternative technologies with international experts. The workshop will involve a seminar and a demonstration of the alternative technology, including recycling equipment for mobile air conditioners and chillers and alternative aerosol technologies such as compressed air. The experts attending this workshop will be available to discuss with individual industry representatives how each of these technologies might be applied in their own operations.

- Cost: \$50,000 - \$100,000

#### **2. Demonstrate Recycling of CFC-12 In Automotive Air Conditioners**

The objective of this project would be to train Egyptian technicians in how to recycle CFC-12 from automobile air conditioners. Recycling machines could be provided to dealerships and specialized automobile air-conditioner repair shops.

Training	\$35,000 - \$50,000
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20 recycling machines @ \$4000	\$80,000
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- Cost: \$115,000 - \$130,000

### **3. Recycle CFC Refrigerants in Chillers**

High volumes of CFC-11 and CFC-12 are emitted from refrigeration equipment due to improper maintenance practices. Usually a large portion of the refrigerant charge is vented to conduct repair work in particular components of the system (e.g., the compressor, condenser, etc.). Portable CFC-11 recycling units that can be fitted to the refrigeration systems to recover the used refrigerant have recently been marketed.

Portable CFC-11 recycling units are available for \$6,000. This machine is capable of recycling the refrigerant while the chiller is in operation. The system can achieve a 65 percent emissions reduction. Ten authorized servicing firms would be provided, one for each recycling machine. CFC emissions and the associated refrigerant costs would be reduced. The service firms would pay for an annual training program provided by the supplier of the recycling units.

- Cost: 10 recycling machines @ \$6,000 = \$60,000

### **4. Substitute Water-Blown Foam for CFC-11-Blown Foam in Refrigerators**

Refrigerator manufacturers in Europe have substituted water-blown foam for CFC-11-blown foam in refrigerators and freezers, resulting in a 30-50 percent reduction in the use of CFC-11. There are no capital investment costs. For a household refrigerator manufacturing plant in Egypt, engineering and start-up costs could range from \$200,000 to \$300,000. Costs could be higher if there is a reduction in energy efficiency. With 30 percent substitution there is no impact on efficiency; with 50 percent substitution energy efficiency would decrease by

3-5 percent. If the Ideal Company, which accounts for 75 percent of the installed domestic refrigerator capacity, is retrofitted, it is estimated that the retrofit costs would be \$200,000-\$300,000.

#### **5. Reduce CFC-12 Charge in Domestic Refrigerators**

Evaporator and condenser tubing can be decreased in diameter and increased in length without sacrificing the refrigerator's capacity or energy efficiency and using only half the amount of CFC-12 as compared to the amount used presently. Conversion of existing refrigerator manufacturing plants would entail capital investment costs of \$50,000 (mostly engineering) and cost savings associated with the reduced use of CFC-12. There would be a 50 percent reduction in emissions.

- Cost: 7 factories @ \$50,000 = \$350,000.

#### **6. Substitute Hydrocarbons for CFCs in Aerosol Applications**

As mentioned earlier, the United Trading and Agency Corporation (UTAC), in Cairo, is the largest cosmetics aerosol filling and marketing company in Egypt, accounting for an 85 percent share of the cosmetics aerosol market.

At present the company is engaged in a major expansion of its facilities. Facilities are presently located in a suburb of Cairo, but the company will move to an industrial area about 45 kms from Cairo. The new facility has a capacity of 15 million units as compared to the existing capacity of 6 million units and is likely to be ready by September 10, 1990. This expansion and relocation will enable the company to eliminate the risks associated at present in manufacturing aerosol products in a predominantly residential area.

The company is also a major exporter of cosmetics aerosols. The main export market is the Soviet Union, which imports 50 percent of aerosols and 70 percent of cosmetics products

manufactured by the UTAC. The Soviet importers have informed the company that they will not accept any aerosol products that contain CFCs beginning in January 1991. The company, therefore, has been advised by its licensors to switch to hydrocarbons. To construct a safe hydrocarbon filling facility will require a significant investment in a tank farm and a gassing room in addition to an enhanced ventilation system in the storage area.

- Cost: on the order of \$2 million

#### **7. Build Ice Plants So That Perishables Can Be Transported Across Egypt**

One of the reasons for the use of refrigerated trucks, and therefore the use of CFCs, is to transport perishables such as fish and vegetables to different markets in Egypt. Instead of CFCs, ice slabs and crushed ice could be used to keep perishables refrigerated. Ice plants could be set up in different parts of the country to make ice easily available. The EEAA suggests plants could be located in Alexandria, Domiat (at the harbor near Port Said), Port Said, Suez, Fayyum (Lake Qaron), and Sadd el-Ali (Aswan High Dam).

- Cost: Six ice plants @ \$200,000 = \$1,200,000

In addition, the Case Study Project Team is also examining the feasibility of installing in various parts of the country small cold storage units and compact crushed ice manufacturing plants using ammonia as the refrigerant.



## **VI. COSTS OF COMPLYING WITH THE MONTREAL PROTOCOL**

This chapter describes the analytical methods used to estimate the costs to Egypt of reducing consumption of ozone-depleting substances (Section A) and presents the results of this cost study (Section B). Many of the alternative technologies are commercially available and their costs are based on published data. Technologies such as CFC recycling systems reduce CFC loss during servicing of mobile air conditioners and commercial refrigeration equipment. The costs are less certain for the emerging technologies that shall be available in the next two or more years such as the ternary blend for refrigeration applications, HFC-134a for mobile air conditioners, and HCFC-141b/HCFC-123 blend for foam-blowing applications. The costs computed in this analysis, are therefore, a best estimate of the total costs to Egypt of phasing out consumption of ozone-depleting substances.

### **A. Methodology Used to Compute Incremental Costs**

#### **1. Economic Framework**

This section describes the economic framework supporting this study. The analysis focuses on estimating the net costs of phasing out the use of the controlled compounds<sup>13</sup>. An important step in estimating these costs is assessing the costs borne by industries currently consuming the controlled substances.

A detailed description of the underlying economic framework used for this analysis is included in the UNEP Economic Assessment of the Montreal Protocol<sup>14</sup>. Costs are based on the changes in consumer welfare and industry profits (consumer and producer surpluses)

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<sup>13</sup> For the remainder of this discussion, "controlled compounds" refers to the substances used in Egypt that are controlled by the current Montreal Protocol (Group I: CFC-11, CFC-12, CFC-113, CFC-114, and CFC-115; Group II: Halon-1201, Halon-1301, and Halon-2402).

<sup>14</sup> United Nations Environment Programme. Economic Panel Report. Montreal Protocol on Substances that Deplete the Ozone Layer. July 1989. Economic Assessment Panel.

caused by proposed reductions in the availability of the controlled compounds. This approach characterizes the markets that use these compounds and estimates the amount of these compounds that each industry (or end use) would demand as CFC availability is reduced. The costs of alternative technologies that industry adopts in response to increased CFC prices define the derived demand schedules for these compounds. A computerized "Cost Model" was developed to estimate the timing and costs of reductions in the consumption of controlled substances.

## **2. Methodology Used to Evaluate the Adoption of Controls**

This section describes the operation of the Cost Model which simulates timing of the adoption of alternative technologies and estimates the total costs of reducing the use of ozone-depleting compounds.

The operation of the Cost Model requires the following input data:

- **baseline chemical demand:** the estimated ODP-weighted consumption of the controlled CFCs and halons if no controls were imposed;
- **reduction schedule:** the timing and amount of reductions over time (see Exhibit VI-1);
- **distribution of consumption by end use;**
- **market penetration and reduction in consumption of ozone-depleting compounds achieved by each alternative technology; and**
- **cost of each alternative technology.**

Each of these input data sets is discussed below. The baseline chemical demand is a projection of the amount of ozone-depleting compounds (in kilograms) that would be used in Egypt if no controls were imposed. The consumption growth rate of 5.0 percent for the period 1990-2000 and 2.5 percent for the period 2001-2010 were used to compute baseline chemical demand.



The reduction schedule defines the target reduction of chemical consumption with respect to the base year (1996) over the period of analysis. The reduction schedule adopted for this analysis follows the reduction schedule specified in the Montreal Protocol followed by a phase-out by the year 2010. According to the current Montreal Protocol, the reduction schedule for CFCs for a country with less than 0.3 kilograms of consumption per capita is:

- freeze CFC consumption in 1999 at 1996 consumption levels,
- reduce CFC consumption by 20 percent of the 1996 levels by the year 2003; and
- reduce CFC consumption by an additional 30 percent of the 1996 levels by the year 2008.

For the purpose of this analysis, it is assumed that CFC consumption is further reduced by 50 percent of the 1996 levels by the year 2010 (i.e., a phase-out is achieved in year 2010). For halons the Montreal Protocol calls for a freeze of halon consumption in 2003 at 1999 levels. At least a 50 percent reduction in the use of Halon-1211 and Halon-1301 can be achieved at zero net cost by using existing dry and foam chemical alternatives and by eliminating unnecessary emissions from testing, training, and accidental discharges<sup>15</sup>.

The distribution of CFC and halon consumption by end use was shown in Exhibits II-3 and II-4. Refrigeration consumes approximately 38.6 percent of all CFC consumption. Foams is next with 35.8 percent; aerosols, 25.1 percent; and solvents, 0.5 percent. The distribution of CFC consumption by end use is important because it defines the level of reduction that can be achieved by the various industries that use CFCs.

The market penetration and reduction in the consumption of ozone-depleting compounds achieved by each alternative technology determines the level of reduction achievable in a given year. The market penetration rate and reduction is defined for each end use separately and takes into account the following factors:

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<sup>15</sup> The full costs associated with halon reductions are not included in this edition of the report.

- starting date: the year in which a technology is first available for adoption;
- penetration time: the amount of time for a control option to be evaluated by industry and adopted by companies for whom it would be cost-effective;
- use reduction: the amount of CFC use that can be reduced relative to use in the base year by implementing a control;
- applicability to new and/or existing equipment: whether a technology can be applied to both new and existing equipment or only to new equipment; and
- market penetration: the portion of the market that is captured by a control option in a given year.

Exhibit VI-1 presents the data corresponding to the first four factors for each of the control options considered. For example, refrigerant recycling for commercial and industrial refrigeration is simulated to be used in 1999, takes 3 years to reach its maximum market penetration<sup>16</sup>, and is applicable to new and existing equipment using CFCs. Exhibit VI-1 shows the use reduction. For example, if refrigerant recycling is adopted, CFC use is reduced by 50 percent for that portion of the commercial/industrial market that implements this technology. The market penetration for each technology varies over the simulation period. Initially, conservation and recycling technologies are available in the short term and take a large proportion of the market; subsequently, alternative chemicals are adopted as greater reductions are required. To calculate market penetration, a distinction is made between technologies that cannot be applied to existing CFC-using equipment and technologies that can be used in existing CFC-using equipment. For example, before 1996, there is an existing stock of equipment that grows as new CFC-using equipment is purchased every year. Some controls, such as alternative HFC and HCFC refrigerants need new equipment specifically designed for these substitutes, and thus, these options can

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<sup>16</sup> The market here refers to the market for particular end-uses (e.g., commercial/industrial refrigeration, household refrigerators, etc.).

**EXHIBIT VI-1. EXPECTED REDUCTION IN USE OF CFCs AFTER ADOPTION OF CONTROLS**

Compound	End Use	Control	Start Year	Years to Reach Maximum Penetration	Use Reduction	Applicable to New (N) and to New and Existing (N/E)
CFC-11	Industrial/Commercial Refrigeration	HCFC-123 Recycling	2000 1999	4 3	100% 50%	N N/E
	Insulation Foam	HCFC-141b/HCFC-123	2000	3	100%	N
	Flexible Foam	HCFC-141b/HCFC-123	2000	3	100%	N
	Packaging Foam	HCFC-22/HCFC-142b	2000	3	100%	N
	Aerosols	Hydrocarbons/Compressed Gases	2000	3	100%	N
CFC-12	Mobile Air Conditioning	HFC-134a Recycling	2000 2000	4 3	100% 50%	N N/E
	Household Refrigerators	Ternary Blend/HFC-152a Reduce Charge	2000 1999	4 3	100% 50%	N N
	Industrial/Commercial Refrigeration	Ternary Blend Recycling	2000 1999	4 3	100% 50%	N N/E
	Aerosols	Hydrocarbons/Compressed Gases	2000	3	100%	N
CFC-113	Metal and Electronic Cleaning	Aqueous Cleaning Recycling	2000 1999	4 3	100% 60%	N N/E
CFC-114	Industrial/Commercial Refrigeration	HCFC-124 Recycling	2000 1999	4 3	100% 50%	N N/E
	Aerosols	Hydrocarbons/Compressed Gases	2000	3	100%	N

only compete in the "replacement" market. These controls are indicated in Exhibit VI-1 with "N", which denotes applicability to new equipment only<sup>17</sup>.

### **3. Types of Costs Considered**

The costs considered in this analysis include the costs to users of CFCs and halons of reducing consumption of these ozone-depleting chemicals. Users of CFCs are assumed to adopt alternative technologies that may cost more, or less, than it would cost to continue using the CFCs. The costs of each alternative technology considered in this analysis includes the incremental capital and operating costs (including chemical substitutes and energy costs), with respect to a base case and one-time retrofit costs. The base case represents the costs that users would incur if they continued using CFCs. In essence, the analysis accounts for net incremental annualized costs or savings to the users for using alternative non-CFC technologies. The annualized costs are expressed in terms of dollars per kilogram of CFC use avoided by dividing the annualized cost estimate by the number of kilograms of CFC use that are avoided by implementing the control.

The dollar per kilogram costs used for Egypt were derived by adjusting the U.S. costs per kilogram estimates upward.<sup>18</sup> Appendix D presents the dollar per kilogram calculations for the U.S. These estimates have been developed based on information provided by international industry sources and experts on individual technologies.

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<sup>17</sup> To achieve a phase-out without retiring CFC-using equipment prematurely requires that CFCs be available for use after 2010. For example, CFCs would be necessary for servicing and maintaining refrigeration equipment that has long, useful lifetimes. Production of CFCs can be phased out by the year 2010 and consumption of CFCs can occur after 2010 if CFCs are available from continuing recycling or from an accumulated pool of recycled CFCs. Consumption of CFCs will decrease after 2010 as alternative controls that eliminate CFC use penetrate the market as CFC-using equipment retires.

<sup>18</sup> As explained on the next page, two scenarios were used for the cost calculations. The magnitude of the adjustment is stated for each scenario.

It should be noted that producers of the new alternative chemicals (e.g., HCFC-123, HCFC-141b) and manufacturers of alternative technologies in Egypt will also incur costs of plant conversion, retooling, etc. This analysis assumes that these costs are reflected in the prices of the alternative chemicals and technologies paid by users, and thus, the potentially higher costs to producers are reflected in higher costs to users. It must be emphasized that the costs for each technology are estimates of average costs. Actual cost evaluations for individual situations will be based on specific needs and constraints.

#### **4. Discount Rate**

Discounted cash-flow analysis is a standard method of financial analysis used to analyze alternative investment projects with different cash-flow characteristics. This method is used to annualize the costs of alternative technologies based on capital and operating costs. The useful lifetime of typical equipment is the period over which costs are discounted. A discount rate reflecting the opportunity cost of capital is needed to bring future cash flows to comparable present values. Although, the costs of capital vary from country to country, this analysis assumes that a discount rate of 2 percent reflects the "cost of capital"<sup>19</sup>.

The costs of each alternative technology are expressed in terms of dollars per kilogram of CFC avoided, and are computed by dividing the annualized cost estimate for each control by the amount by which CFC use is reduced by implementing the control.

In summary, input data for the model consists of (1) baseline CFC demand (in million kilograms), (2) a series of alternative technologies to reduce CFC use, (3) the level of total reduction achievable by alternative technologies, and (4) the costs per kilogram of CFC reduced by each technology.

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<sup>19</sup> The capital likely to be transferred to Egypt for implementation of the Montreal Protocol will be provided by an international fund made up of contributions by individual countries. The cost of capital assumed here is representative of the social cost of capital in the U.S. This discount rate can be changed to test the sensitivity of results to various discount rates.

## **B. Cost Results**

The costs to Egypt of phasing out CFC consumption are calculated under two scenarios:

- **Scenario 1: Likely Growth Rate - Likely Cost.** CFC use grows at an annual rate of 5.0 percent for the period 1990-2000 and at 2.5 percent for the period 2001-2010 in the absence of Protocol restrictions; the costs of implementing the substitute technologies and using alternative chemicals is 5 percent higher in Egypt compared to the U.S.
- **Scenario 2: Likely Growth Rate - High Cost.** CFC use grows at an annual rate of 5.0 percent for the period 1990-2000 and 2.5 percent for the period 2001-2010 in the absence of Protocol restrictions; the costs of implementing the substitute technologies and using alternative chemicals is 30 percent higher in Egypt compared to the U.S.

The costs of implementing options could be higher in Egypt than in the United States.

Associated costs would include the following:

- transportation costs for imported equipment;
- maintenance and servicing costs for the new technologies;
- incremental infrastructure development costs;
- costs due to exchange rate variations;
- technology transfer costs; and
- costs due to the absence of scale economies.

The estimated costs to Egypt for phasing out the consumption of CFCs are \$30.5 million for Scenario 1 and \$37.8 million for Scenario 2 (U.S. dollars). Exhibit VI-2 presents the distribution of costs by end use for each scenario for the period 1990-2010. Technologies that replace the use of CFCs in foams account for 69.1 percent of the social costs; those replacing CFC use in refrigeration account for 30.8 percent, and those replacing CFC-based solvents, 0.1 percent. (Phasing out aerosol uses of CFCs does not result in any costs to society.) The costs for individual end uses and controls that are part of the phase-out costs are presented in Exhibit VI-2.

**Exhibit VI-2. Costs to Egypt of Phasing Out CFC Consumption**  
(millions of U.S. dollars)

Compound	End Use	Scenario 1		Scenario 2	
		Likely Growth Rate/ Likely Cost (1990-2010)		Likely Growth Rate/ High Cost (1990-2010)	
CFC-11	Aerosols	0.0		0.0	
	Refrigeration	8.75		10.87	
	Foams	<u>21.11</u>		<u>26.07</u>	
	Subtotal		24.86		36.94
CFC-12	Aerosols	0.0		0.0	
	Refrigeration	<u>0.31</u>		<u>0.39</u>	
	Subtotal		0.31		0.39
CFC-113	Solvents	0.03	0.03	0.03	0.03
CFC-114	Aerosols	0.0		0.0	
	Refrigeration	<u>0.32</u>		<u>0.40</u>	
	Subtotal		<u>0.32</u>		<u>0.40</u>
	TOTAL		30.52		37.76

## **1. Foam**

CFC-11 can be replaced with alternative blowing agents composed of a mixture of HCFC-141b and HCFC-123 in insulation and flexible foam applications and HCFC-22 and HCFC-142b in packaging foam applications. The use of these alternative blowing agent mixtures is estimated to cost Egypt between \$21.1 and \$26.07 million for the period 1990-2010.

## **2. Refrigeration**

Reducing CFC-11 use in refrigeration applications will cost Egypt between \$8.75 million and \$10.87 million for the period 1990-2010. This assumes recycling technology is applied to conserve CFC-11 use and HCFC-123 is used for commercial/industrial refrigeration applications. The costs of reducing CFC-12 in refrigeration applications shall cost Egypt between \$0.31 million and \$0.39 million for the period 1990-2010. These costs assume use of recycling technology to conserve CFC-12 use and use of the ternary blend or HFC-152a for household refrigeration applications, and the ternary blend for commercial/industrial refrigeration. The limited amount of CFC-12 used in mobile air conditioning in Egypt is phased out using recycling technology and HFC-134a. Finally, the cost to Egypt of reducing CFC-114 use in refrigeration applications will be between \$0.32 million and \$0.4 million. This estimate is based on using recycling technology to conserve CFC-114 use and using HCFC-124 for commercial/industrial refrigeration applications.

The costs to Egypt of reducing CFC-11 is much greater than the costs of reducing CFC-12 in refrigeration applications, because most of the CFC-12 consumed in Egypt is for household refrigeration applications. Alternative technologies to manufacture household refrigerators using 50 percent of the CFC-12 refrigerant charge and the use of a ternary blend



or HFC-152a instead of CFC-12 result in negligible costs. The costs associated with these alternative technologies are offset by the savings as explained below<sup>20</sup>.

Refrigerant charge can be reduced in a refrigerator through the use of evaporator and condenser tubing that is smaller in diameter and longer, but does not sacrifice refrigeration capacity or energy efficiency. Capital costs to retrofit refrigeration manufacturing lines to accommodate the use of reduced CFC-12 charges are estimated to be \$50,000 for a plant producing 400,000 units. Reducing CFC-12 charge by 50 percent saves \$97,800 (assuming CFC-12 = \$1.63/kg and average quantity of CFC used over lifetime is 0.3 kg). Thus, the operating savings offset capital investment.

The use of a ternary blend of alternative refrigerant (40% HCFC-22, 40% HFC-152a, and 20% HCFC-124) or HFC-152a does not require changes in refrigerator manufacturing equipment to accommodate the compressor and other system components because of similar thermodynamics and chemical compatibility characteristics of the ternary blend and CFC-12. The ternary blend is assumed to cost \$5.60/kg and HFC-152a is assumed to cost \$9.05/kg.. The use of the ternary blend in household refrigeration results in an annual decrease in energy consumption of 3 percent, whereas the use of HFC-152a results in an annual decrease in energy consumption of 7 percent. Energy savings over the useful life of the refrigerator (approximately 20 years) offset the increased costs for the ternary blend or HFC-152a refrigerant.

### **3. Solvents**

Aqueous cleaning is a commercially available technology currently used to replace CFC-113 used for metal and electronics cleaning. This technology replaces the use of CFC-

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<sup>20</sup> A more detailed explanation of these costs is presented in Appendix C.

113 with water and detergent. Aqueous cleaning is assumed to be used in new equipment and costs more than CFC-113 equipment.

The use of engineering controls and better housekeeping practices are feasible alternatives to reduce CFC-113 use and emissions. The costs of the engineering controls are recovered in the first year due to the high solvent recovery rate and, therefore, the use of this technology will result in cost savings. For the purposes of this analysis this technology is considered as a zero-cost option. The costs to Egypt of using aqueous cleaning is estimated at \$0.8 million for the period 1990-2010.

#### **4. Aerosols**

The use of CFC-11, CFC-12, and CFC-114 in aerosol applications in Egypt can be phased out by using liquified petroleum gas (LPG) or compressed gases such as carbon dioxide as propellants. If LPG is the substitute, capital investment will be required for equipment and machinery such as LPG storage tanks, safety equipment, fire-extinguishing equipment, alarm systems, and retrofit of filling lines. If compressed carbon dioxide is used, new propellant storage tanks and retrofitting of existing filling equipment will be required. A number of aerosols manufacturers in Egypt have already successfully switched from CFCs to LPG. Appendix B describes the steps El-Nasr company took to convert to LPG technology, and Appendix C describes the cost borne by Kafr El Zayat, an Egyptian aerosol manufacturer, in making the same conversion. The cost to phase-out CFCs in aerosol applications would be negligible because the costs saving associated with the use of LPG and compressed carbon dioxide would offset the capital investment required to implement these technologies.

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## **APPENDIX A**

**MINISTERIAL DECREE NO. 977/1989  
ISSUED ON 8/11/1989**

### **CONCERNING THE BANNING OF THE USE OF CFCS AS A PROPELLANT IN THE VARIOUS AEROSOL PRODUCTS**

**The Ministry of Industry**

After having reviewed Law No. 2/1957 concerning the standardization authority code of provisions and Law No. 21/1958 concerning the organization of industry and encouraging its establishment, and the President's decree No. 392/1979 concerning the establishment of the General Egyptian Authority for Standardization and Products Quality.

and H.E. the Minister of Cabinet and Administrative Affairs' letter No. 1975 dated 19/8/1989 concerning the banning of use of CFCs as propellants in the various aerosol products,

and the Chairman of the General Authority of Standardization and Products Quality's memorandum dated 8/11/1989 in this concern.

#### **HAS DECIDED**

**Article (1): Industrial concerns shall not be approved to use CFCs as propellants in any of the various aerosol products.**

**Article (2): Industrial concerns currently using CFCs shall be permitted a grace period till the close of December 1990, knowing that the said ban shall be applicable as of January 1, 1991.**

**Article (3): This decree is to be issued in the Egyptian Federal Gazette and shall come into force the day following its publication.**

**Ministry of Industry**

**Engineer/Mohamed Mahmoud Abdel Wahab  
(signed)**

بسم الله الرحمن الرحيم



جمهورية مصر العربية

وزارة الصناعة

مكتب الوزير

قرار وزارى رقم ٩٧٧ لسنة ١٩٨٩

صاد بتاريخ ٨ / ١١ / ٨٩

بشأن حظر استخدام الفريون فى صناعة الايروسولات  
بمختلف أنواعها

وزير الصناعة

بعد الاطلاع على القانون رقم ٢ لسنة ١٩٥٧ فى شأن التوحيد القياسى ،  
وعلى القانون رقم ٢١ لسنة ١٩٥٨ فى شأن تنظيم الصناعة وتشجيعها ،  
وعلى قرار رئيس الجمهورية رقم ٣٩٢ لسنة ١٩٧٩ بتنظيم الهيئة المصرية العامة للتوحيد  
القياسى وجودة الانتاج ،  
وعلى كتاب السيد الاستاذ الدكتور وزير شئون مجلس الوزراء وزير الدولة للتنمية الادارية  
رقم ١٩٧٥ المؤرخ ١٩ / ٨ / ١٩٨٩ بشأن حظر استخدام الفريون فى صناعة  
الايروسولات بمختلف أنواعها ،  
وعلى مذكرة السيد الاستاذ الدكتور رئيس مجلس ادارة الهيئة المصرية العامة للتوحيد  
القياسى وجودة الانتاج المؤرخة ٨ / ١١ / ١٩٨٩ فى هذا الشأن ،

تقرر :

مادة ١ - يحظر على المنشآت الصناعية استخدام الفريون كمادة دافعة فى صناعة الايروسولات  
بمختلف أنواعها .

مادة ٢ - تمنح المنشآت الصناعية المستخدمة لغاز الفريون مهلة حتى نهاية ديسمبر ١٩٩٠  
على ان يعمل بهذا الحظر اعتبارا من أول يناير ١٩٩١ .

مادة ٣ - ينشر هذا القرار فى الوقائع المصرية ، ويعمل به من اليوم التالى لتاريخ نشره .

وزير الصناعة

( مهتمس / محمد محمود عبد الوهاب )

مشاركون

١/١

## **APPENDIX B**

### **EGYPT'S TECHNICAL EXPERIENCE IN CONVERTING A FORMER CFC-PROPELLANT AEROSOL PLANT TO A HYDROCARBON-PROPELLANT PLANT\***

El-Nasr company for intermediate chemicals is one of the main aerosol-producing companies in Egypt. The majority of aerosol products produced are pesticides, but the company also produces personal care products. The company's total capacity is 15 million units per year. Described below are the steps that El-Nasr took to accomplish the conversion from CFC-based production to production based on liquified petroleum gas (LPG).

#### **1. CONVERSION STEPS:**

The following steps were followed to convert the production line for using LPG instead of CFC-11 and CFC-12 as a propellant:

- Production equipment was adapted for using LPG;
- The following items were purchased and/or conducted:
  - LPG storage tanks
  - LPG pumps
  - LPG piping and connections
  - LPG destenching system;
- All electric switchboards, motors, and sensors were made flame proof (EX-type);
- All lighting systems were changed to EX-type;
- Adequate ventilation systems (to prevent LPG gas accumulation) were constructed in the following areas:

---

\* Sayed Meshaal's study entitled "An Optimal Conversion Model for An Aerosols Production Plant Using LPG as Propellant Instead of CFCs," submitted to the U.S. EPA in 1989, was based on El-Nasr's experience.

- Production line area
  - Gassing room
  - Warehouses
  - Product storage area;
- The following warning systems and fire-fighting systems were put in place or enhanced:
    - Sprinkler system
    - Deluge system
    - Alarm system
    - Ventilation;
  - Adequate warehouses and storage areas were constructed or arranged for.

## 2. PREPARATION OF LPG STORAGE AREA:

The storage area was established according to the following considerations:

- The international regulations, requirements, and rule for safe handling, transportation, and storing of LPG;
- The maximum daily off-take required;
- The time taken to process an order and to receive deliveries;
- The requirements for increasing the production capacity in future.

As shown in the attached diagram, the storage area includes the following:

- Crude LPG storage tanks;
- Destenching columns (adsorbers);
- Purified (deodorized) LPG storage tanks;
- Unloading, transfer, and process LPG pumps;
- Deluge-sprinkler underground water basin and its pumps;
- LPG gas and flame detectors; and
- Ex. proof lighting.

### 2.1 Crude LPG Storage Area

Includes three storage tanks manufactured locally, two unloading pumps, and two transfer pumps.



Erection, piping, the different connections, and engineering supervision were done in-house.

Each of the three crude LPG storage tanks have 40,000 liters water capacity. The total crude LPG capacity that can be stored is 67 tons.

All equipment listed above was located under roof. The road tanker vehicle unloading bay was also located under the same roof. The area was surrounded by a fence.

## 2.2 Destenching Columns

Due to the presence of the hazardous hydrocarbon gas, a stenching agent (ethyl mercaptan, sulphur, or dimethyl sulphide) is to be added during the production process in the oil refinery plants.

In order to use the propane/butane mixture as a propellant in aerosols, a destenching (sweetening) process must be done to obtain an acceptable odor and to remove other impurities.

The following table shows a typical analysis of Egyptian liquified petroleum gases (LPG), supplied by Cairo Oil Refinery Co.:

<u>Item</u>	<u>Refinery Spec.</u>	<u>Sample Analysis</u>
Specific gravity at 60°F	-	0.562
Vap. press. psig at 70°F	45/50	47.5
Propane content % L.V.	25 ± 5	28.6
Butane content % L.F.	80 ± 10	70.3
Mercaptan PPM	<10	<10
Hydrogen sulphide PPM	nil	-

This elimination takes place by means of three adsorbers arranged in tandem, of which:

- The 1st column (A) is filled with silica gel (350 kg).
- The 2nd column (B) is filled with activated carbon (about 300 kg).
- The 3rd column (C) is filled with molecular sieves (350 kg of type 13 x 1.6).

The columns (A+B) serve to remove the greater part of water, mercaptans, H<sub>2</sub>S, and Olefins. The third column (C) is used for fine purification of the propane/butane mixture.

The molecular sieves are synthetic alumina silicate crystal powders whose diameters range from 1 to 3 microns. The size and position of the metal ions in the crystal controls the effective diameter that interconnect the millions of tiny cavities in each crystal. This micro (sponge-like) form permits the adsorption of the molecules of sulphur compounds. The purified (de-odorized) LPG contains: 0.0 ppm H<sub>2</sub>S and <0.5 ppm olefins. In this quality, the LPG can be used as a propellant gas for aerosols.

The age of the destenching columns charge depends mainly on the impurities content in the crude propane/butane mixture.

Note:

- The destenching columns were manufactured locally with low costs.
- The charge can serve for purification of about 600 tons LPG (depending on the charges and LPG quality).
- The approximate total cost includes the cost for charge, valves, piping, and two transfer pumps with 80 liter per minute (1/min) capacity.

### **2.3 Deodorized (Purified) LPG Storage Tanks Area**

This area includes the following components:

- Two deodorized LPG storage tanks of 25,000 liter water capacity each;
- Two process LPG pumps of 80 l/min capacity each, at  $\Delta p$  10 bar;
- Steel structure roof with dimensions of 16 x 12 x 6 m;
- Deluge-sprinkler nozzles and piping;
- LPG detectors (LEL 20% - 40%);
- Flame detectors; and
- Ex. proof lighting.

## **3. PRODUCT PREPARATION**

As indicated in the diagram, the product preparation zone includes the following items:

- Bulk storage tanks for petroleum solvent (kerosene);
- Pumps needed for unloading and transfer of solvents and product;
- Mixing laboratory; and
- Product storage tanks.

Since these petroleum solvents are flammable, all precautions for safe handling, transferring, and storing (similar to LPG) have been carried out.

#### **4. FIRE-FIGHTING SYSTEM**

To reduce the risk of ignition, the following guidelines should be observed:

- Ensure all electrical equipment is flame proof.
- Avoid using uncovered light bulbs and causing sparks, which can be fire hazards.
- Ensure that there is adequate ventilation.
- Adopt good safety and checking procedures for leakage or accumulation of ignitable mixtures.
- Ensure all equipment is adequately bonded and checked regularly to prevent accumulation of electro-static charges and occurrence of electrical charges.

The latest fire-fighting system has been introduced into the plant to minimize the risk of ignition, thereby guaranteeing maximum safety. The system includes:

- Ventilators (2-speed);
- Deluge system; and
- Sensors and a command switchboard.

The plant is divided into hazardous areas, depending on the level of hazard presented:

- LPG storage area.
- Gassing room.
- Production line area.
- Product storage area.
- Two warehouses (1 and 2).

##### **4.1 The Sensors and Command Switchboard**

The system includes the following components:

- Fire detectors;
- Low pressure-temperature sensors;
- High pressure-temperature sensors;
- Gas detectors:

- >20% LEL
- >40% LEL; and

- Two switchboards

#### 4.2 The Functioning of the System

The system performs the following function in case of emergency:

- Shuts down the production line;
- Shuts down the LPG pumps;
- Opens the deluge valves;
- Starts the deluge pumps;
- Starts the sprinkler system;.
- Increases the speed of the ventilators; and
- Sounds alarm.

Some or all of the above will occur, depending on the type of emergency.

#### 4.3 Ventilators

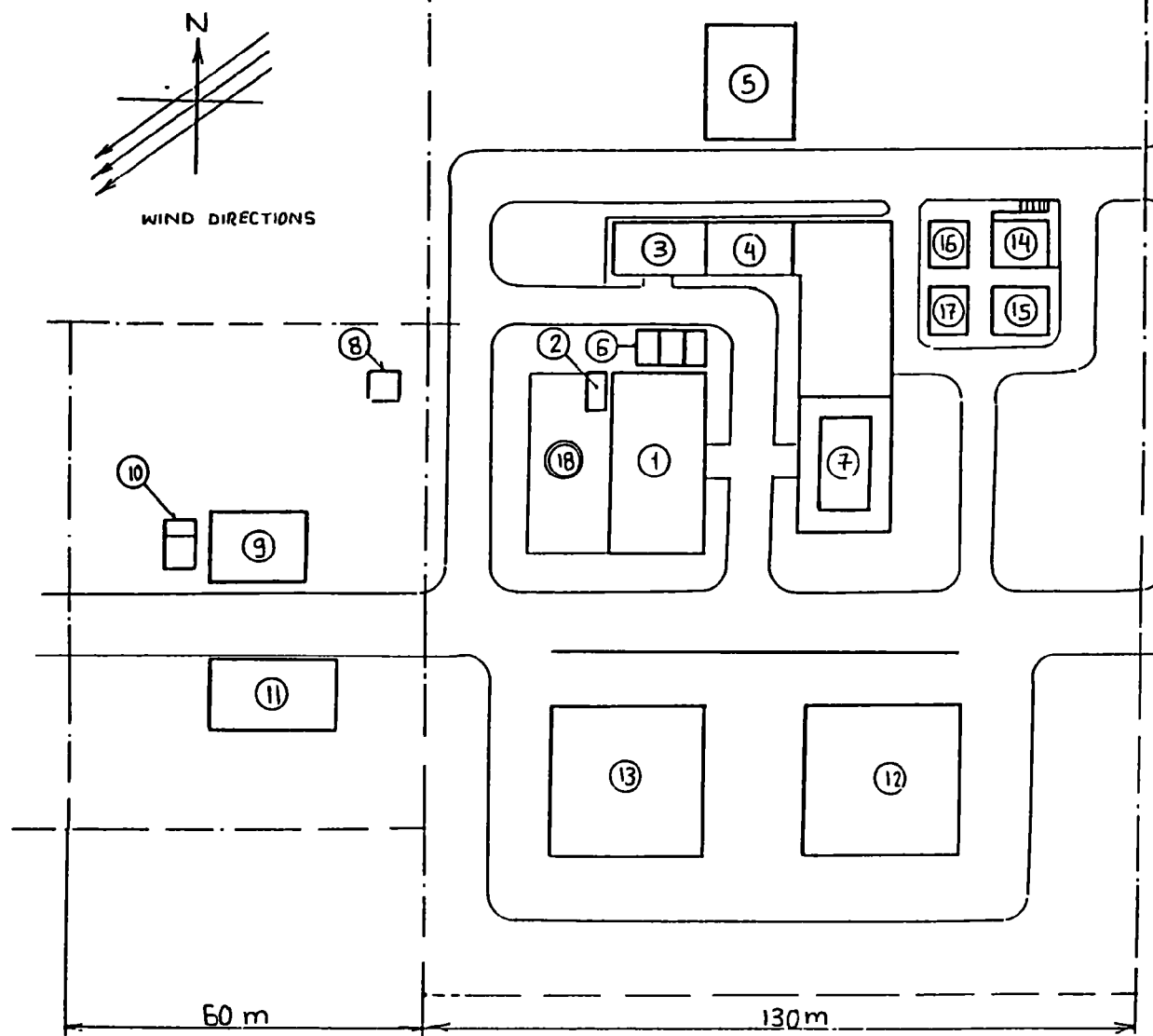
The system includes the following ventilators with the following characteristics:

<u>Area</u>	<u>No. of Fans</u>	<u>Characteristics</u>
Gassing room	1	9,000/18,000 m <sup>3</sup> /h
Production line room	2	7,500/5,000 m <sup>3</sup> /h
Product storage	2	6,000/12,000 m <sup>3</sup> /h
Warehouse No. 1	2	6,000/12,000 m <sup>3</sup> /h
Warehouse No. 2	2	6,000/12,000 m <sup>3</sup> /h

#### 4.4 Deluge and Sprinkler Systems

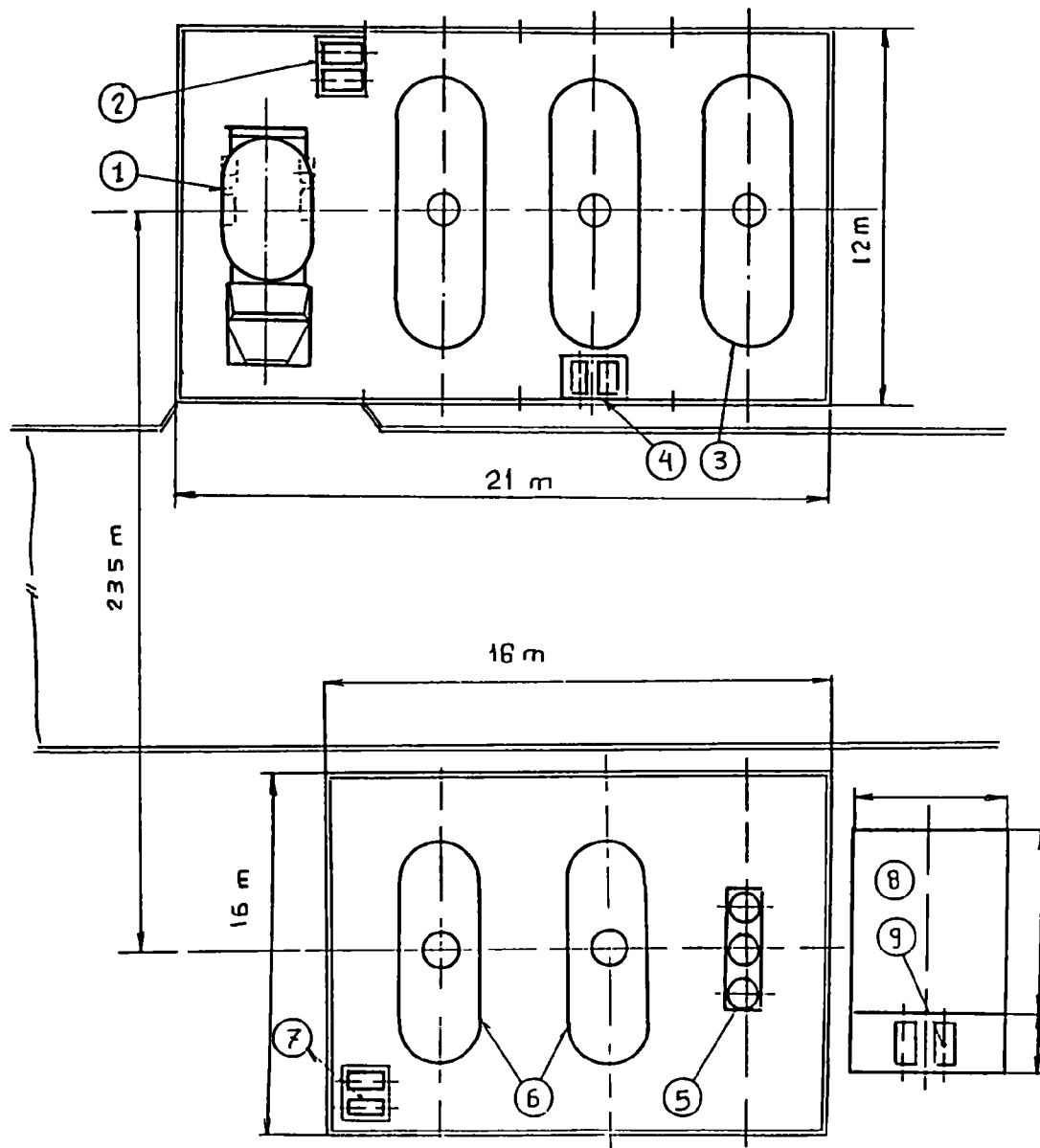
This system has the following components:

- Deluge pump, 350 m<sup>3</sup>/hr (90-100 kw);
- Sprinkler pump, 150 m<sup>3</sup>/hr (35-40 kw);
- Deluge valves; and
- Nozzles and piping.

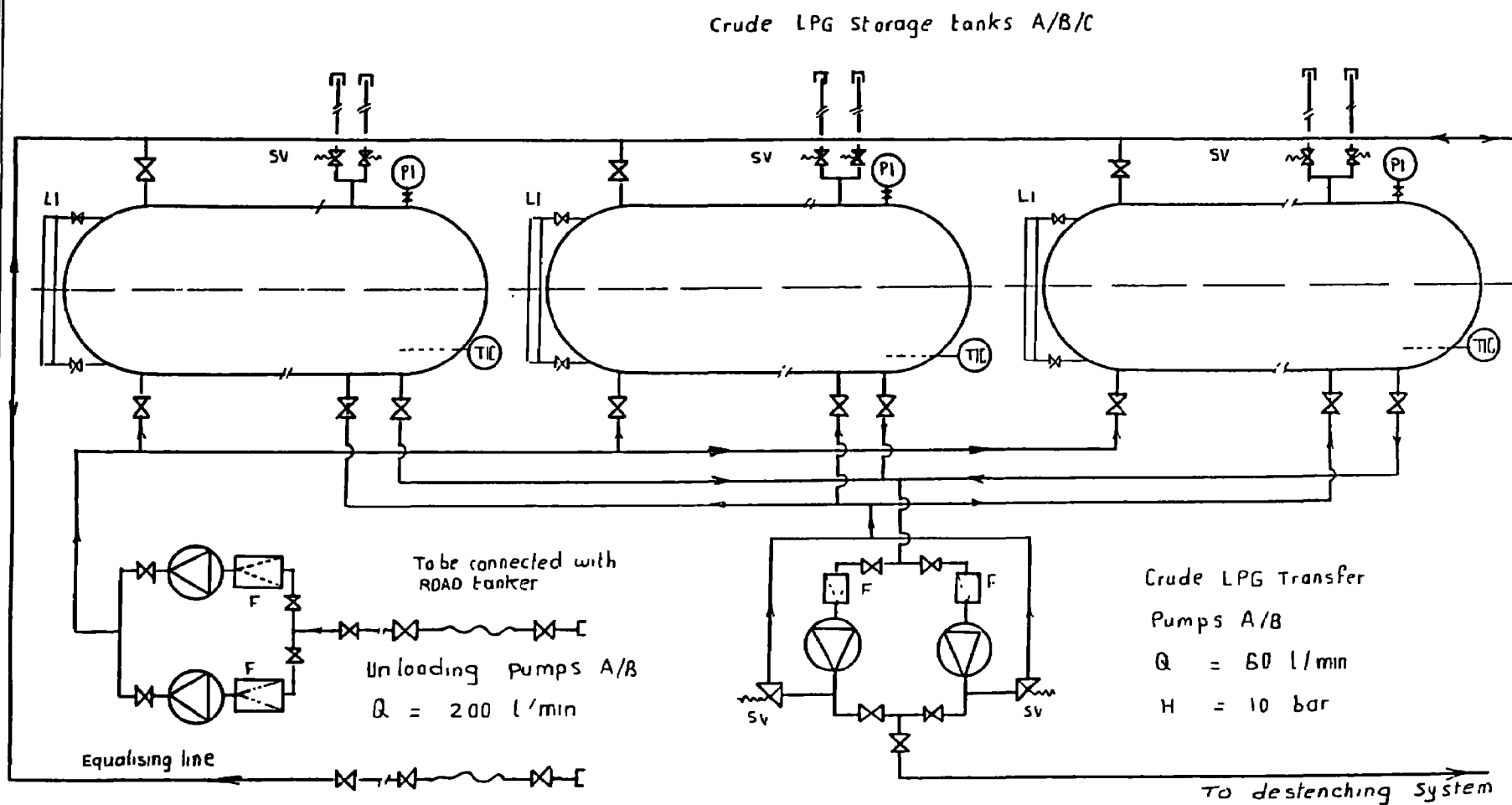


18	Drainage pit
17	Air Compressors room
16	Cooling water towers
15	Workshop
14	Elect transformers room
13	Warehouse
12	Warehouse
11	Crude LPG storage area
10	Deluge water pit + pumps
9	Deodor LPG storage area
8	Electric Room
7	Raw materials store
6	Management + Quality cont
5	Kerosine storage area
4	Product + solvent storage
3	Product prep Lab
2	Gas Filling room
1	Production line room

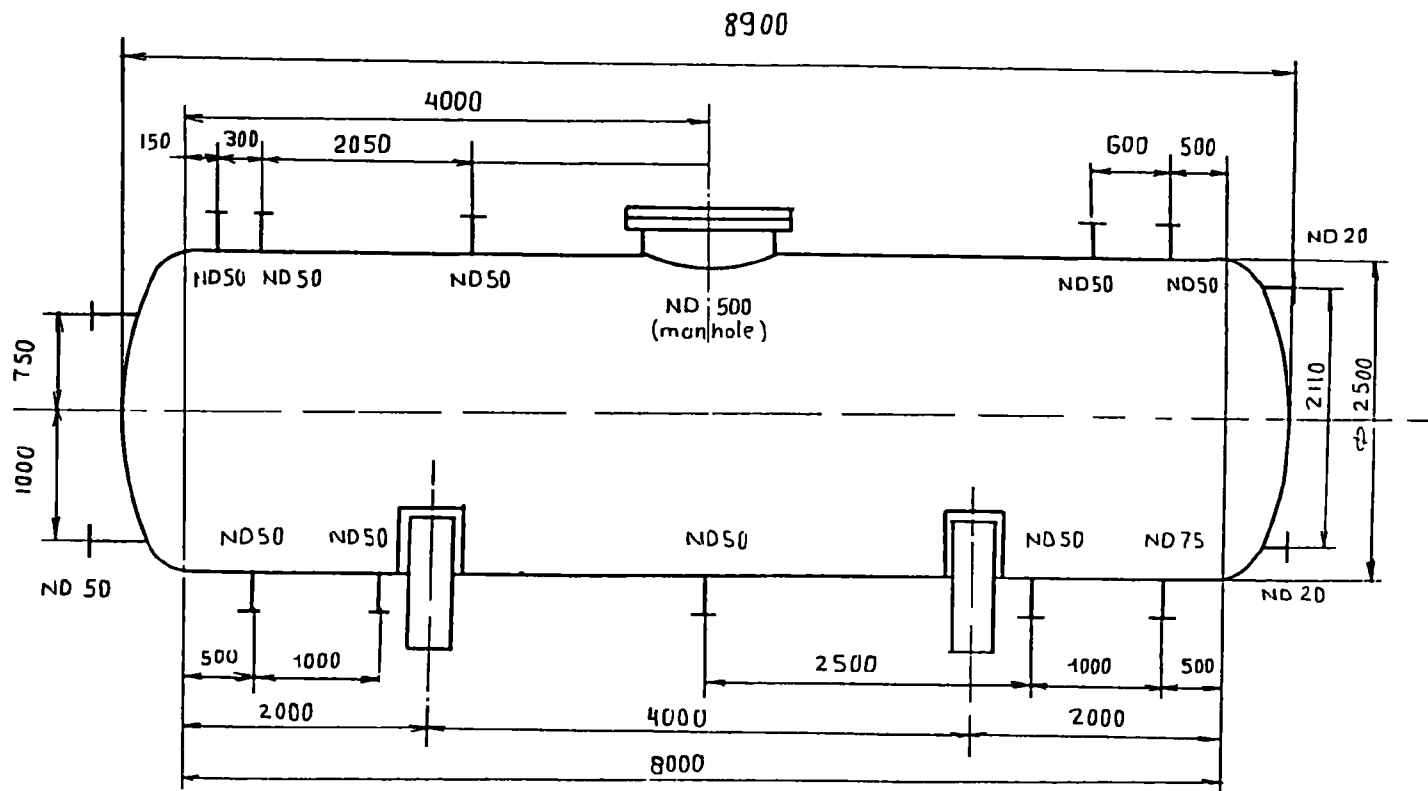
NO OF	ITEM DESCRIPTION
NCIC AEROSOL PLANT LAYOUT	
SCALE	1:1000



9	2	Deluge water pumps (350 m <sup>3</sup> /h)
8	1	Deluge water pit
7	2	LPG Process pumps (80 l/min)
6	2	De odorised LPG storage tanks
5	1	De stenching system
4	2	Crude LPG Trans Pump (60 l/min)
3	3	Crude LPG storage Tanks
2	2	LPG Unloading Pump (200 l/min)
1		LPG Road Tanker
NO	QUN	ITEM DESCRIPTION
NCIC AEROSOL PLANT		BULK STORAGE OF LPG AREA LAYOUT
		SCALE 1:200

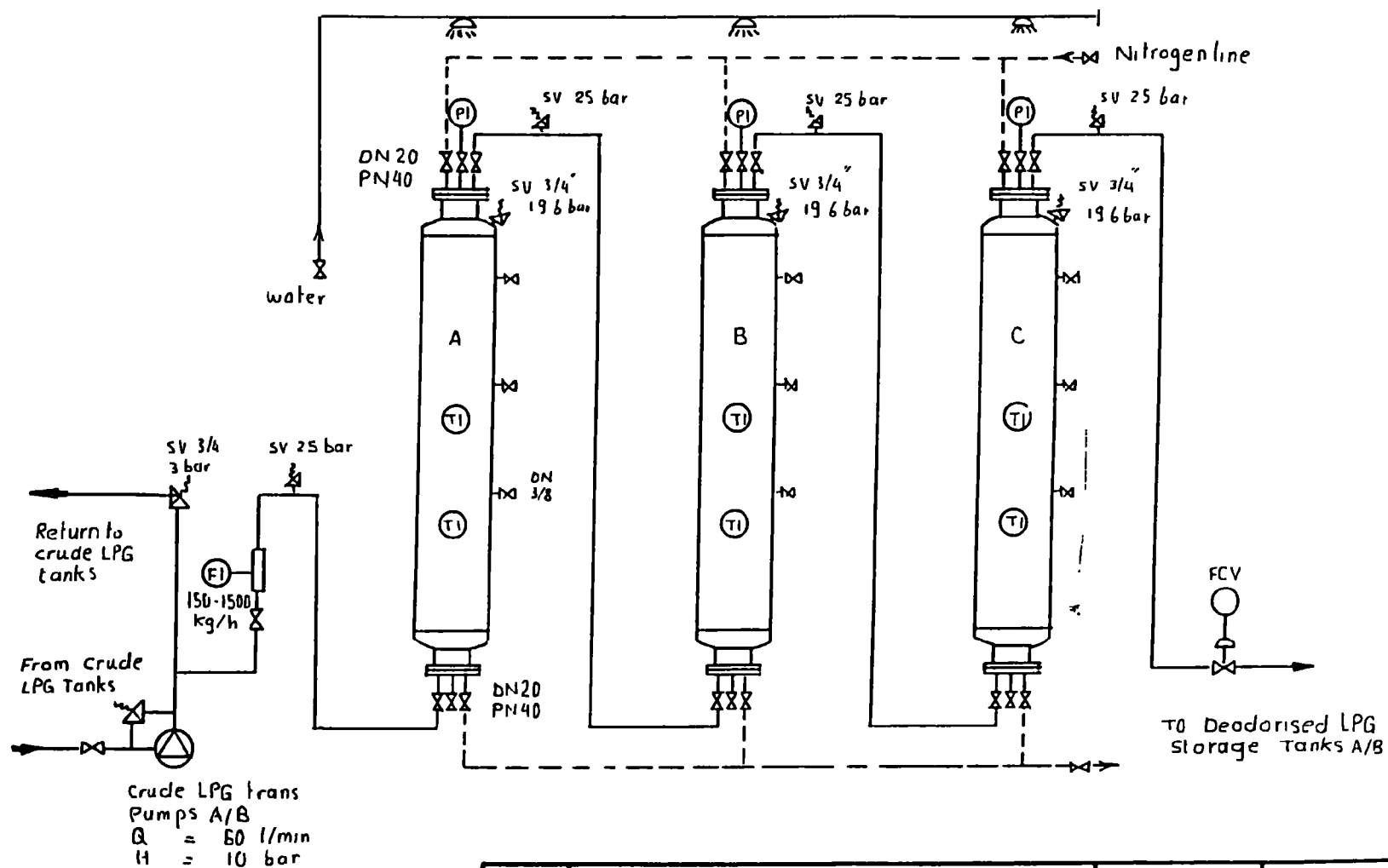


NCIC AEROSOL PLANT	Crude LPG Storage Station	P&I Diagram	
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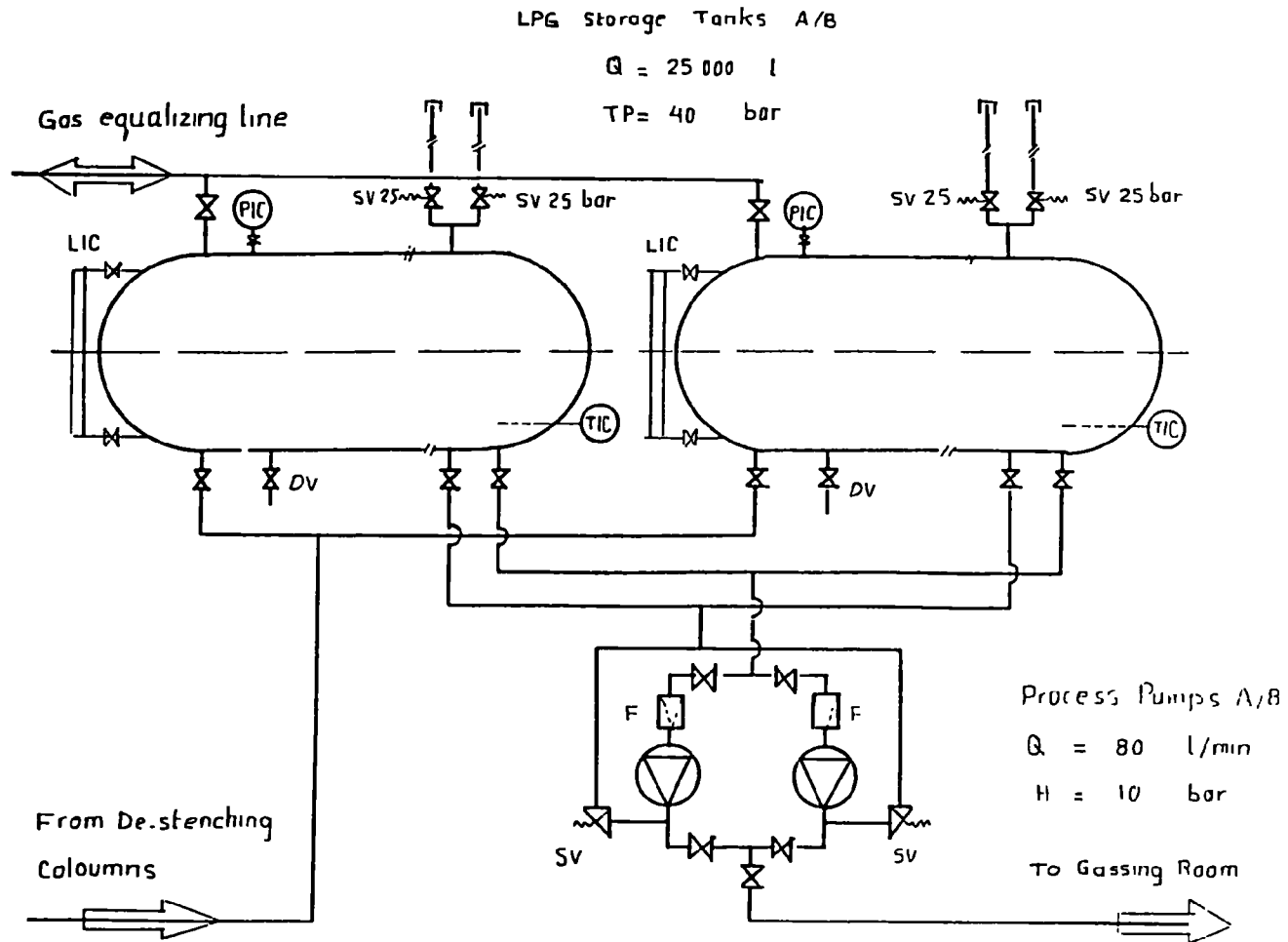


NCIC AEROSOL PLANT	Detail drawing for Crude LPG Storage Tanks A/B/C TP = 40 bar    Q = 40.000 l    Material = H II	SCALE 1 : 50
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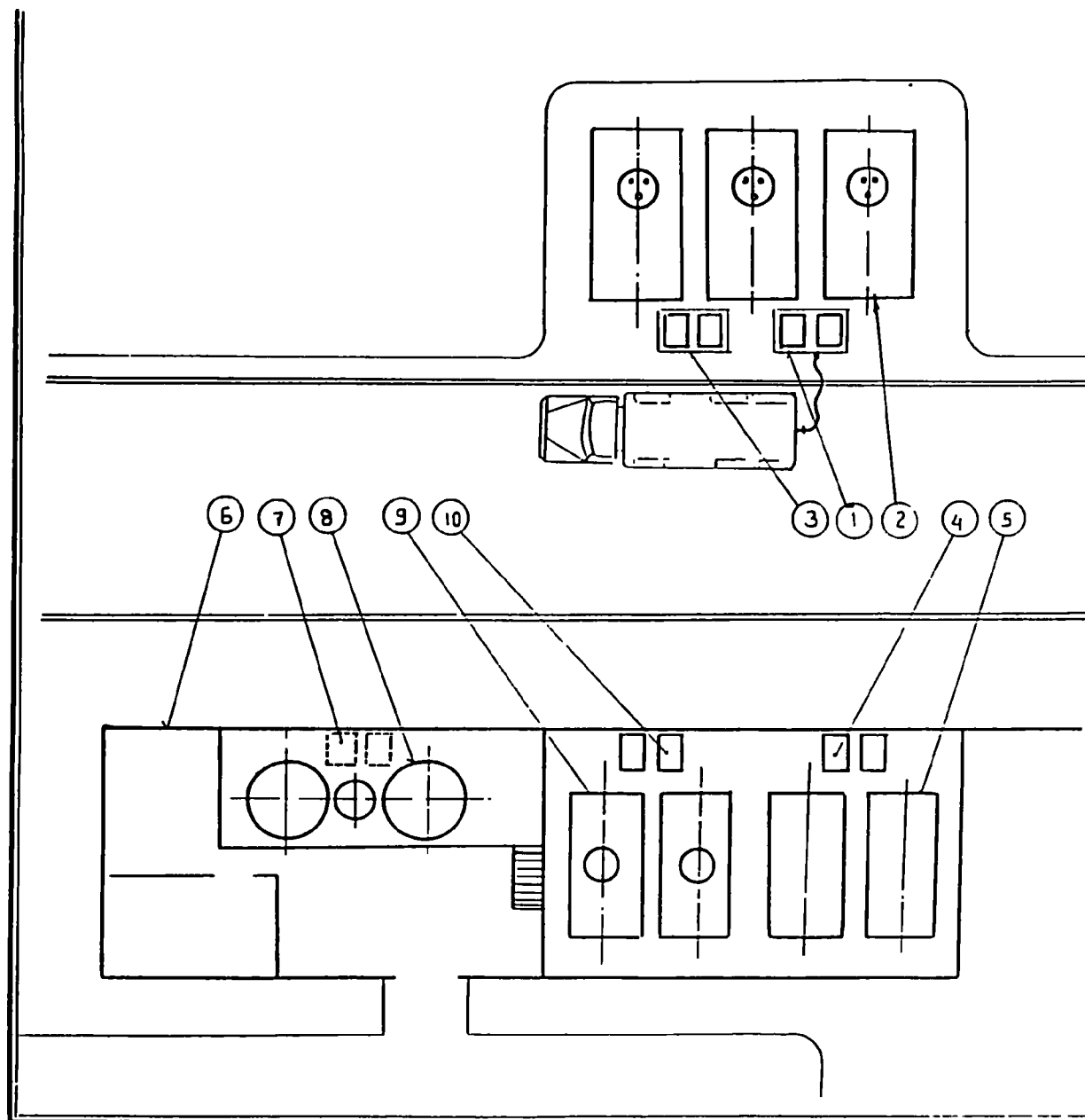


NCIC AER050L PLANT	Adsorption (De-stenching) Columns	P&I Diagram	
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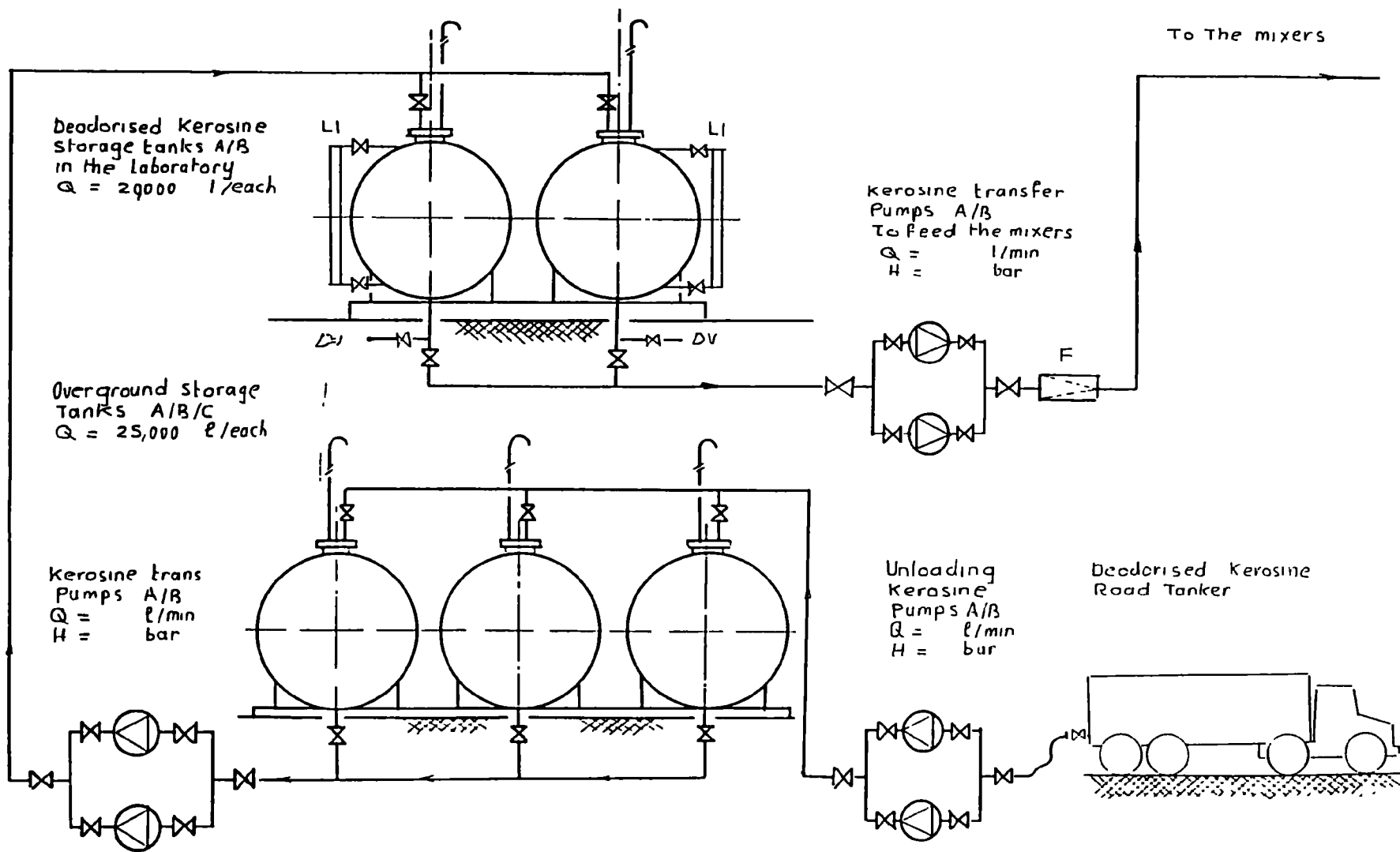


NCIC  
AEROSOL  
PLANT

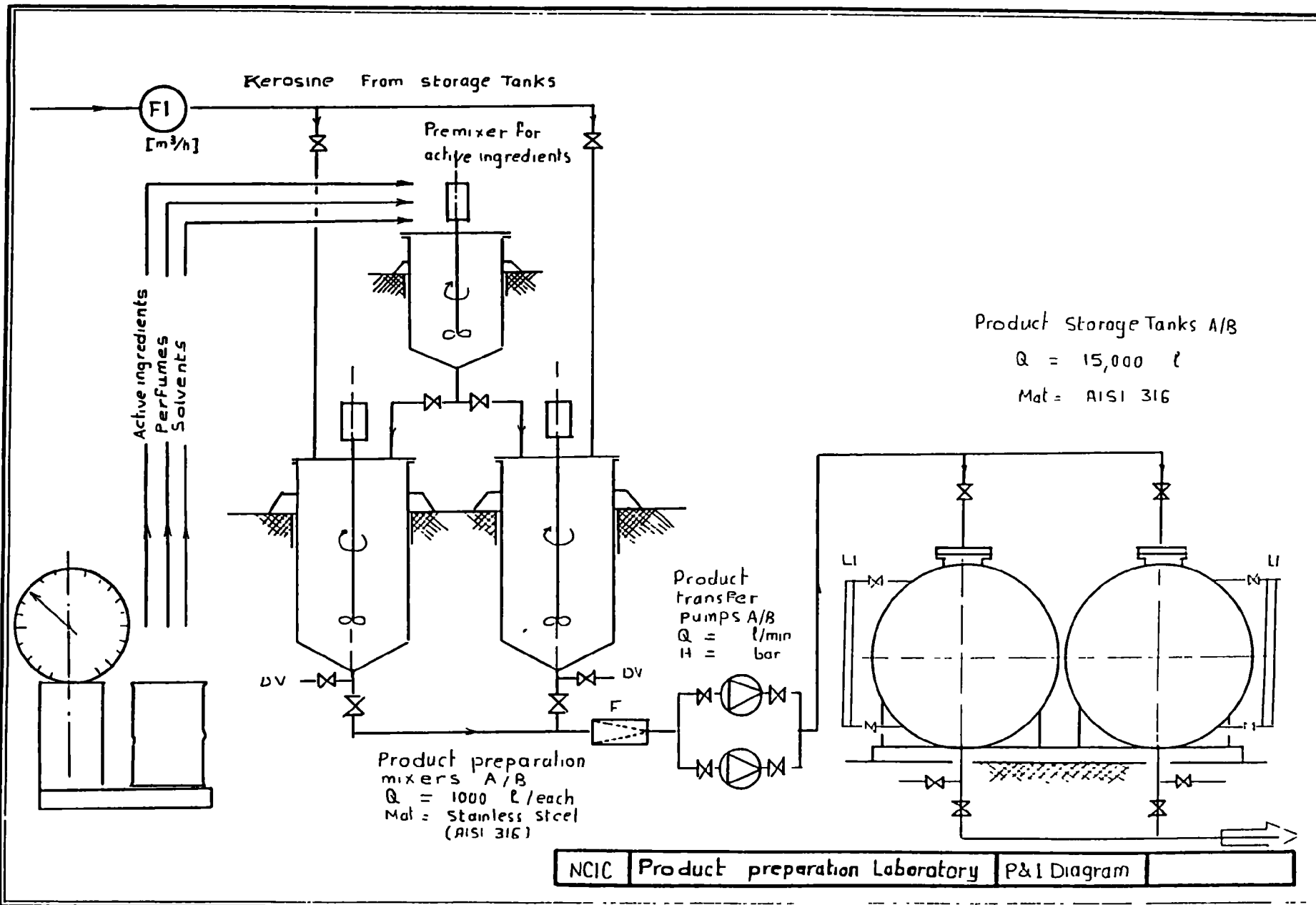
Deodorised LPG Storage System  
(P&I Diagram)



10	Product trans pumps to filling
9	Product storage tanks (2x12t)
8	Mixers
7	Product trans pumps to tanks
6	Product Lab
5	Petroleum solvent Storage tanks
4	Petroleum solvent trans pumps
3	Transfer pumps to Lab tanks
2	Storage Tanks (3x25 tons)
1	kerosine Unloading pumps
Product prep Laboratory Layout	
NCIC AEROSOL PLANT	SCALE 1 : 200



NCIC AEROSOL PLANT	Bulk Kerosine Storage system	P&I Diagram
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## APPENDIX C

### **COST TO CONVERT FROM CFC-BASED AEROSOL PRODUCTION TO LPG-BASED PRODUCTION FOR ONE EGYPTIAN COMPANY**

Kafr El Zayat pesticides and chemical company (KZ), a public-sector company, was the first aerosol-producing company that used liquified petroleum gas (LPG) as a substitute for CFCs. KZ produces chemicals and pesticides in a variety of forms, such as liquids, powders, and aerosols, and has a production capacity of 8 million containers per year. Containers used have capacities of 300, 400, and 640 cubic centimeters (cm<sup>3</sup>). The costs to accomplish conversion of the CFC aerosol filling line were estimated as follows:<sup>1</sup>

#### Capital Costs (in US\$)

- Capital investment for machinery and equipment for the production lines: \$566,000
- Capital investment for ancillary equipment (safety equipment, fire-extinguishing equipment, and alarm systems): \$793,000
- Total capital investment: \$1.36 Million

#### Operating Costs (in U.S.\$)

- Costs of LPG and raw material used<sup>2</sup>: \$1.24 million

By using LPG instead of CFCs Kafr El Zayat saved U.S. \$800,000 in annual operating costs. As a result, KZ recovered its capital costs in less than 2 years.

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<sup>1</sup> All costs are based on estimates provided in Egyptian pounds (£E) and a conversion factor of U.S. \$1.0 = £E 2.65

<sup>2</sup> This estimate is based on costs of £E 0.16 per 100 grams of LPG and the assumption that a 400 cm<sup>3</sup> container of aerosol contains 55 percent LPG by weight.





## **APPENDIX D**

### **CALCULATIONS USED TO DERIVE THE U.S. COST PER KILOGRAM ESTIMATES FOR EACH OF THE CONTROLS**

This appendix provides detailed estimates of the capital and operating costs for all technologies described. Estimates are based on information provided by international industry sources and experts on individual technologies. The data has been used in such reports as "Costs and Benefits of Phasing Out Production of CFCs and Halons in the U.S.," Draft Report, Office of Air and Radiation, U.S. Environmental Protection Agency, November 3, 1989, and "Regulatory Impact Analysis: Protection of the Stratospheric Ozone Layer," Draft Report, Office of Air and Radiation, U.S. Environmental Protection Agency, August 1, 1988.

## **SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR HCFC -123 IN INDUSTRIAL/COMMERCIAL REFRIGERATION**

CFC Used: CFC-11

End Use: Industrial/Commercial Refrigeration

Control: HCFC-123

### Characteristics of Average CFC-11 Refrigeration Unit:

Capital Costs of Unit: \$50,000

Energy Consumption of Unit: 1,597,284,000 Btu/year

Average Life of Unit: 25 years

CFC-11 Base Charge Size of Unit: 500 kg

Service Practices: Serviced and refilled six times during its lifetime. Each time unit is serviced an excess amount of 7 percent of the base charge is used.  
Total service charge  
1.07\*500 kg.

### Characteristics of HCFC-123 Unit

New industrial/commercial refrigeration equipment will contain HCFC-123. The capital cost of this equipment will be 10 percent greater than that of the CFC-11 unit. The energy consumption of the HCFC-123 unit will be 1 percent greater.

### Incremental Costs

Capital Costs = \$5000      Annualized Costs at 2 percent and 25 years = \$256/year

Energy Costs = \$313/year at \$0.067 per kwh

Chemical Costs:

Price of HCFC-123 = \$4.17/kg

Price of CFC-11 = \$1.41/kg

Costs of Chemical =  $(4.17 - 1.41) * (7.49) * 500 / 25 \text{ years} = \$413/\text{year}$

Annual Costs per kilogram of CFC-11 Saved =  $(256 + 313 + 413) * 25 / 500 * 7.49 = \$6.55/\text{kg}$

**SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR  
CFC-11 RECYCLING FOR INDUSTRIAL/COMMERCIAL REFRIGERATION**

CFC Used: CFC-11

End Use: Industrial/Commercial Refrigeration

Control: Recycling

CFC-11 Price: \$1.41 per kg

Characteristics of CFC-11 Recycling

Average Charge of CFC-11 Refrigeration Unit: 500 kg

Incremental Capital Costs Calculation

Capital Costs Recycling Unit: \$15,000

Number of Recycling Machines Required to service U.S Stock of CFC-11 Chillers in 1985: 230

U.S. Stock of CFC-11 Chillers: 37,000

Average Lifetime of Recycling Equipment: 5 years

Total Capital Costs for all Recycling Machines Required: \$3.45 million

Annual Capital Costs (at 2 percent and 5 years): \$731,946

Total Number of Recycling Jobs per Year in the U.S: 37,000

Annual Capital Costs per Recycling Job: \$20

Incremental Operating Costs

Recovery Rate of Recycling Machine: 14 kg per hour

Operating Costs per Hour: \$25

Total Operating Costs per Recycling Job: \$893

Total Capital and Operating Costs Per Job:  $$(893 + 20) = \$913$

### Chemical Savings

**Recycling and Servicing Events:** Six servicing/recovery events over life of refrigeration unit; six recovery events at leak testing; and one recovery event at disposal of refrigeration equipment.

Recycling equipment saves 70 percent of the CFC that would be lost at servicing. Total amount of CFC saved over lifetime due to servicing:  $6 \times 500 \times 0.70 = 2,100$  kg

Total amount of CFC used for leak testing is 5 percent of CFC charge. Total amount of CFC saved from leak testing:  $0.05 \times 500 \times 6 \times 0.70 = 105$  kg

Total CFCs saved over lifetime = 2,205 kg

Total CFC Savings at Servicing and Leak Testing = \$518 per service job

Total Costs (capital+ operating + chemical):  $\$913 - \$518 = \$395$  per job

Total Costs Over Lifetime of Refrigeration Unit = Servicing Costs + Disposal Costs  
=  $6 \times 395 + 913 = \$3,283$

Total Costs per Kilogram of CFC Saved = \$1.49 per kg

**SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR  
HCFC-141b/HCFC-123 FOAM BLOWING AGENT FOR FLEXIBLE  
FOAM & INSULATION FOAM APPLICATIONS**

CFC Used: CFC-11

End Use: Flexible Foam and Insulation Foam Applications

Control: HCFC-141b/HCFC-123 Foam-Blowing Agent

Price of CFC-11: \$1.41 per kg

Price of HCFC-123: \$4.17 per kg

Price of HCFC-141b: \$3.31 per kg

Characteristics of Flexible and Insulation Foam-Blowing Applications Using HCFC-123/HCFC-141b

CFC-11 flexible foam and insulation foam-blowing factories will have to be retrofitted to accommodate the new HCFC-123/HCFC-141b foam-blowing agent.

**Incremental Capital Costs:** The retrofitting costs are \$32 per metric ton (MT) of foam. The useful lifetime for flexible and insulating foams factory is 25 years. Annualized costs at a 2 percent discount rate are \$1.64 per MT of foam

**Incremental Chemical Costs:** CFC-11 is replaced with a blend of HCFC-123/HCFC-141b. 50 percent of CFC-11 is replaced with HCFC-123 which has a replacement factor of 1.25 (i.e., every kg of CFC-11 is replaced with 1.25 kg of HCFC-123). Similarly the remaining 50 percent of CFC-11 is replaced with HCFC-141b. This has a replacement factor of 0.91.

170.16 kg of CFC-11 is used for every MT of foam produced.

Chemical costs:  $0.5 \times 170.16 \times (0.91 \times 3.31 - 1.41) + 0.5 \times 170.16 \times (1.25 \times 4.17 - 1.41) = \$460$  per MT of foam

**Incremental Capital & Operating Costs:** \$461.6 per MT of foam

**Amount of CFC-11 Saved:** 170.16 kg per MT of foam produced

**Costs per Kilogram of CFC Saved =** \$ 2.71 per kg

## **SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR HCFC-134a IN MOBILE AIR CONDITIONERS**

CFC Used: CFC-12

End Use: Mobile Air Conditioning

Control: HFC-134a

### **Characteristics of CFC-12 Refrigeration Unit:**

Energy Consumption of Unit: 2,501,000 Btu/year

Average Life of Unit: 11 years

Base Charge Size of Unit: 1.727 kg

Actual charge used to fill and leak test unit is 32% greater than base charge  
(i.e.,  $1.32 * 1.727$  kg)

Service Practices: Recharged and serviced with 4.6 kilograms over its lifetime.

Total Charge used Over Lifetime:  $(1.32 + 4.6)$  kg = 5.92 kg

Price of CFC-12 = \$1.63/kg

Price of HFC-134a = \$6.65/kg

### **Characteristics of HFC-134a Unit**

CFC-12 used in mobile air conditioning is replaced with HFC-134a.

### **Incremental Costs**

**Capital Costs :** One time retooling costs to industry estimated at \$100 million for an industry manufacturing 13.2 million mobile air conditioning units per yr.

Annualized capital costs at a 2% discount rate and a lifetime of 11 years results in costs of \$0.77 per year per mobile air conditioner unit.

**Energy Costs:** An HFC-134a unit consumes 3% more energy than a CFC unit

The energy costs at \$0.023 per kwh are \$0.50/year

**Chemical Costs:**  $5.92 \text{ kg} * (6.65 - 1.63)/11 \text{ years} = \$2.70/\text{year}$

**Annual Costs per Kilogram of CFC-12 Saved** =  $(0.77 + 0.5 + 2.7) * 11/16.1 = \$ 7.4 \text{ per kg}$

**SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR  
MOBILE AIR CONDITIONER RECYCLING**

CFC Used: CFC-12

End Use: Mobile Air Conditioner (MAC) Recycling

Control: Recycling

Characteristics of Mobile Air Conditioner Recycling Unit:

Capital Costs of Recycling Unit: \$2,000

Lifetime of Recycling Unit: 5 years

Salvage Value of Unit: \$400

Annualized Costs of Recycling Equipment (discount rate of 2%): \$347

Number of Recycling Shops in the U.S.: 16,946

Number of Servicing Jobs in the U.S. per Shop per Year: 312

Total Number of Service Jobs in the U.S.: 5,287,152

Annual Capital Costs per Job per Shop: \$1.11

Characteristics of Mobile Air Conditioner Unit:

Initial charge of MAC: 1.727 kg

Regular servicing occurs when 70 percent of the initial charge remains in the MAC.

10 percent of MACs are vented at regular servicing

12.5 percent of all MACs are serviced each year due to accidents, ruptures in the hoses, and general failures. 100 percent of these MACs are vented, and it is assumed that 55 percent of the charge remains at venting.

At each servicing job 0.795 kg of CFC are used for leak detection.

At refill 20 percent of the charge is emitted (i.e., it takes 1.2 times the charge to fill the MAC).

Based on the costs per job and the above emissions estimates the costs per kilogram of CFC-12 saved is: \$4.88 per kg

## **SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR TERNARY BLEND IN HOUSEHOLD REFRIGERATORS**

CFC Used: CFC-12

End Use: Household Refrigerators

Control: Ternary Blend

### **Characteristics of CFC-12 Refrigeration Unit:**

Energy Consumption of Unit: 1100 kwh/year

Average Life of Unit: 19 years

Base Charge Size of Unit: 0.21 kg

Actual charge used to fill unit is 8 percent greater than base charge (i.e.,  $1.08 * 0.21$  kg)

Service Practices: Recharged and serviced with 0.36 times the base charge during lifetime. Total service charge  $0.36 * 0.21$  kg.

Total Charge used Over Lifetime:  $(1.08 + 0.36) * 0.21$  kg = 0.30 kg

Price of CFC-12 = \$1.63/kg

Price of Ternary Blend = \$5.60/kg

### **Characteristics of Ternary Blend Unit**

The ternary blend is a drop-in chemical for household refrigerators.

### **Incremental Costs**

Capital Costs: The ternary blend is a near drop in and thus its incremental capital costs are negligible.

Energy Costs: The ternary blend unit consumes 3 percent less energy than CFC-12-based units.

The energy savings at \$0.067 per kwh are \$2.21/year

Chemical Costs:  $0.30$  kg \*  $(5.60 - 1.63)/19$  years = \$0.063/year

Annual Costs per kilogram of CFC-12 Saved =  $(0.063 - 2.21) * 19/0.30 = - \$ 136$  per kg

For the purposes of this analysis all negative costs controls are assumed zero costs controls (i.e., costs per kilogram is zero).



## **SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR HFC-152a IN HOUSEHOLD REFRIGERATORS**

CFC Used: CFC-12

End Use: Household Refrigerators

Control: HFC-152a

### **Characteristics of CFC-12 Refrigeration Unit:**

Energy Consumption of Unit: 1100 kwh/year

Average Life of Unit: 19 years

Base Charge Size of Unit: 0.21 kg

Actual charge used to fill unit is 8 percent greater than base charge (i.e.,  $1.08 * 0.21$  kg)

Service Practices: Recharged and serviced with 0.36 times the base charge during lifetime. Total service charge  $0.36 * 0.21$  kg.

Total Charge used Over Lifetime:  $(1.08 + 0.36) * 0.21$  kg = 0.30 kg

Price of CFC-12 = \$1.63/kg

Price of HFC-152a = \$9.05/kg

### **Characteristics of HFC-152a Unit**

The HFC-152a is a near drop-in chemical for household refrigerators.

### **Incremental Costs**

Capital Costs: The HFC-152a is a near drop in and thus its incremental capital costs are negligible.

Energy Costs: The HFC-152a unit consumes 7 percent less energy than CFC-12 units.

The energy savings at \$0.067 per kwh are \$5.16/year

Chemical Costs:  $0.30$  kg \*  $(9.05 - 1.63)/19$  years = \$0.117/year

Annual Costs per Kilogram of CFC-12 Saved =  $(0.117 - 5.16) * 19/0.30$  = - \$ 319 per kg

For the purposes of this analysis all negative costs controls are assumed zero costs controls (i.e., costs per kilogram is zero).

## **SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR REDUCED CHARGE IN HOUSEHOLD REFRIGERATION**

CFC Used: CFC-12

End Use: Household Refrigerators

Control: Reduced Charge

### **Characteristics of Manufacturing Household Refrigerators Using Reduced Charge**

CFC-12 use can be reduced in household refrigerators using evaporator and condenser tubing that is smaller in diameter and longer so as to provide the same refrigeration characteristics and energy efficiency.

### **Incremental Costs**

**Raw Material/Chemical Savings:** CFC-12 is estimated to cost \$1.63 per kg and the total quantity used during a refrigerators lifetime is 0.3 kg. Reducing CFC-12 charge by 50 percent saves \$0.24 per household refrigerator.

Savings for a plant manufacturing 400,000 refrigerators = \$97,800

**Energy Costs:** Same

**Capital Costs:** Capital costs include costs to retrofit refrigeration manufacturing lines to accommodate the use of reduced CFC-12 charge. Capital investment for typical refrigeration plant producing 400,000 units per year is \$50,000.

**Annual Costs per Kilogram of CFC-12 Saved = 0.0**

The operating costs savings resulting from the use of reduced CFC-12 charge offset the capital investment required.

## **SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR TERNARY BLEND IN INDUSTRIAL/COMMERCIAL REFRIGERATION**

**CFC Used: CFC-12**

**End Use: Industrial/Commercial Refrigeration**

**Control: Ternary Blend**

### **Characteristics of CFC-12 Refrigeration Unit:**

**Energy Consumption of Unit: 71,379,040 Btu/year**

**Average Life of Unit: 10 years**

**Base Charge Size of Unit: 120 kg**

**Actual charge used to fill unit is 10.5 percent greater than base charge (i.e.,  $1.105 * 120$  kg)**

**Service Practices:      Recharged and serviced with 3.31 times the base charge during  
lifetime. Total service charge  $3.31 * 120$  kg.**

**Total Charge used Over Lifetime:  $(1.105 + 3.31) * 120$  kg = 530.4 kg**

**Price of CFC-12 = \$1.63/kg**

**Price of Ternary Blend = \$5.60/kg**

### **Characteristics of Ternary Blend Unit**

**The ternary blend is a drop-in chemical in industrial/commercial refrigeration units.**

### **Incremental Costs**

**Capital Costs:      The ternary blend is a drop-in chemical and thus its incremental capital  
costs are negligible.**

**Energy Costs:      The ternary blend unit consumes 3 percent less energy than a CFC-12 unit.  
The energy savings at \$0.067 per kwh are \$42/year**

**Chemical Costs:  $530.4$  kg \*  $(5.60 - 1.63)/10$  years = \$210.6/year**

**Annual Costs per Kilogram of CFC-12 Saved =  $(210.6 - 42) * 10/530.6$  = \$3.2 per kilogram**

## **SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR CFC-12 RECYCLING FOR INDUSTRIAL/COMMERCIAL REFRIGERATION**

CFC Used: CFC-12

End Use: Industrial/Commercial Refrigeration

Control: Recycling

CFC-12 Price: \$1.63 per kg

### Characteristics of CFC-12 Recycling

Average charge of CFC-12 Refrigeration Unit: 727 kg

### Incremental Capital Costs Calculation

Capital Costs Recycling Unit: \$15,000

Number of Recycling Machines Required to Service U.S stock of CFC-12 chillers in 1985: 39

U.S. Stock of CFC-12 Chillers: 6,100

Average Lifetime of Recycling Equipment: 5 years

Total Capital Costs for all Recycling Machines Required: \$575,000

Annual Capital Costs (at 2 percent and 5 years): \$121,991

Total Number of Recycling Jobs per Year in the U.S: 6,100

Annual Capital Costs per Recycling Job: \$20

### Incremental Operating Costs

Recovery Rate of recycling machine: 14

Operating Costs per Hour: \$25

Total Operating Costs per Recycling Job: \$1,299

Total Capital and Operating Costs Per Job:  $$(1299 + 20) = \$1,319$

### Chemical Savings

**Recycling and Servicing events:** Six servicing/recovery events over life of refrigeration unit; six recovery events at leak testing; and one recovery event at disposal of refrigeration equipment.

Recycling equipment saves 85 percent of the CFC that would be lost at servicing. Total amount of CFC saved over lifetime due to servicing:  $6 \times 727 \times 0.85 = 3,708$  kg

Total Amount of CFC used for leak testing is 5 percent of CFC charge. Total amount of CFC saved from leak testing:  $0.05 \times 727 \times 6 \times 0.85 = 185.4$  kg

Total CFCs saved over lifetime = 3,893 kg

Total CFC Savings at Servicing and Leak Testing = \$1,057 per service job

Total Costs (capital + operating + chemical):  $\$1,319 - \$1,057 = \$262$  per job

Total Costs Over Lifetime of Refrigeration Unit = Servicing Costs + Disposal Costs =  $6 \times 262 + 1,319 = \$2,891$

Total Costs per Kilogram of CFC Saved = \$0.75 per kg

**SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR  
HCFC-141b/HCFC-123 FOAM BLOWING AGENT FOR  
INSULATION FOAM APPLICATIONS**

CFC Used: CFC-12

End Use: Insulation Foam Applications

Control: HCFC-141b/HCFC-123 Foam Blowing Agent

Price of CFC-12: \$1.63 per kg

Price of HCFC-123: \$4.17 per kg

Price of HCFC-141b: \$3.31 per kg

Characteristics of Insulation Foam-Blowing Applications Using HCFC-123/HCFC-141b

CFC-12 insulation foam blowing factories will have to be retrofitted to accommodate the new HCFC-123/HCFC-141b foam-blowing agent.

**Incremental Capital Costs:** The retrofitting costs are estimated at \$32 per metric ton (MT) of foam. The useful lifetime for insulation foam factory is 25 years. Annualized costs at a 2 percent discount rate are \$1.64 per MT of foam

**Incremental Chemical Costs:** CFC-12 is replaced with a blend of HCFC-123/HCFC-141b. 50 percent of CFC-12 is replaced with HCFC-123, which has a replacement factor of 1.25 (i.e., every kg of CFC-12 is replaced with 1.25 kg of HCFC-123). Similarly, the remaining 50 percent of CFC-12 is replaced with HCFC-141b, which has a replacement factor of 0.91.

170.16 kg of CFC-12 is used for every MT of foam produced.

Chemical costs:  $0.5 \times 170.16 \times (0.91 \times 3.31 - 1.63) + 0.5 \times 170.16 \times (1.25 \times 4.17 - 1.63) = \$422$  per MT of foam

**Incremental Capital & Operating Costs:** \$423.6 per MT of foam

**Amount of CFC-12 Saved:** 170.16 kg per MT of foam produced

**Costs per Kilogram of CFC Saved = \$ 2.48 per kg**

**SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR  
HCFC-22/HCFC-142b FOAM BLOWING AGENT FOR FOAM PACKAGING APPLICATIONS**

CFC Used: CFC-12

End Use: Foam Packaging Application

Control: HCFC-22/HCFC-142b Foam Blowing Agent

Price of CFC-12: \$1.63 per kg

Price of Chemical Substitute: \$3.29 per kg

**Characteristics of Packaging Foam-Blowing Applications Using HCFC-22/HCFC-142b**

CFC-12 packaging foam-blowing factories will have to be retrofitted to accommodate the new HCFC-22/HCFC-142b foam-blowing agent.

Incremental Capital Costs: The retrofitting costs are \$38 per metric ton (MT) of foam. Useful lifetime for packaging foam factory is 25 years. Therefore, annualized costs are \$1.95 per MT of foam

Incremental Chemical Costs: 152 kg of CFC are used for every MT of foam produced.  
  
Chemical costs:  $152 \times 1.66 = \$252$  per MT of foam produced.

Incremental Capital & Operating Costs: \$254 per MT of foam

Amount of CFC Saved: 152 kg per MT of foam produced

Costs per Kilogram of CFC Saved = \$1.67 per kg

## **SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR COMPRESSED GASES IN AEROSOL APPLICATIONS**

**CFC Used: CFC-11, CFC-12, CFC-114**

**End Use: Aerosols**

**Control: Compressed Gases**

### **Characteristics of Aerosol Filling Lines**

CFC use in aerosol application is replaced with compressed gases such as carbon dioxide. The use of compressed gases will require special technology capable of handling high vapor pressure gases such as air, nitrogen, and carbon dioxide.

### **Incremental Costs**

**Raw Material/Chemical Savings:** Carbon dioxide is estimated to cost \$1.00 per kg. Therefore each kilogram of CFC-12 replaced saves \$0.63.

**Energy Costs:** Same

**Capital Costs :** Capital costs include costs to retrofit aerosol filling lines to accommodate the use of carbon dioxide. Capital investment for typical aerosol plants is estimated at \$45,000 to \$120,000.

**Costs per Kilogram of CFC-12 Saved = 0.0**

The operating costs savings resulting from the use of compressed carbon dioxide and LPG offset the capital investment required.



## **SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR HYDROCARBONS IN AEROSOL APPLICATIONS**

**CFC Used: CFC-11, CFC-12, CFC-114**

**End Use: Aerosols**

**Control: Hydrocarbons**

### **Characteristics of Aerosol Filling Lines**

CFC use in aerosol applications is replaced with hydrocarbons such as liquified petroleum gas (LPG). The use of LPG will require special technology capable of handling the LPG, such as LPG storage tanks, fire-extinguishing equipment, special safety equipment, and adjustment to filling lines.

### **Incremental Costs**

**Raw Material/Chemical Savings:** LPG is estimated to cost \$0.6 per kg.  
The total costs of LPG for an 8 million unit factory is \$1.24 million. The total cost of CFC would be \$2.93 million.

**Savings in material costs: \$1.69 million per year**

**Energy Costs:** Same

**Capital Costs :** The capital costs to retrofit a factory producing 8 million containers per year is estimated at \$1.36 million. This includes \$566,000 for capital investment for machinery and equipment for filling lines and \$793,000 for auxiliary equipment such as safety equipment, fire-extinguishing equipment, and alarm systems.

**Costs per Kilogram of CFC Saved = 0.0**

**The operating costs savings resulting from the use of LPG offset the capital investment required.**

## **SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR HCFC BLEND IN STERILIZATION**

**CFC Used: CFC-12**

**End Use: Sterilization**

**Control: HCFC-Based Proprietary Blend**

### **Characteristics of Using HCFC-Based Proprietary Blend for Sterilization Applications**

CFC-12 can be replaced in sterilization applications using a proprietary HCFC blend that is currently under development. The sterilization equipment using this blend is similar to the CFC-12 sterilization equipment.

### **Incremental Costs**

**Chemical Costs:** CFC-12 costs \$1.63 per kg. The HCFC-based proprietary blend costs 10.63 per kg. Thus, each kilogram of CFC-12 replaced with the proprietary blend will cost \$9 per kg.

**Energy Costs:** Same

**Capital Costs:** The sterilization equipment using the proprietary blend will cost the same as CFC-12 sterilization equipment. Therefore, incremental capital costs are negligible.

**Annual Costs per Kilogram of CFC-12 Saved = \$9 per kilogram**

**SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR  
AQUEOUS CLEANING IN METAL AND ELECTRONICS CLEANING**

**CFC Used: CFC-113**

**End Use: Metal and Electronics Cleaning**

**Control: Aqueous Cleaning**

**Characteristics of CFC-113 Solvent Cleaning Open-Top Vapor Degreaser Unit**

**Capital Costs of CFC-113 Unit: \$16,316**

**Energy Consumption of Unit:** Unit consumes 27 kw of electricity (\$3630/yr) based on energy costs for heating the solvent, the workload, compensation for heat loss due to radiation, and operating an auxiliary still.

**Average Life of Unit: 10 years**

**Total Virgin Solvent used: 5300 kg per year**

**Price of CFC-113 = \$1.96 per kg**

**Characteristics of Aqueous Cleaning Unit**

A typical conveyORIZED spray washer would be needed to replace an open-top solvent cleaner.

**Incremental Costs**

**Capital Costs :** Capital costs include those for aqueous cleaning equipment (wash tanks, rinse tanks, air knife, and dryer), installation, and floor space.

**Costs: \$50,000     Annualized Costs = \$5566 at 2% discount**

**Energy Costs:** Electricity costs for aqueous cleaning and drying equipment are based on consumption of 33 kwh (22% greater than the CFC-113 machine).

**The energy costs at \$0.067 per kwh are \$804 per year**

**Raw Material/Chemical Savings:** Based on the costs of aqueous cleaner chemicals and water: \$9,388 per year

**Waste Treatment/Disposal Costs: \$7000 per year**

**Total Incremental Operating Costs: +7000 + 804 - 9388 = - \$1584 per year**

**Annual Costs per Kilogram of CFC-113 Saved = (5566 - 1584)/ 5300 = \$0.75 per kilogram**

**SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR  
RECYCLING IN THE METAL AND ELECTRONICS INDUSTRIES**

CFC Used: CFC-113

End Use: Metal and Electronics Cleaning

Control: Recycling/Engineering Controls

Price of CFC-113: \$1.96 per kg

Characteristics of Recycling/Engineering Controls

Engineering controls are based on a combination of improved house-keeping practices, refrigerated freeboard chiller, increased freeboard height, and automatic hoist.

Incremental Capital Costs

Engineering controls: \$11,000

Annualized Costs at 2 percent Discount and a Lifetime of Ten Years: \$1,224

Incremental Operating Costs

Energy Costs: \$112      Based on increased energy to operate the freeboard chiller

Solvent Savings: \$5,360      Based on the fact that an average open-top degreaser consumes 5,300 kg of CFC-113. Engineering controls reduce evaporative, drag out, and downtime solvent loss. This results in virgin solvent use reduction of 51.6 percent.

Total Operating Savings: \$5,248

Total Capital and Operating Savings: \$4,024

Costs Per Kilogram of Reducing CFC-113: -\$1.47

For the purposes of this analysis all negative costs controls are assumed zero costs controls (i.e., costs per kilogram is zero).

## **SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR HCFC-124 IN INDUSTRIAL/COMMERCIAL REFRIGERATION**

CFC Used: CFC-114

End Use: Industrial/Commercial Refrigeration

Control: HCFC-124

### Characteristics of Average CFC-114 Refrigeration Unit

Capital Costs of Unit: \$200,000

Energy Consumption of Unit: 10,750,950,000 Btu/year

Average Life of Unit: 25 years

CFC-114 Base Charge Size of Unit: 568.2 kg

Service Practices: Serviced and refilled six times during its lifetime. Each time unit is serviced an excess amount of 7 percent of the base charge is used. Total service charge  $1.07 \times 568.2$  kg. Initial charge 568.2 kg. Total Charge over lifetime  $1.07 \times 568.2 + 568.2$  kg

### Characteristics of HCFC-124 Unit

New industrial/commercial refrigeration equipment will contain HCFC-124. The capital cost of this equipment will be 10 percent greater than that of the CFC-114 unit. The energy consumption of the HCFC-124 unit will be 2 percent greater.

### Incremental Costs

Capital Costs = \$20,000    Annualized Costs at 2 percent and 25 years = \$1024.41/year

Energy Costs = \$4,219/year at \$0.067 per kwh

Chemical Costs:

Price of HCFC-124 = \$4.89 per kg

Price of CFC-114 = \$2.38 per kg

Costs of Chemical =  $(4.89 - 2.38) \times (7.07) \times 568.2 / 25 \text{ years} = \$403.32/\text{year}$

Annual Costs Per Kilogram of CFC-114 Saved =  $(1024 + 4219 + 403) \times 25 / 568 \times 7.07 = \$35.1/\text{kg}$

## **SUMMARY CALCULATION FOR COST PER KILOGRAM ESTIMATE FOR CFC-114 RECYCLING FOR INDUSTRIAL/COMMERCIAL REFRIGERATION**

CFC Used: CFC-114

End Use: Industrial/Commercial Refrigeration

Control: Recycling

CFC-114 Price: \$2.38 per kg

### **Characteristics of CFC-114 Recycling**

Average Charge of CFC-114 Refrigeration Unit: 568 kg

### **Incremental Capital Costs Calculation**

Capital Costs of Recycling Unit: \$15,000

Number of Recycling Machines Required to Service U.S Stock of CFC-114  
Chillers in 1985: 21

U.S. Stock of CFC-114 Chillers: 2,700

Average Lifetime of Recycling Equipment: 5 years

Total Capital Costs for all Recycling Machines Required: \$250,000

Annual Capital Costs (at 2 percent and 5 years): \$53,040

Total Number of Recycling Jobs per Year in the U.S: 2,700

Annual Capital Costs per Recycling Job: \$20

### **Incremental Operating Costs**

Recovery Rate of Recycling Machine: 14 kg per hour

Operating Costs per hour: \$25

Total Operating Costs per Recycling Job: \$1,014

Total Capital and Operating Costs Per Job:  $$(1014 + 20) = \$1,034$

### Chemical Savings

**Recycling and Servicing Events:** Six servicing/recovery events over life of refrigeration unit; and one recovery event at disposal of refrigeration equipment.

Recycling equipment saves 85 percent of the CFC that would be lost at servicing. Total amount of CFC saved over lifetime due to servicing:  $6 \times 568 \times 0.85 = 2,897$  kg

Total CFCs saved over lifetime = 2,897 kg

Total CFC Savings at Servicing and Leak Testing = \$1,149 per service job

Total Costs (capital + operating + chemical):  $\$1,034 - \$1,149 = -\$115$  per job

Total Costs Over Lifetime of Refrigeration Unit = Servicing Costs + Disposal Costs =  $-6 \times 115 + 1034 = \$344$

Total Costs per Kilogram of CFC Saved = \$0.12 per kg