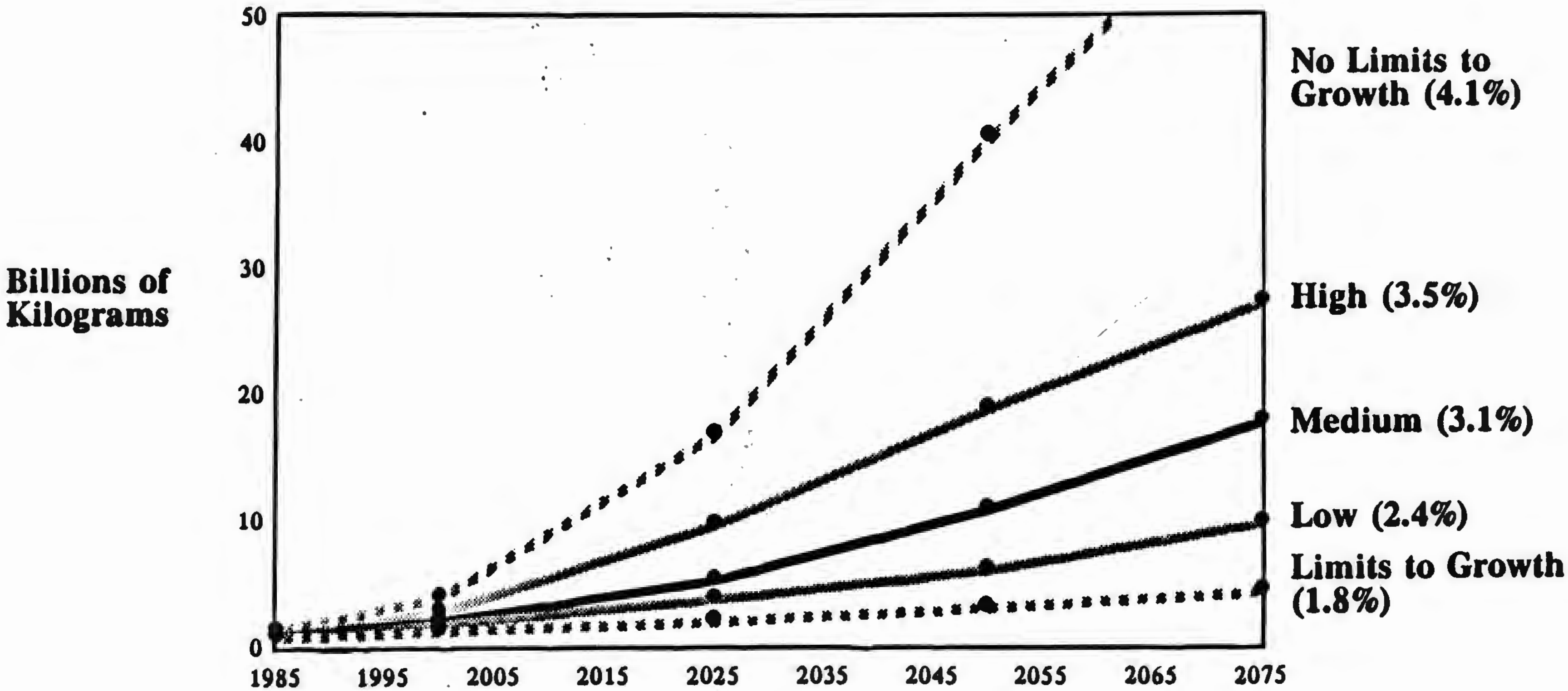
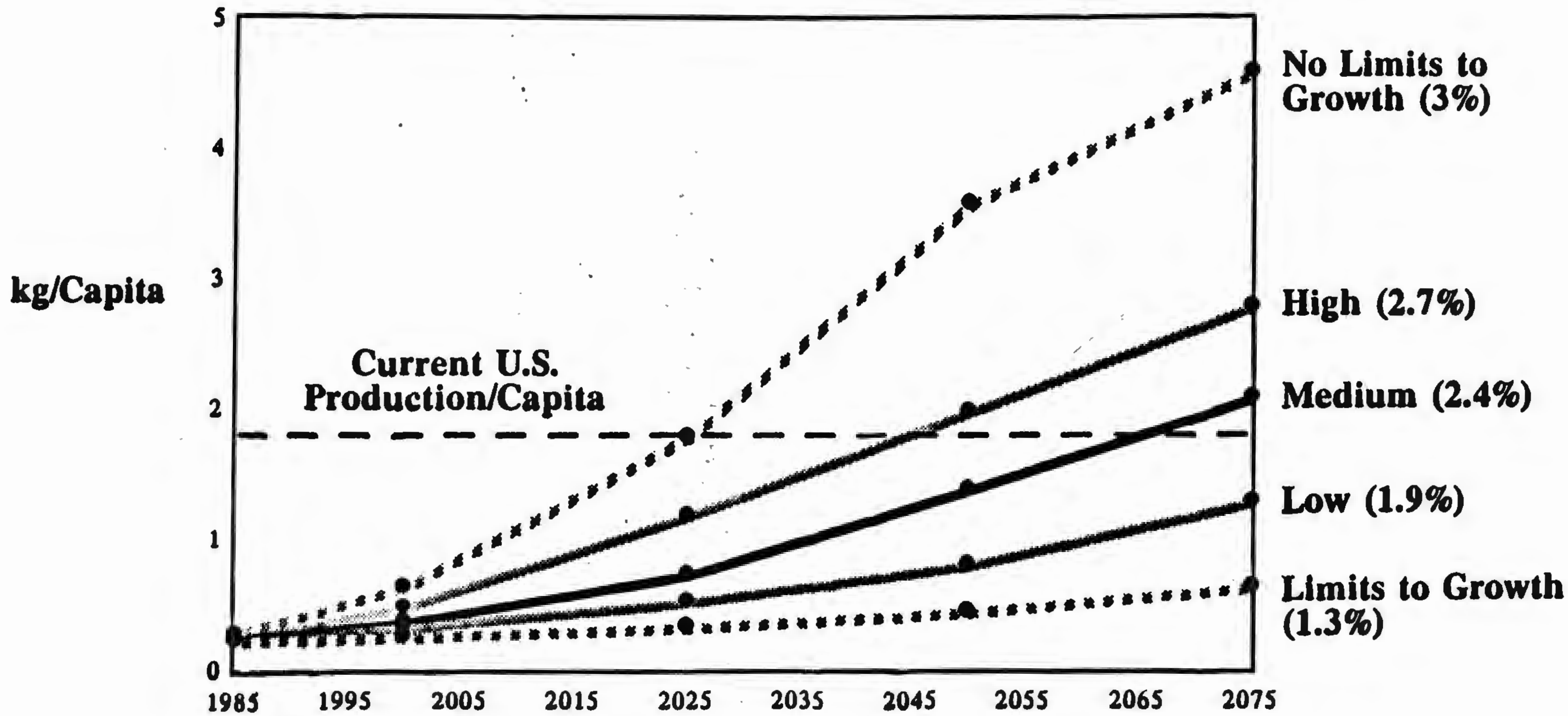
Collection: Masterman, Vicki: Files
Folder Title: Stratospheric Ozone V (3 of 12)
Box: 2

Results: Production
World: CFC–11, CFC–12, CFC–22, CFC–113



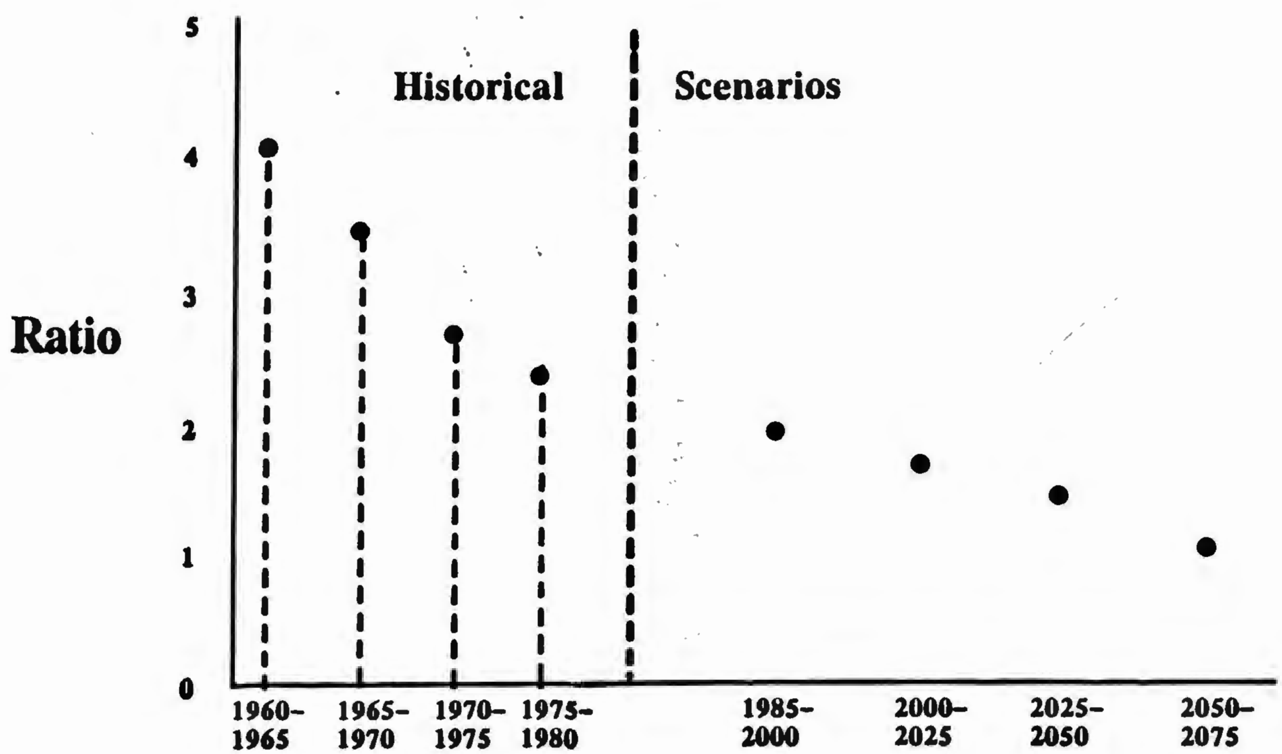
SOURCE: Gibbs, (ICF) 1986

Results: Production/Capita
World: CFC-11, CFC-12, CFC-22, CFC-113



SOURCE: Gibbs, (ICF) 1986

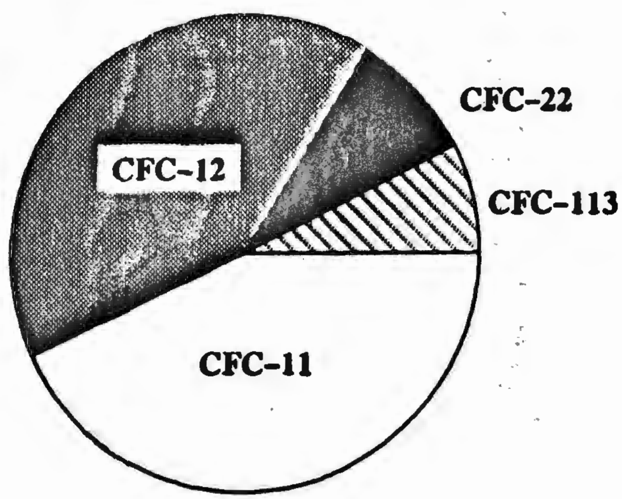
Results: Ratio of Growth in Production/Capita to Growth in GNP/Capita World: CFC-11, CFC-12, CFC-22, CFC-113



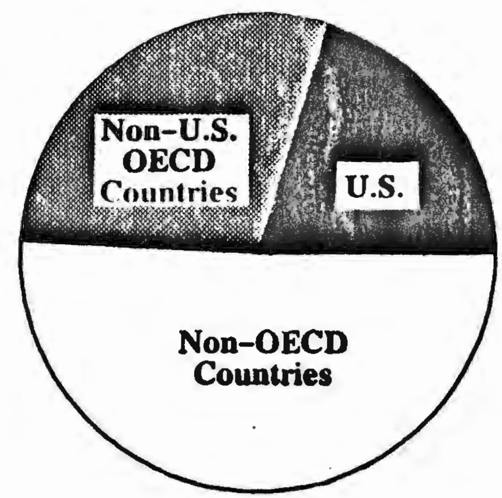
SOURCE: Gibbs, (ICF) 1986

Results: Shares of Growth
World: CFC–11, CFC–12, CFC–22, CFC–113

Most of the Growth is in CFC–11 and CFC–12 (1985–2075)



About Half the Growth is in the Non–OECD Countries (1985–2075)



SOURCE: Gibbs (ICF) 1986

Probablistic Projections of CFC Consumption

Nordhaus and Yohe modelled CFC use based on:

* technological developments
  -- new products
  -- new processes

* population level and distribution

* per capita income and distribution

* regulatory environment

Impt b/c factored in the

Uncertainty explicitly modelled

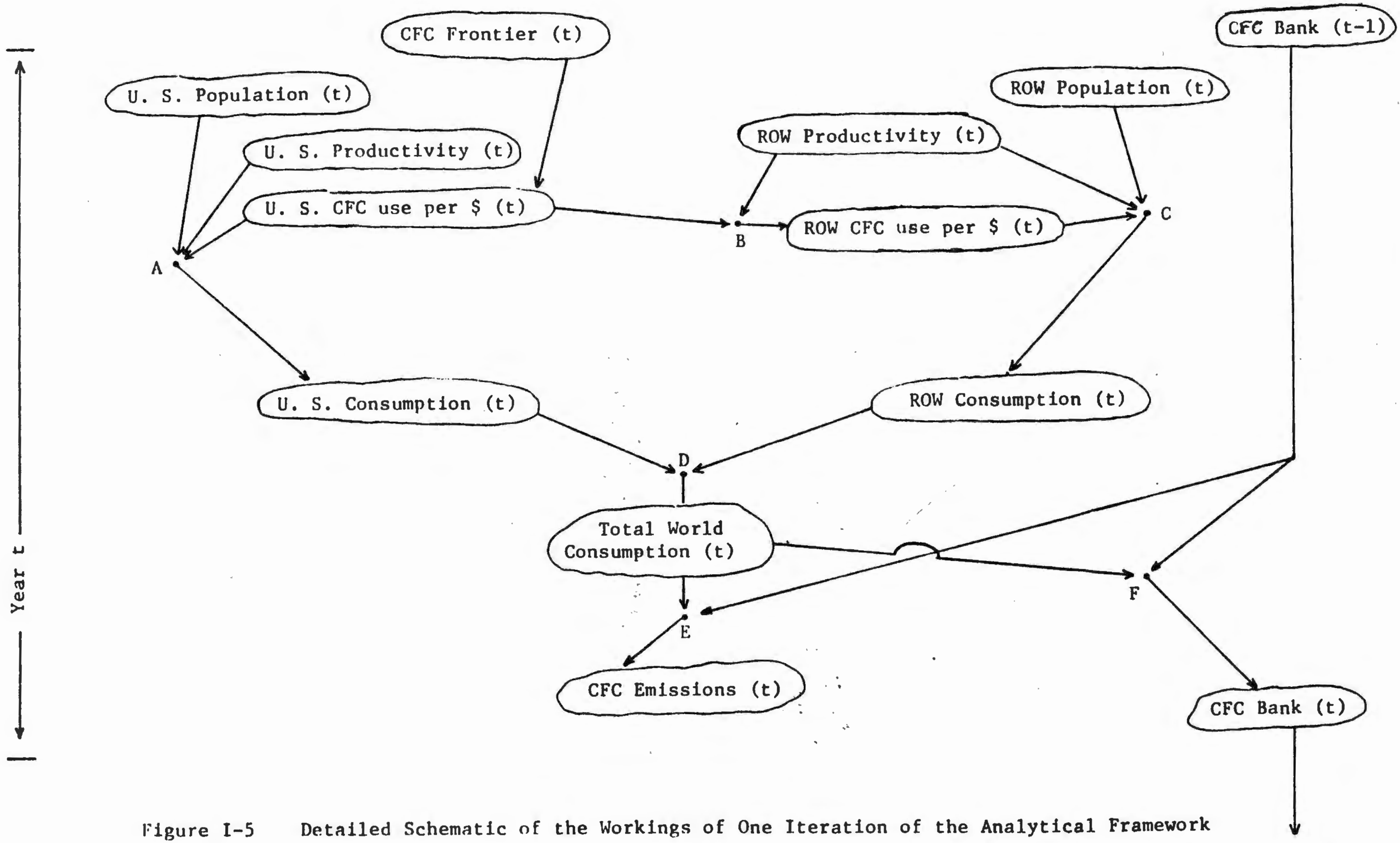
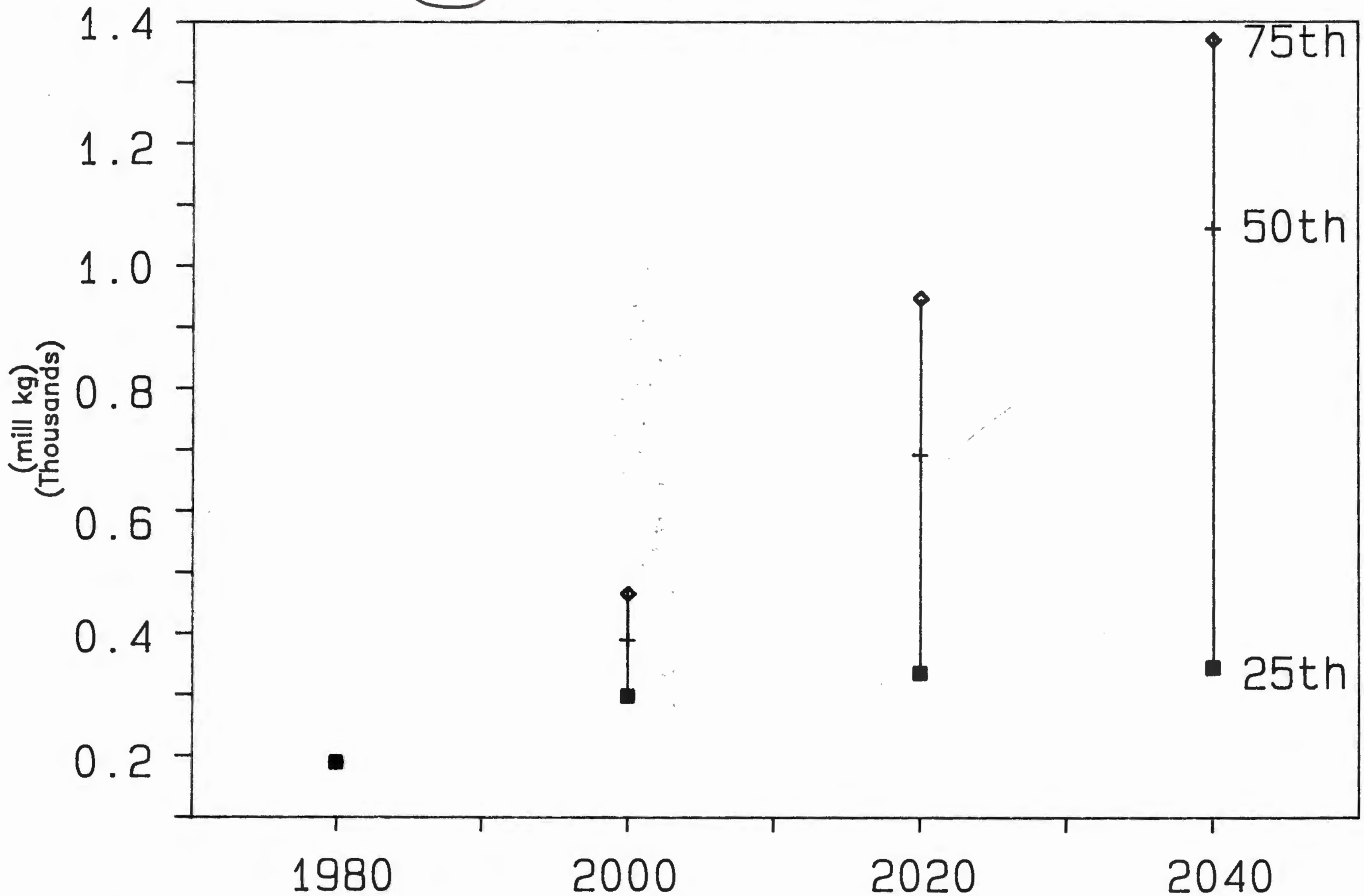


Figure I-5 Detailed Schematic of the Workings of One Iteration of the Analytical Framework

SOURCE: Nordhaus and Yohe , 1986

Monte Carlo Projections of CFCs

in U.S. for non-aerosol CFC-11 and CFC-12



Source: Nordhaus and Yohe (1986)

Future CFC Use in Developing Nations

Kohler study projected consumption of goods containing CFCS:

* Automobiles

* Refrigerators

* Air Conditioning

Conclusions:

* Consumption of CFC-intensive products will increase at a faster rate than GNP per capita

* Developing country markets are far from saturation

* Substantial growth in emissions over time

Growth in use in LDCs

Table 6

STOCK OF DOMESTIC REFRIGERATORS IN DEVELOPING COUNTRIES IN 2000
BASED ON THE 1980 CROSS-SECTIONAL MODEL
(POINT ESTIMATE OF INCOME COEFFICIENTS)

(In millions of units and % of households)

Country	1980 Estimated	Scenario A Assuming 1960-80 GNP Growth	Scenario B IMF 1987-90 GNP Forecast	Scenario C Assuming 1% Annual GNP Growth
Total--Developing Countries	108	298	295	208
Asia				
Total	48.1	146.2	166.8	92.5
China	10.6 (4)	38.3 (13)	52.6 (18)	17.6 (6)
India	5.4 (3)	12.3 (5)	26.4 (11)	10.9 (4)
Indonesia	2.9 (8)	12.4 (23)	9.2 (17)	5.6 (10)
Iran	6.5 (67)	16.0 (91)	13.5 (77)	12.9 (74)
South Korea	3.8 (40)	10.9 (85)	9.4 (73)	6.0 (48)
Saudi Arabia	2.1 (94)	4.7 (100)	4.6 (96)	4.6 (96)
Turkey	4.3 (38)	10.8 (66)	8.8 (54)	7.4 (46)
Other	12.5	40.8	42.3	27.5
Western Hemisphere				
Total	39.7	88.9	83.0	69.8
Argentina	4.0 (58)	6.6 (74)	7.1 (79)	5.9 (66)
Brazil	15.4 (52)	38.2 (84)	31.9 (70)	27.0 (59)
Mexico	9.2 (53)	19.6 (72)	19.2 (70)	16.4 (60)
Venezuela	2.7 (73)	5.6 (86)	5.5 (84)	5.1 (79)
Other	8.4	18.9	19.3	15.4
Africa				
Total	18.3	62.6	45.3	45.3
Algeria	2.3 (48)	7.0 (72)	5.5 (56)	5.4 (56)
Nigeria	5.4 (25)	23.5 (56)	14.1 (33)	13.6 (32)
South Africa	4.1 (56)	9.5 (73)	8.0 (62)	8.3 (64)
Other	6.5	22.6	17.7	18.0

SOURCES: Equation (3), IMF (1985), World Bank (1984b).

SOURCE: Kohler et al. (RAND), 1987

Table 3

STOCK OF AUTOMOBILES IN DEVELOPING COUNTRIES IN 2000
BASED ON 1980 CROSS-SECTIONAL MODEL

Country	1980 Estimated	Scenario A Assuming 1960-80 GNP Growth	Scenario B IMF 1987-90 GNP Forecast	Scenario C Assuming 1% Annual GNP Growth
Total--Developing Countries	30.9	118.3 (100)	88.4 (100)	61.7 (100)
Asia				
Total	15.9	65.0 (54.9)	49.8 (56.3)	30.7 (49.8)
China	3.1	9.0	11.8	4.8
India	1.7	3.5	6.4	3.2
Indonesia	0.7	2.7	2.1	1.4
Iran	1.9	10.6	4.9	4.4
South Korea	0.8	5.3	3.1	1.4
Saudi Arabia	1.8	11.7	4.6	4.6
Turkey	1.0	3.2	2.2	1.8
Other	4.8	19.0	14.5	9.1
Western Hemisphere				
Total	10.1	34.1 (28.8)	26.4 (29.9)	18.9 (30.6)
Argentina	1.0	2.2	2.8	1.7
Brazil	3.8	17.5	10.1	7.2
Mexico	2.3	6.4	6.1	4.4
Venezuela	0.9	2.8	2.5	2.0
Other	2.0	5.2	5.0	3.6
Africa				
Total	5.0	19.2 (16.2)	12.2 (13.8)	12.1 (19.6)
Algeria	0.5	2.3	1.4	1.4
Nigeria	1.2	6.0	3.1	3.0
South Africa	1.1	3.2	2.2	2.4
Other	2.2	7.8 (6.6)	5.4 (6.1)	5.3

SOURCES: Equation (1), IMF (1985), World Bank (1984b).

SOURCE: Kohler et al. (RAND), 1987

Table 9

PROJECTED VALUE OF TOTAL EXPENDITURES FOR AIR CONDITIONING MACHINERY IN DEVELOPING COUNTRIES IN 2000

(In millions of 1980 U.S. dollars)

Country	1980 Estimated	Scenario A Assuming 1960-80 GNP Growth	Scenario B IMF 1987-90 GNP Forecast	Scenario C Assuming 1% Annual GNP Growth
Total--Developing Countries	1,925	11,554	5,970	4.054
Asia				
Total	1,011	7,557	3,380	2,071
China	132	483	600	212
India	70	152	304	136
Indonesia	34	144	105	64
Iran	130	966	363	308
South Korea	50	426	223	88
Saudi Arabia	183	3,267	508	508
Turkey	56	214	140	107
Other	356	1,950	1,137	648
Western Hemisphere				
Total	625	2,547	1,877	1.245
Argentina	67	159	208	115
Brazil	234	1,395	702	469
Mexico	141	446	423	290
Venezuela	64	227	198	147
Other	119	320	346	224
Africa				
Total	288	1,450	713	738
Algeria	33	161	89	89
Nigeria	63	380	175	166
South Africa	68	224	145	158
Other	124	685	304	325

SOURCES: Equation (5), IMF (1985), World Bank (1984b).

SOURCE: Kohler et al. (RAND), 1987

Table 10 presents these results for the three main geographic regions, as well as for a number of countries that have a large influence on the final estimates.

Table 10

PROJECTED USE OF CFC-RELATED AEROSOLS IN DEVELOPING COUNTRIES IN 2000 (POINT ESTIMATE OF INCOME COEFFICIENT)

(Income elasticity: 1.14)

Country	1980 (mt)	2000 (mt)	% Change
Total--Developing Countries	9,400	24,997	166
Asia			
Total	4,804	14,195	196
China	982	3,547	261
India	512	1,745	241
Indonesia	248	630	154
Iran	559	1,284	130
South Korea	269	961	257
Saudi Arabia	494	1,171	137
Turkey	305	652	114
Western Hemisphere			
Total	3,052	7,614	149
Argentina	313	790	152
Brazil	1,145	2,865	150
Mexico	687	1,709	149
Venezuela	259	672	159
Africa			
Total	1,545	3,187	106
Algeria	166	374	126
Nigeria	385	877	128
South Africa	319	561	76

SOURCE: Kohler et al. (RAND), 1987

Major Issues

* Future demand consists of:

  -- existing products
    ** market expansion, then saturation
    ** technical improvements that decrease intensity of use per unit of output

  -- new products that are developed through R&D

* Regulation will shift new products towards other approaches

  -- stringency is important

  -- in long term, demand will grow more slowly or decline

Need to model change from baseline -- controls that reduce demand -- shift in demand due to technological rechanneling

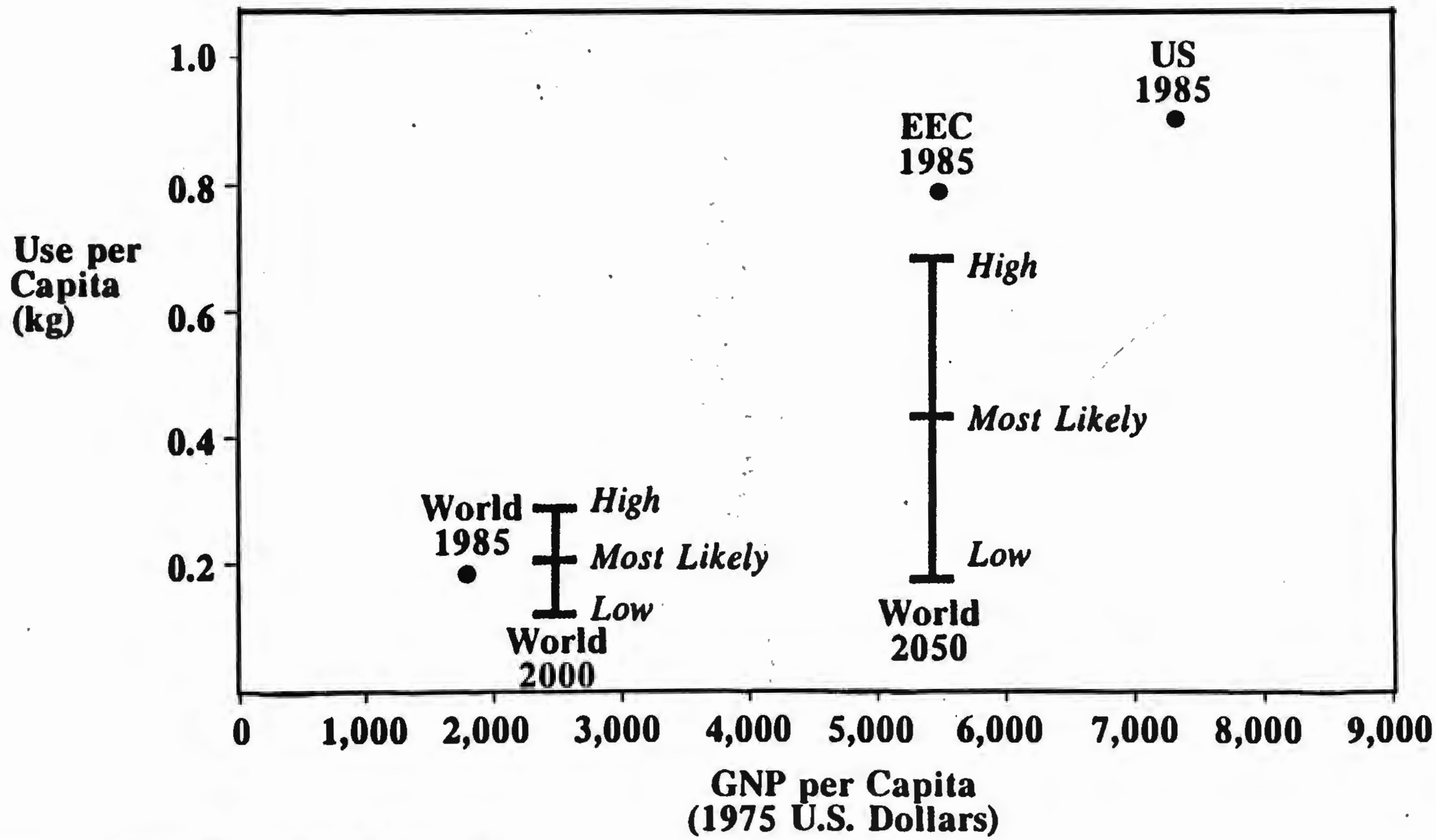
wk'g on incorp'g ↓'d growth assumps.

* This cld relax the needed regs b/c prob wld diminish in future

CONSENSUS PROJECTIONS

- For use in policy testing
- Represent the full range of estimates provided
- Four approaches
    - Eliminate extremes
    - Average
    - Composite
    - Economic growth

GROWTH RATES ARE REASONABLE
CFC-11 AND CFC-12



Source: "Overview Paper for Topic #2:
Projections of Future Demand,"
UNEP Workshop, May 1986

REGULATION OF SUBSTITUTES

How has the current use of CFCs been affected by regulations on the use of substitutes?

How might future regulations influence possible substitutes for CFCs in solvent use? Foam blowing? Aerosols?

How might such regulations vary by country? or region?

To what extent should such factors be included in developing scenarios of future CFC use?

SUPPLY CONSTRAINTS NOT SIGNIFICANT

Current production capacity

- May become binding worldwide by 2000
- Additions ongoing; especially likely in developing world

Raw materials

- Fluorspar adequate worldwide
- Other raw materials not binding

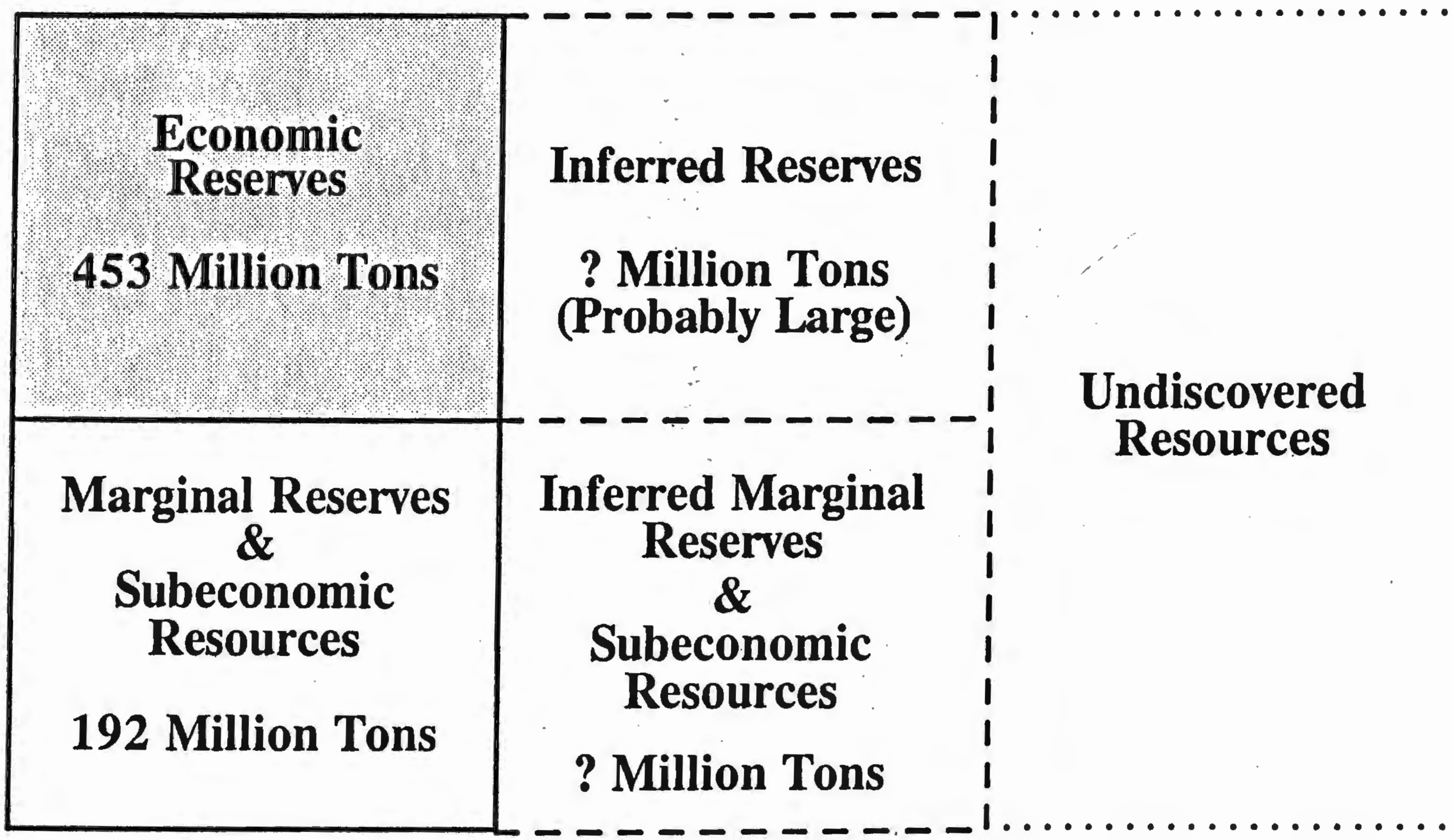
OVERVIEW

- *OBJECTIVE*: **Identify whether the availability of fluorine may become a constraint on future CFC production**

- *METHOD*: **Compare published estimates of fluorspar resources to estimates of potential future demand from**
  - **CFCs (18%)**
  - **Aluminum (42%)**
  - **Steel (35%)**

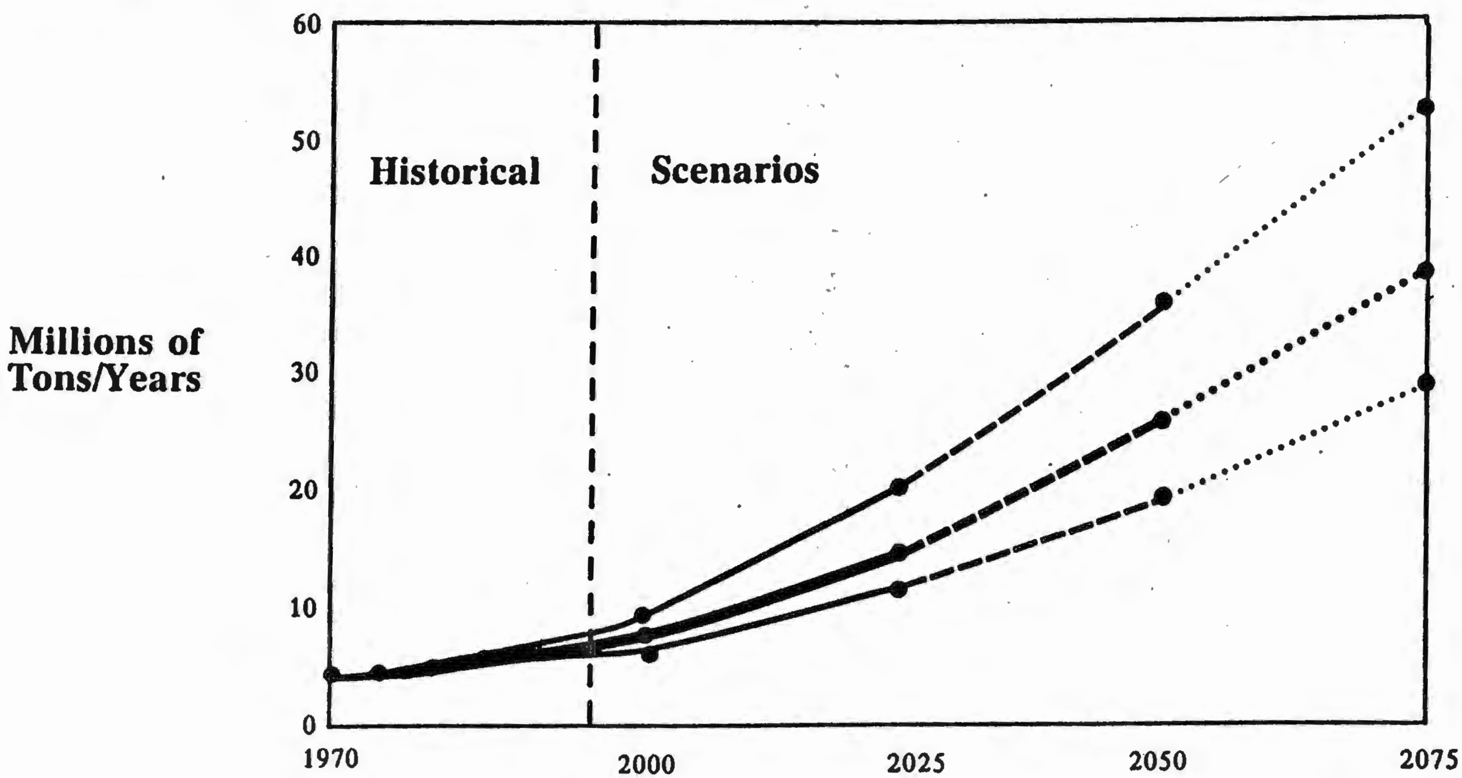
- *RESULTS*:
  - **Fluorspar is plentiful: reserves are expected to last 40 years**
  - **From current deposits we infer that considerably more fluorspar resources exist**

Fluorspar Resources



Expected Demand for Fluorspar

- Demand has been flat for approximately 10 to 15 years: 4.5 million tons per year
- Fluorspar requirements have been declining per unit of steel and aluminum
- Range of projected future fluorspar demand: 1.8% to 2.6% per year



Comparison of Demand and Resources

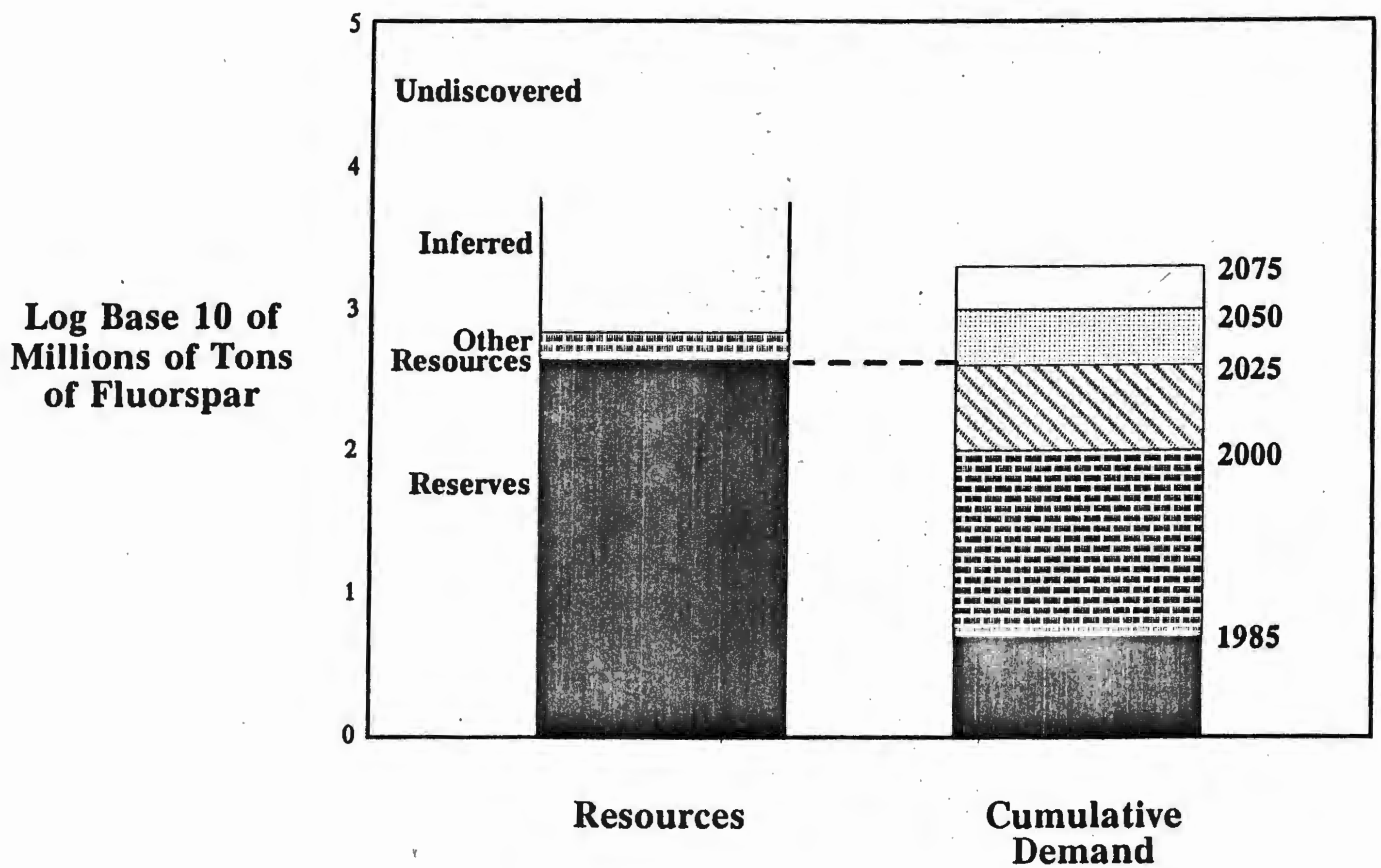


EXHIBIT D-2

Emissions from a Hypothetical 100 Million Kilograms of Production in 1985

1 Year	2 Cumulative Fraction Released	3 Annual Fraction Released	4 Annual Emissions (millions of kg)
1985	0.190	0.190	19.0
1986	0.271	0.081	8.1
1987	0.344	0.073	7.3
1988	1.000	0.656	65.6
TOTAL		1.000	100.0

Get for 12

non-hermetically sealed refrig's (incl's insulating foams) & 11 is small % of refrig.

EXHIBIT D-1

Release Tables for CFC-11

	Aerosol Propellant		Flexible Foam		Rigid Polyurethane Foam		Rigid Nonurethane Foam		Refrigeration		Miscellaneous	
Year	Cumulative Fraction Released	Annual Fraction Released	Cumulative Fraction Released	Annual Fraction Released	Cumulative Fraction Released	Annual Fraction Released	Cumulative Fraction Released	Annual Fraction Released	Cumulative Fraction Released	Annual Fraction Released	Cumulative Fraction Released	Annual Fraction Released
1	1.000	1.000	1.000	1.000	0.145	0.145	0.600	0.600	0.190	0.190	1.000	1.000
2					0.190	0.045	1.000	0.400	0.271	0.081		
3					0.235	0.045			0.344	0.073		
4					0.280	0.045			1.000	0.656		
5					0.325	0.045						
6					0.370	0.045						
7					0.415	0.045						
8					0.460	0.045						
9					0.505	0.045						
10					0.550	0.045						
11					0.595	0.045						
12					0.640	0.045						
13					0.685	0.045						
14					0.730	0.045						
15					0.775	0.045						
16					0.820	0.045						
17					0.865	0.045						
18					0.910	0.045						
19					0.955	0.045						
20					1.000	0.045						

Source: Quinn, T., et al. (1980), "Projected Use, Emissions, and Bank of Potential Ozone Depleting Substances," The RAND Corporation, prepared for the U.S. Environmental Protection Agency, Washington, D.C.

*** DRAFT FINAL ***

EXHIBIT C-1

SCHEMATIC OF CFC USE, EMISSIONS, AND BANKS

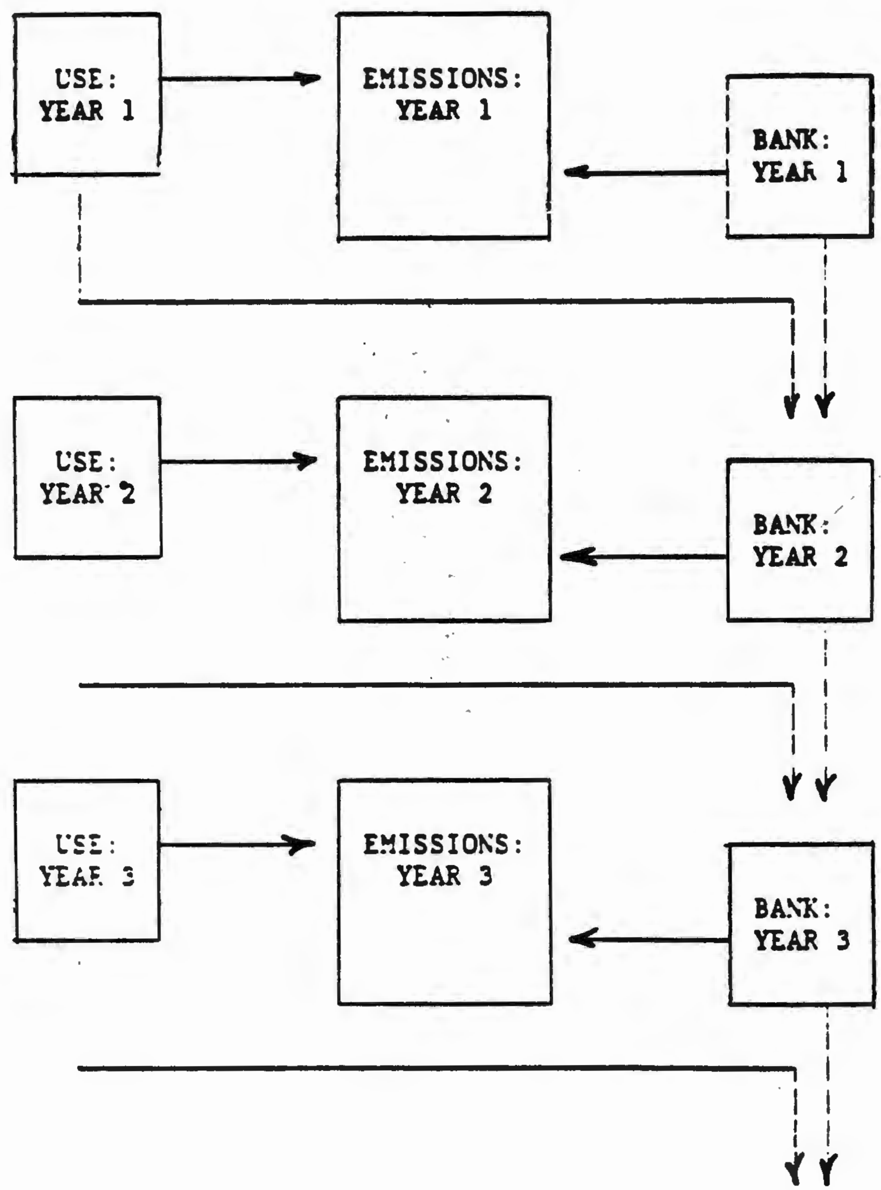


EXHIBIT D-3

Emissions from Production Over a Series of Years (millions of kilograms)

Year	Production	1985	1986	1987	1988	1989	1990
1985	100	19.0	8.1	7.3	65.6	--	--
1986	110	--	20.9	8.9	8.0	72.2	--
1987	120	--	--	22.8	9.7	8.8	78.7
1988	130	--	--	--	24.7	10.5	9.5
1989	140	--	--	--	--	26.6	11.3
1990	150	--	--	--	--	--	28.5
TOTAL EMISSIONS PER YEAR		19.0	29.0	39.0	108.0	118.1	128.0

Bank

EXHIBIT C-2

EMISSIONS FROM EXISTING BANKS
(percentage)

Years from Now	CFC-11	CFC-12
1-10	27.5	85.0
11-20	27.0	6.3
21-30	6.2	7.5
31-40	3.9	0.1
41-50	3.8	0.1
51-60	3.3	0.1
61-70	2.8	0.1
71-80	2.7	0.1
81-150	22.8	0.7
Total	100.0	100.0

Source: See text.

Exhibit C-3 shows the rate of release after the use of CFCs in non-aerosol applications.[2] For example, 66.4 percent of the use of CFC-11 in non-aerosol applications is estimated to be released promptly, i.e., in the year of use (the exhibit shows this 66.4 percent being released zero years after use). Again, CFC-11 shows a substantial fraction being banked over a long period of time.

These release rates were derived by: (1) identifying the mix of applications of each CFC (i.e., the fraction going to air conditioners, foams, refrigerators, etc.); (2) identifying the rate of emissions from each of these applications; and (3) weighting the rates of emissions by the mix of the applications to estimate release rates for the CFC type. The data describing the rates of release by application and the mix of applications are presented in Exhibit C-4. These release rate estimates were developed from Environment Committee Report on Chlorofluorocarbons by OECD (1982). The mix of uses is for the U.S. in 1976 as reported in Economic Implications of Regulating Chlorofluorocarbon Emissions from Nonaerosol Applications, by The Rand Corporation (June 1980). The emissions rates reported in Exhibits 3 and 4 were used for all parts of the world, throughout the entire period examined.

[2] The release rate for the aerosol applications of CFC-11 and CFC-12 as well as all the use of CFC-113 is assumed to be 100 percent in the year of use.

EMISSIONS - CONCENTRATIONS MODEL

Exponential decay based on lifetime:

$$C_t = e^{-1/L} C_{t-1} + a X_t$$

C_t = concentration in year t (ppbv)

L = lifetime (years)

a = conversion factor from mill kg to ppbv

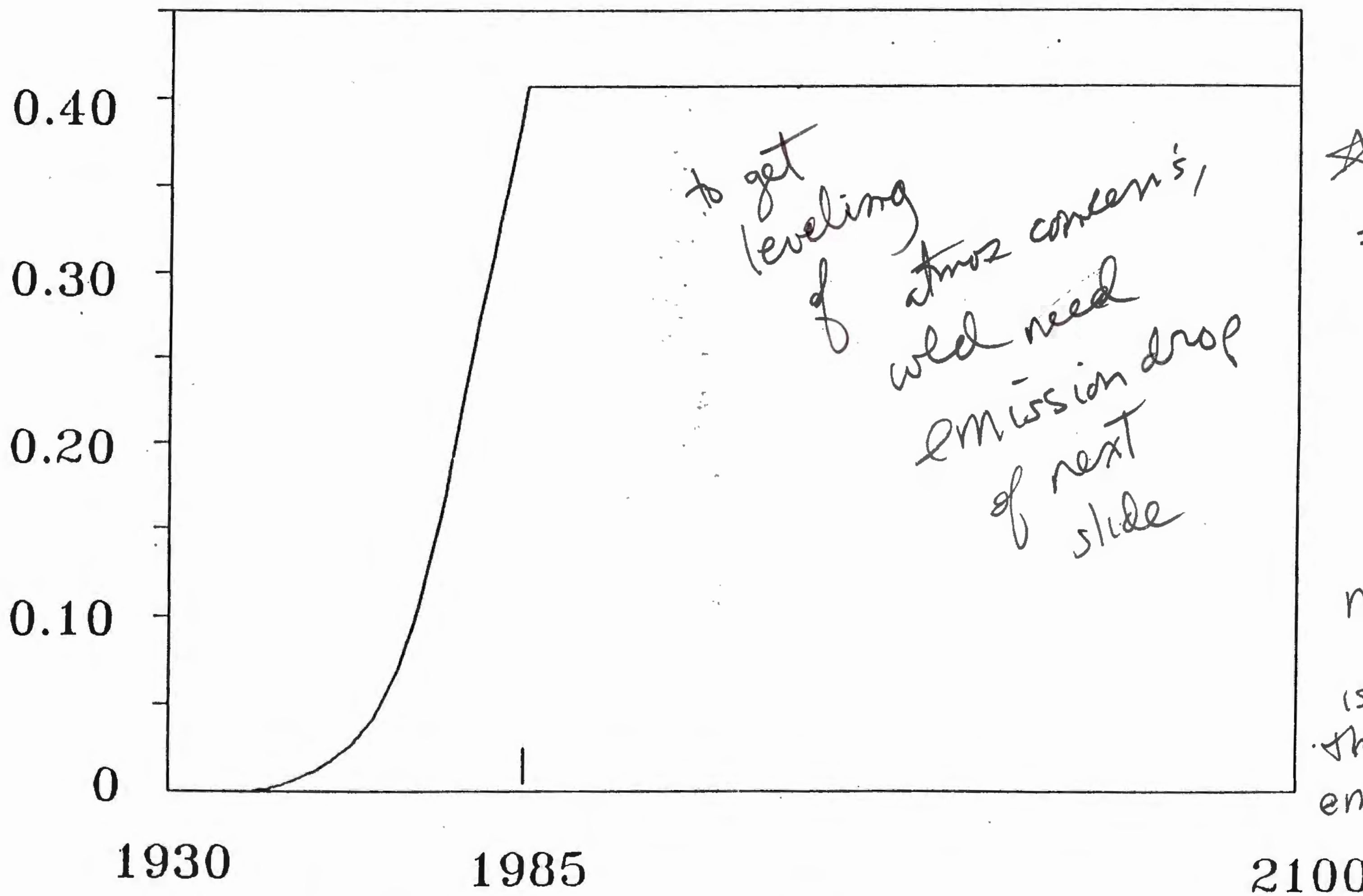
X_t = emissions in year t (mill kg)

Source: Rind and Lebedeff (GISS), 1984.

This is true for 11, & 113 & qualitatively for halons (b/c lifetime longer & depletion pot'l)

CFC−12 Atmospheric Concentrations

(ppbv)



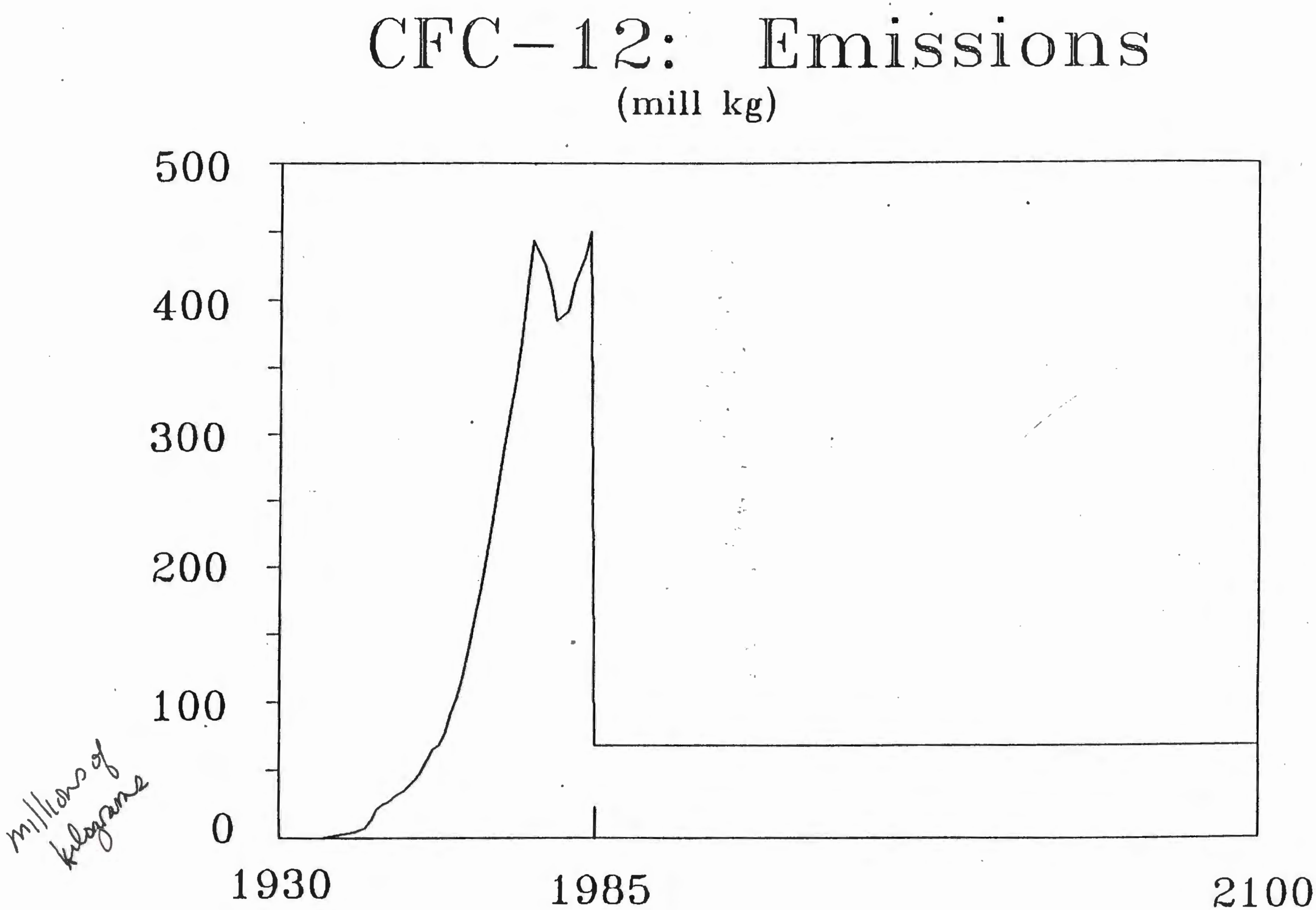
to get leveling of atmos concen's, wld need emission drop of next slide

☆ The 95% # in U.S. position is a result of this slide

↓

natural removal rate of CFC12 is so much less than the 1985 emissions level that need to go 85% less than 1985 to stabilize concen's.

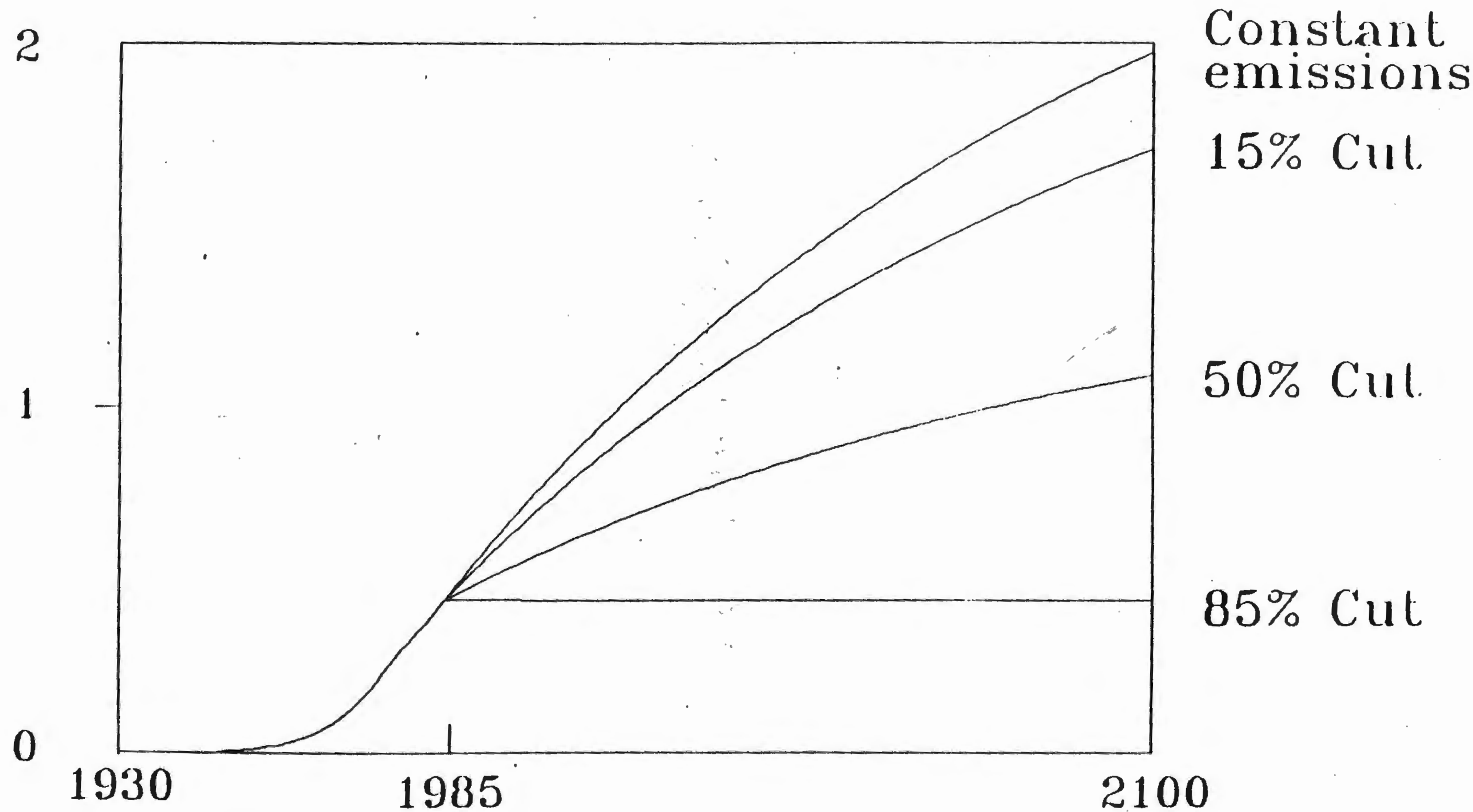
Source: Hoffman (1986), "Analysis of Stringency of Control Strategies to Achieve Alternative Ozone Depletion Limits," UNEP Workshop



Source: Hoffman (1986), "Analysis of Stringency of Control Strategies to Achieve Alternative Ozone Depletion Limits," UNEP Workshop

CFC-12: Atmospheric Concentrations from Different Emission Trajectories

(ppbv)



Source: Hoffman (1986), "Analysis of Stringency of Control Strategies to Achieve Alternative Ozone Depletion Limits," UNEP Workshop

* The 7 complex models are equally precise in modelling atmospheric concentrations.

FIGURE 1

EFFECTS OF CHANGES IN COMPOSITION OF ATMOSPHERE

Rising Levels	Effect on Plants	Effect on Surface Climate	Effect on Tropospheric Chemistry	Effect on Stratospheric Composition and Structure
CO_2	Changes physiology; increases photosynthesis; changes water relations	Greenhouse gas	No direct effect	Cools stratosphere, increasing ozone levels by slowing destruction processes
Methane	None	Greenhouse gas	Creates ozone; alters OH abundance; increases CO abundance	o Interferes with catalytic destruction by chlorine, thereby increasing ozone o Alters vertical distribution of ozone, increasing greenhouse effect and possibly changing circulation patterns. o Creates additional greenhouse effect in stratosphere by adding water, adding to tropospheric greenhouse warming normally considered
N_2O	None	Greenhouse gas	No direct effect	Contributes odd nitrogen to stratosphere: -- can, in some cases, interfere with chlorine catalysis of ozone -- by itself, acts as catalyst to ozone destruction
CO	None	Indirectly increases CO_2 and O_3, two greenhouse gases	Alters OH abundance thereby increasing methane abundance	Does not reach stratosphere in significant quantity; indirect

FIGURE 2

GRAPH OF CO_2 CONCENTRATIONS: 1958-1984

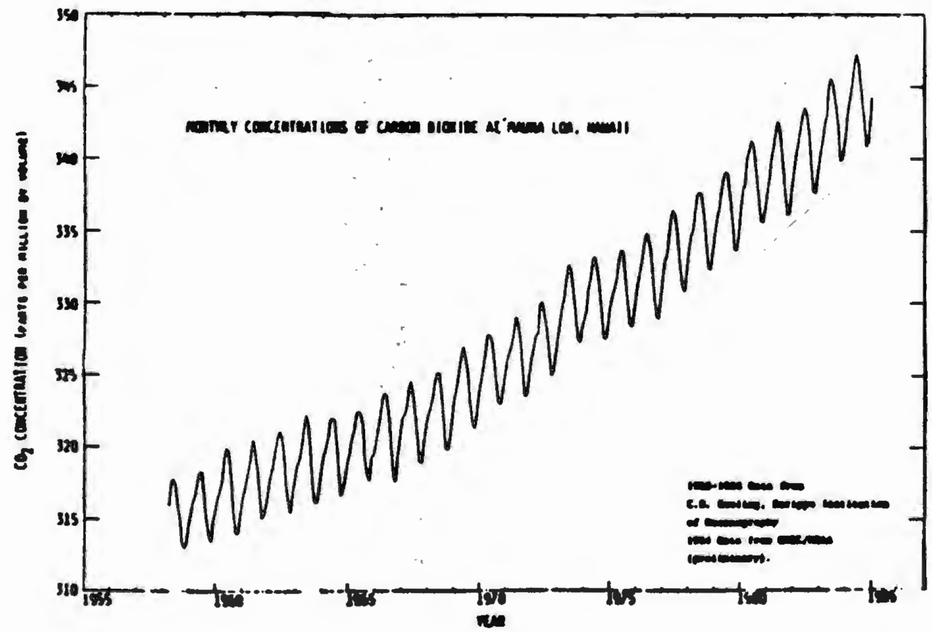
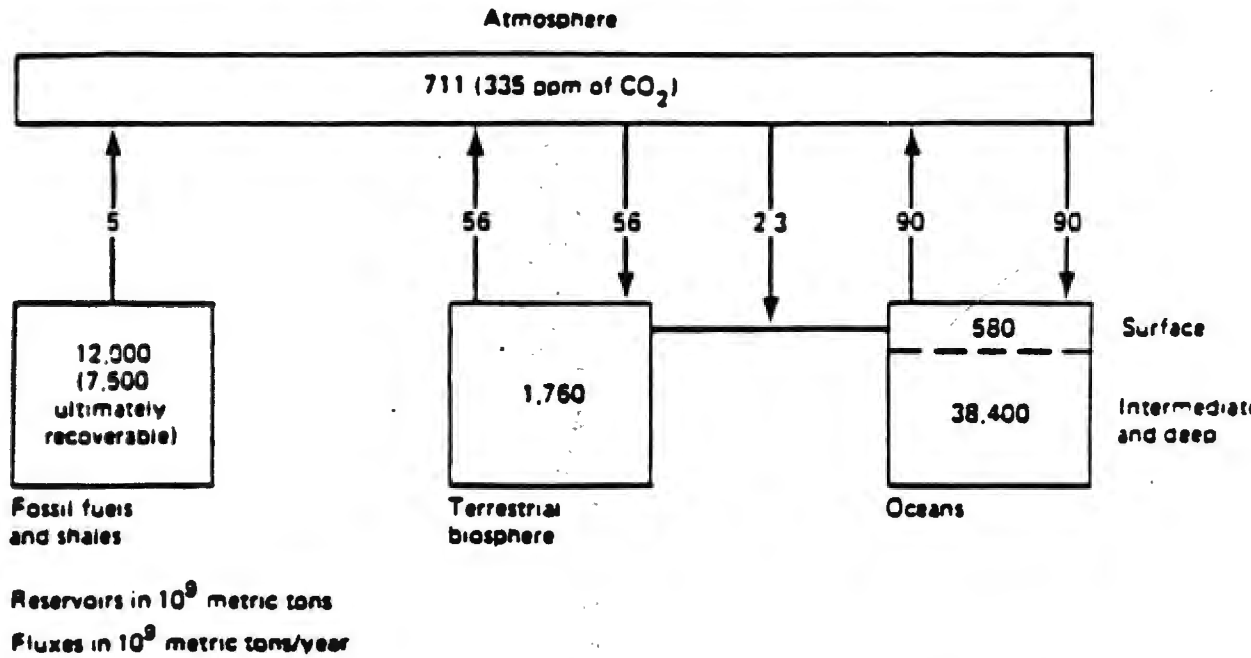


FIGURE 4

A SCHEMATIC OF THE CARBON CYCLE



Source: CEQ (1981), as shown in World Meteorological Society, "Report of the Scientific Workshop on CO_2," Report 474, Geneva 1977.

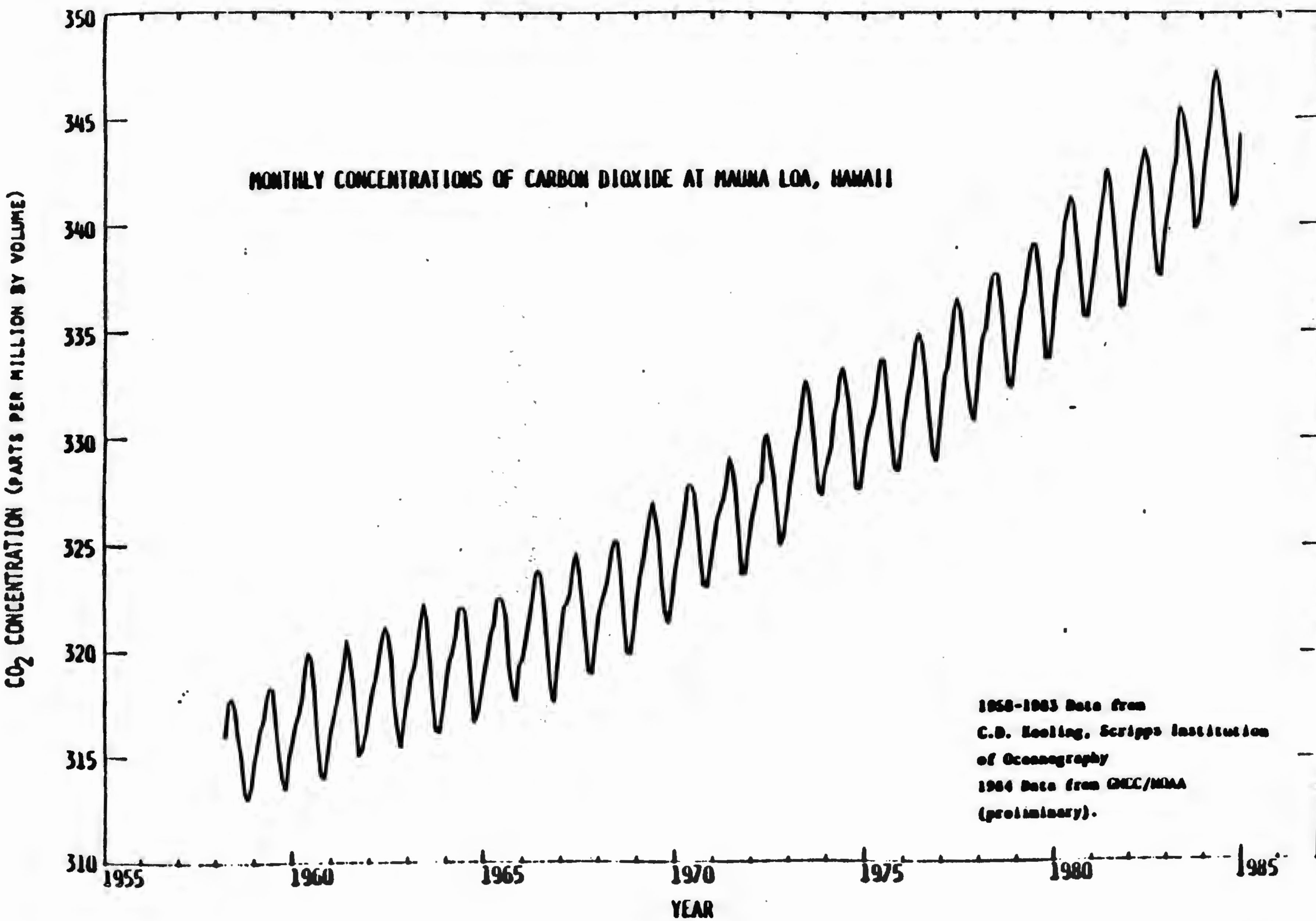
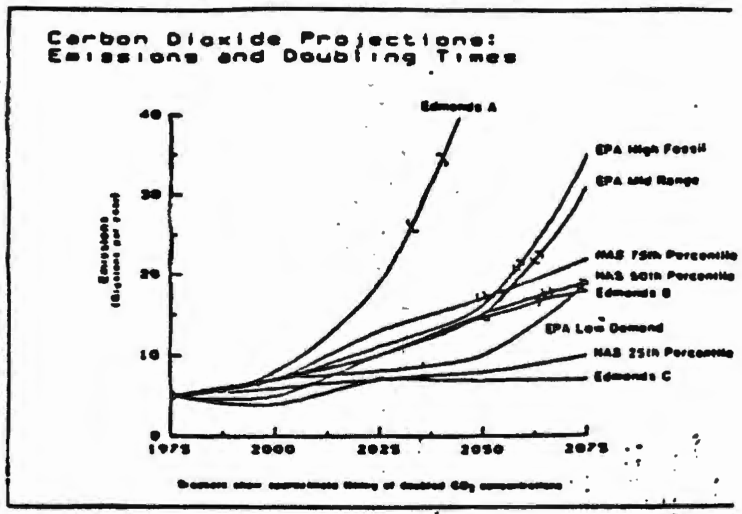

MONTHLY CONCENTRATIONS OF CARBON DIOXIDE AT MAUNA LOA, HAWAII
CO_2 CONCENTRATION (PARTS PER MILLION BY VOLUME)
350
345
340
335
330
325
320
315
310
1955
1960
1965
1970
1975
1980
1985
YEAR
1958-1983 Data from
C.D. Keeling, Scripps Institution
of Oceanography
1984 Data from GMCC/NOAA
(preliminary).

FIGURE 5

GRAPH OF CO_2 EMISSIONS AND CONCENTRATIONS PROJECTIONS (NAS, EPA, Edmonds)

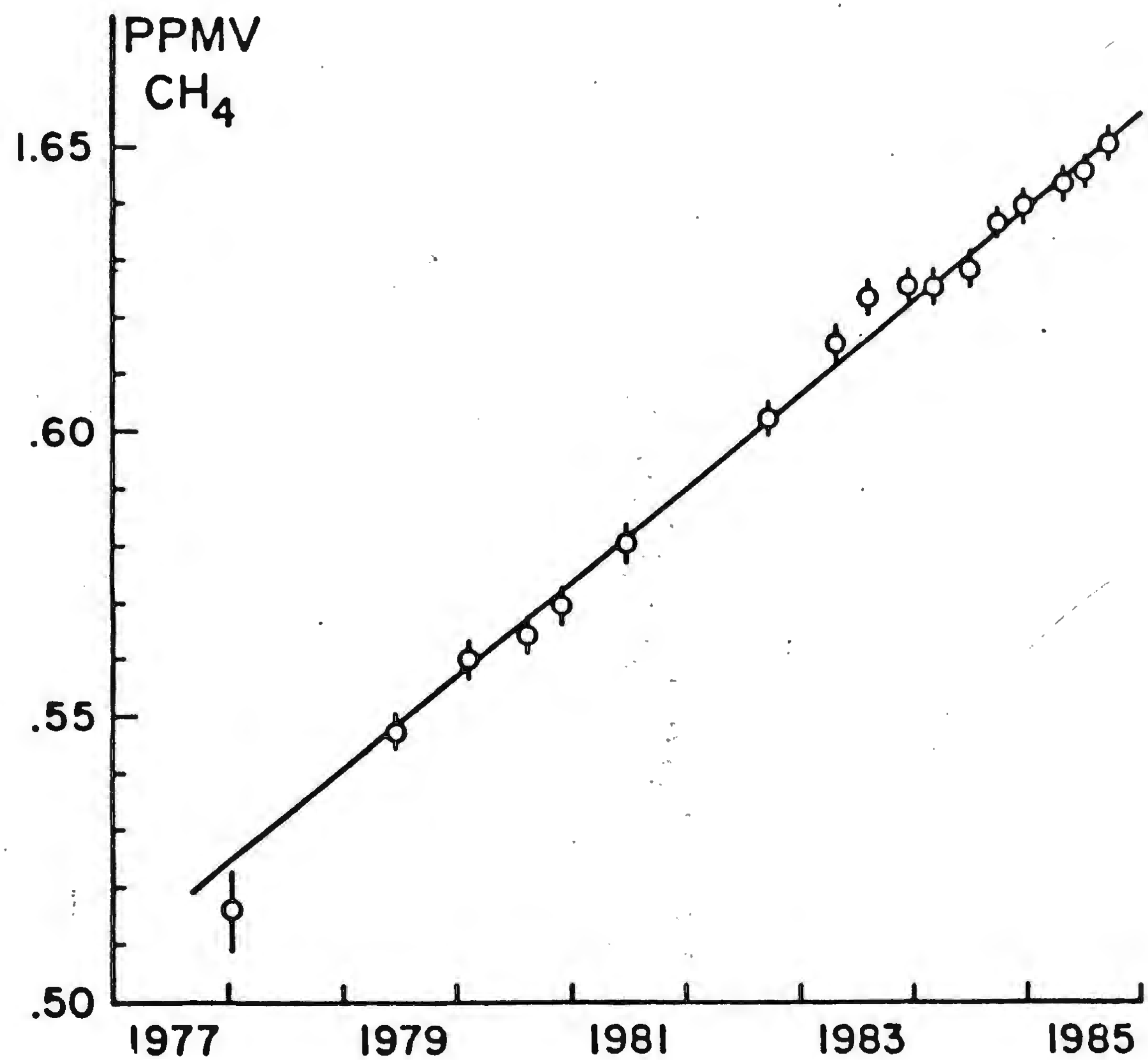


SUMMARY OF SCENARIOS PROPOSED FOR POLICY TESTING

Carbon dioxide (CO_2) concentrations:

Year	NAS 50th Percentile CO_2 Concentration (ppm)
1975	340
2000	366
2025	422
2050	508
2075	625
2100	770

Source: Nordhaus and Yohe (1983).



Globally averaged concentrations of CH_4 from 1977 to 1985
(Rowland)

FIGURE 7

METHANE SOURCES (10^{12} gm yr-1)
(multiply by 0.75 to obtain g C/yr)

	COLUMN I Ehhalt & Ehhalt & Schmidt	COLUMN II Rasmussen	
Enteric fermentation (cattle, sheep, etc.)	100-200	100-150	
Rice paddies	~280	100±50	a
Wetlands	190-300	150±50	b
Biomass burning	-	10-60	c
Fresh water lakes	1-25	-	d
Oceans	1-17	-	f
Tundra	0.3-3	-	d
Anthropogenic/fossil fuel	16-50	-	f
Other	-	10-150	e
Total	586-825	390-765	

Column I is taken from Ehhalt (1974) and Ehhalt and Schmidt (1978).

Column II is taken from Khalil and Rasmussen (1983).

a All rice studies.

b Harris - area est. and fluxes, Khalil and Rasmussen.

c $\Delta CH_4/\Delta CO_2$ = 0.3-2%, Seiler *et al*. paper.

d Assumed in (b).

e Seiler *et al*.

f Should be updated.

Adapted from NASA (1986).

↳ CO globally will go down in 2000 b/c >effic cars.

* CO Affects Methane to ↑ Concentr

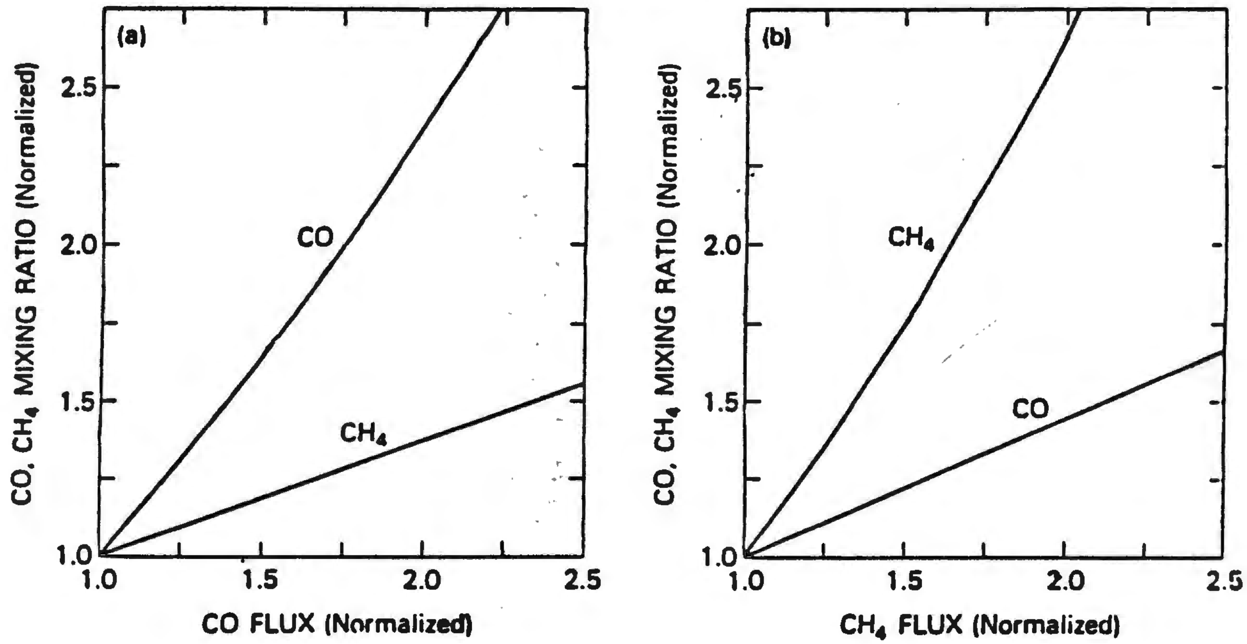
↑'g Source term methane

↓'g sink term methane

└ CO is impt to this

FIGURE 6

TWO WAYS THAT METHANE CONCENTRATIONS COULD HAVE CHANGED



Increase in concentration of CH_4 wholly attributable to increase in CO flux

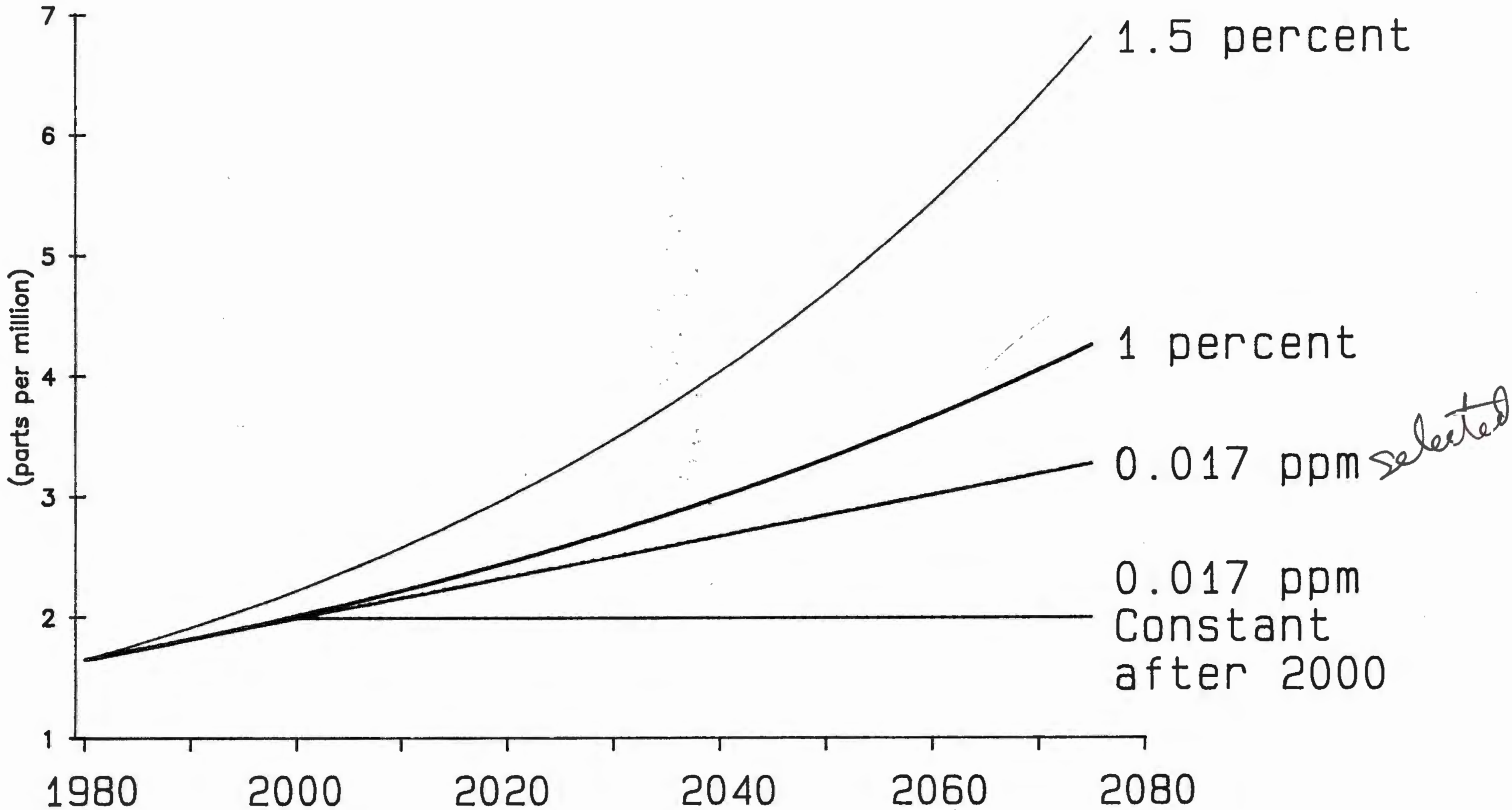
Increase in concentration of CH_4 wholly attributable to increase in CH_4 flux

Source: Thompson and Cicerone, 1985.

SUGGESTED SCENARIO FOR METHANE

Continued growth at 0.017 ppbv

Methane Scenarios for Policy Testing



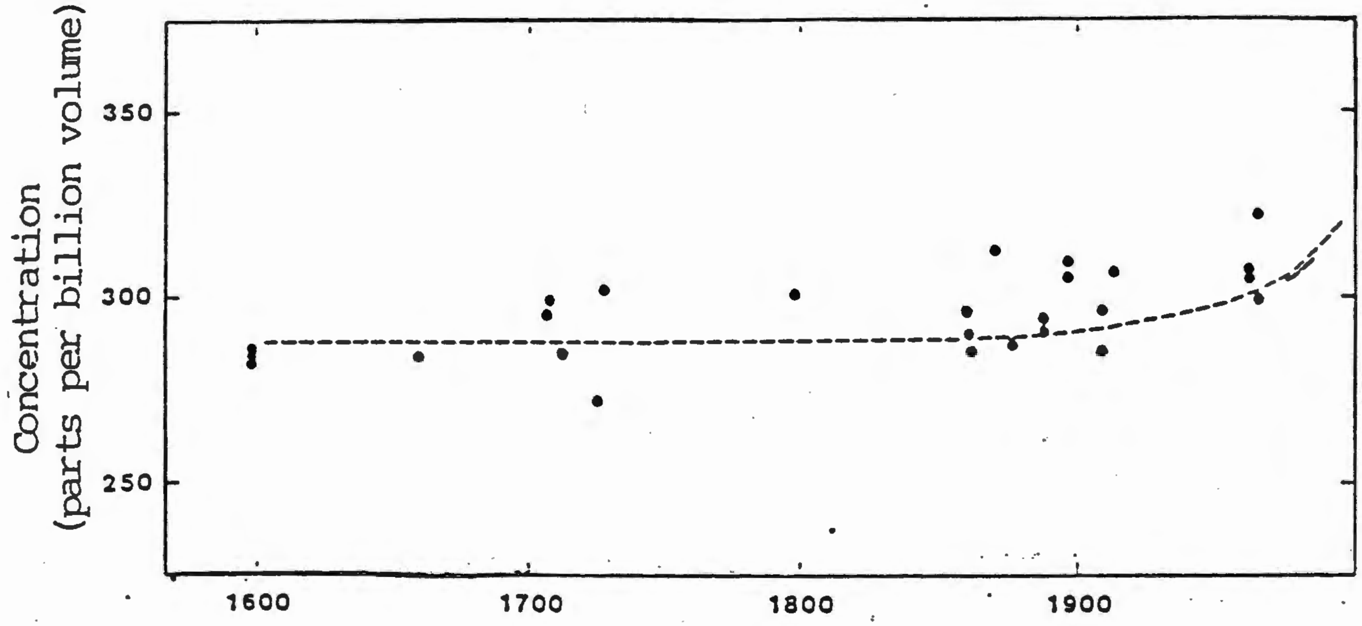


Figure 5. Ice core measurements of historical nitrous oxide (N_2O) concentrations.

The ice core data show that concentrations were relatively constant until the time of the Industrial Revolution. Since the year 1600 they have increased by 8 percent. Source: Pearman, G.I., et al. Evidence of changing concentrations of atmospheric CO_2, N_2O and CH_4 from air bubbles in Antarctic ice. Nature. 320: 248-250, 1986.

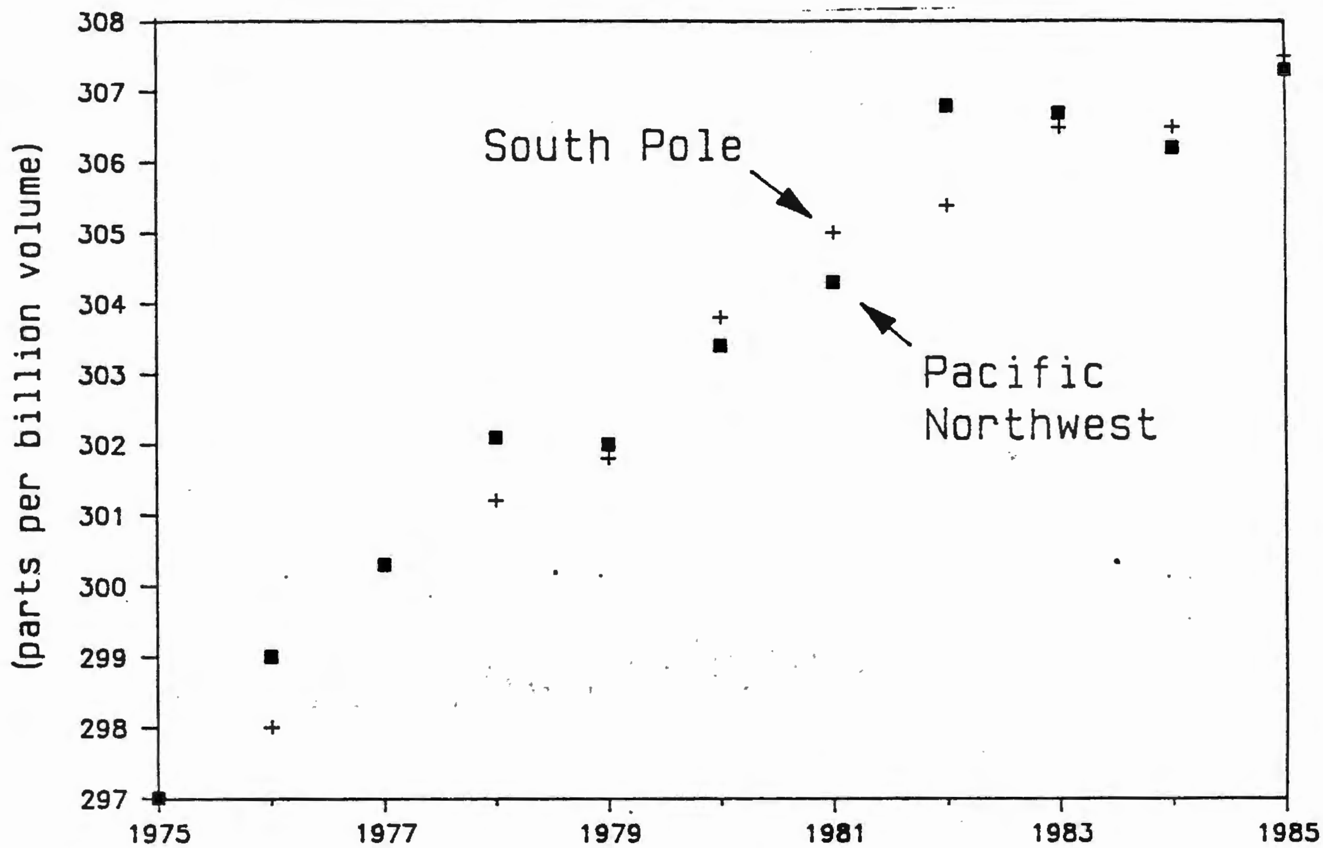


Figure 4. Measured increases in tropospheric concentrations of nitrous oxide (N_2O).

Data were taken at the South Pole and in the U.S. Pacific Northwest. Concentrations are increasing at about 0.3 percent per year. Source: Rasmussen, R.A., and M.A.K. Khalil. Atmospheric trace gases: trends and distributions over the last decade. Science. 232: 1623-1624, 1986.

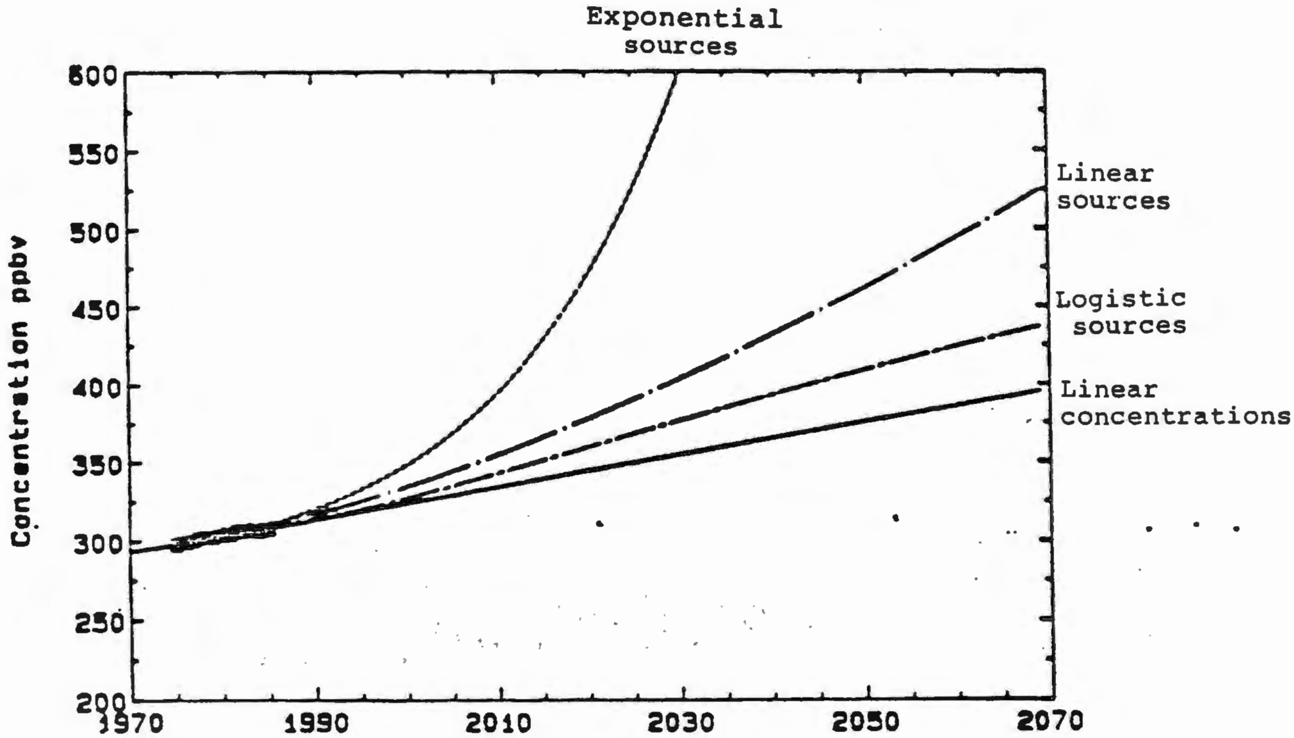


Figure 8. Projected increases in nitrous oxide (N_2O).

"Projections are based on various models for extrapolating present concentrations and emissions. The methods considered are a linear extrapolation of present rates of growth of concentrations, linear and exponential increases of present anthropogenic emissions, and a logistic model for the growth of emissions." Source: Khalil, M.A.K., and R.A. Rasmussen. Logistic and other models for the trends of nitrous oxide. In: National Oceanic and Atmospheric Administration. Geophysical Monitoring for Climatic Change. 1985 Annual Report. Volume 12, 1986.

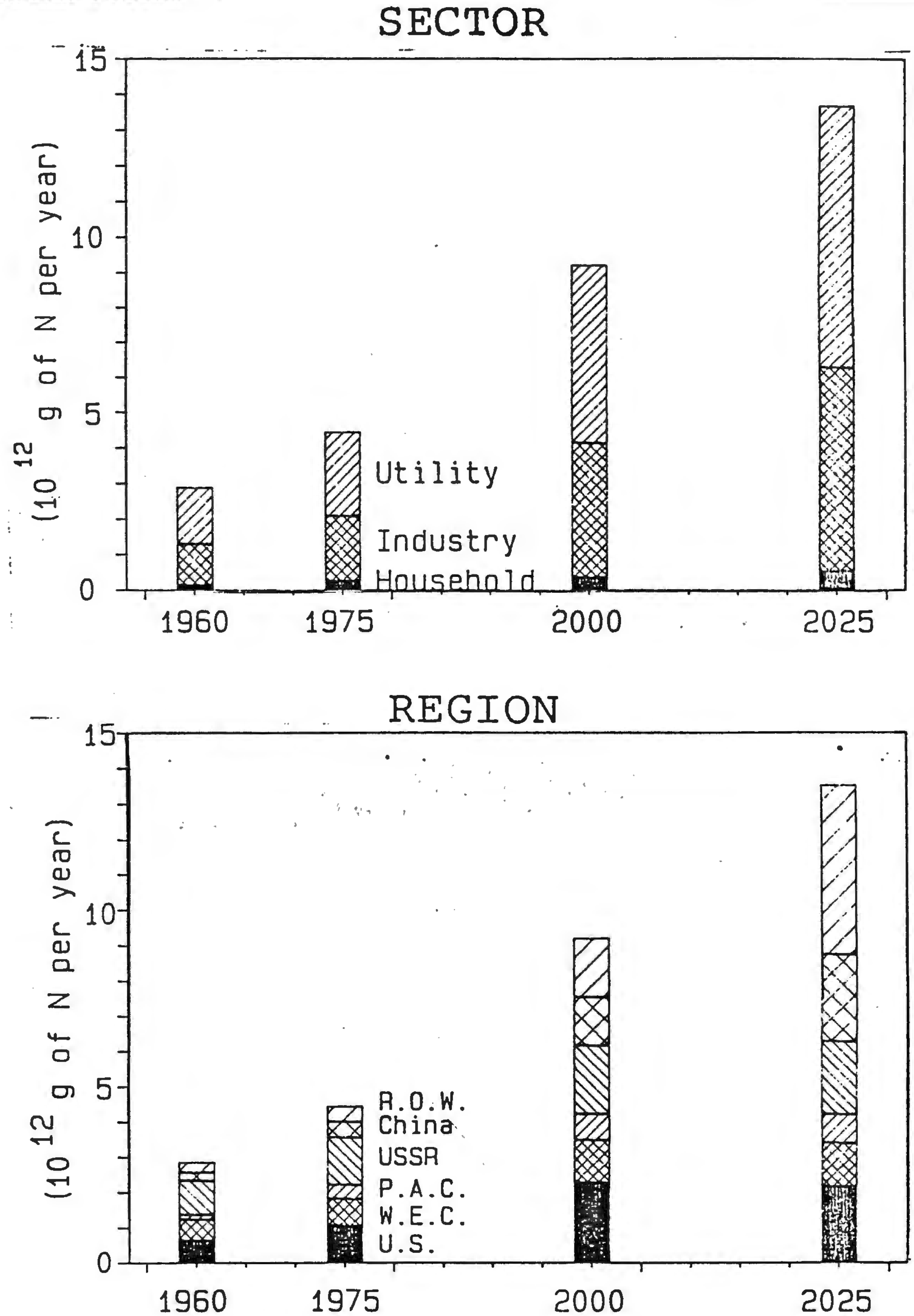


Figure 9. Historical and projected nitrous oxide (N_2O) emissions from combustion by sector and region.

Increases in N_2O are large: a doubling in emissions from 1975 to 2000 and a 44 percent increase from 2000 to 2025. Source: Source: Kavanaugh, M. Estimates of future CO, N_2O and NO_x emissions from energy combustion. Atmospheric Environment. 21(3): 463-468, 1987.

SUGGESTED SCENARIO FOR NITROUS OXIDE

0.2 percent per year growth in concentrations

Two Kinds of Models Useful for Assessment

1-D   2-D

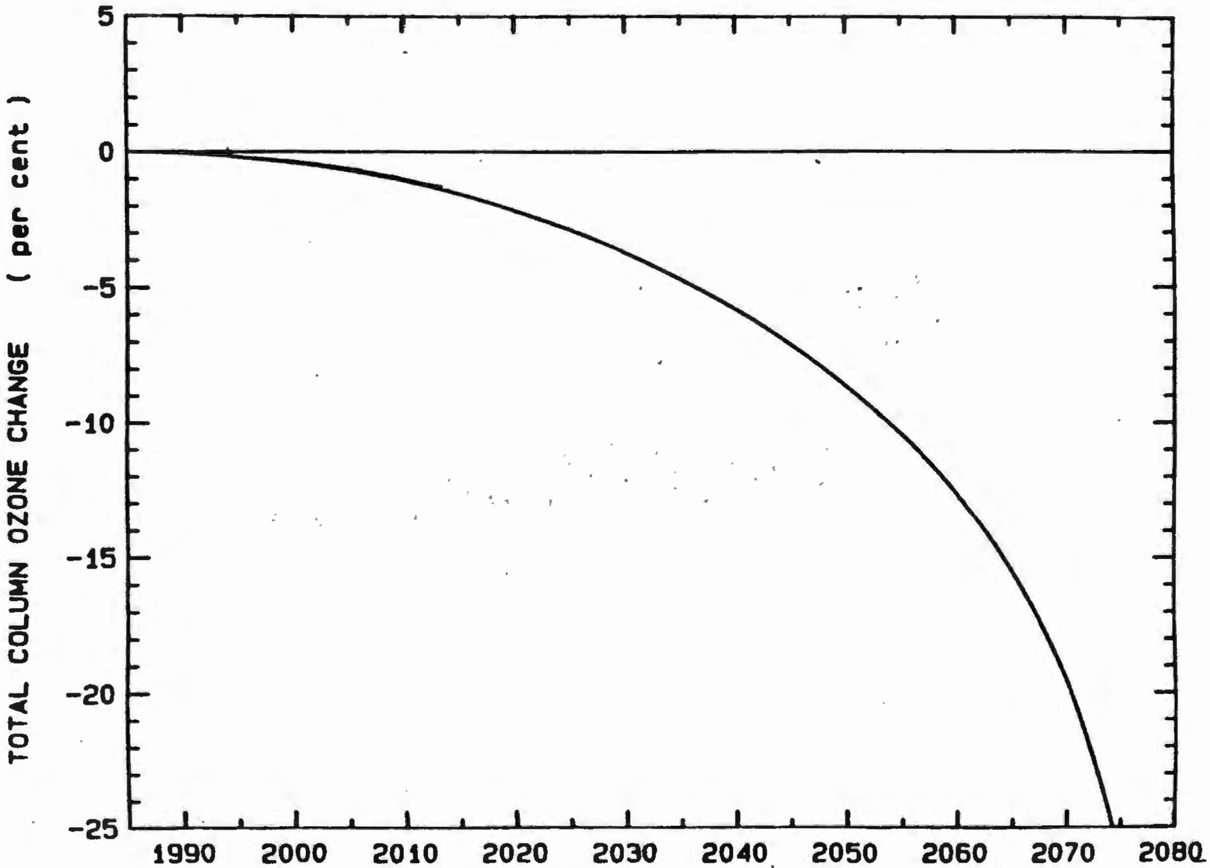
Watson's quote.

"In summary, while the 1-D models remain useful tools for assessment it is becoming clear that 2-D models provide a much more detailed picture of the atmospheric response to perturbations"

– World Meteorological Organization, 1986.

EXHIBIT 5-37a

Time Dependent, Globally Averaged Change in Ozone
for Coupled Perturbations
(LLNL 1-D Model)
"Reference Case"

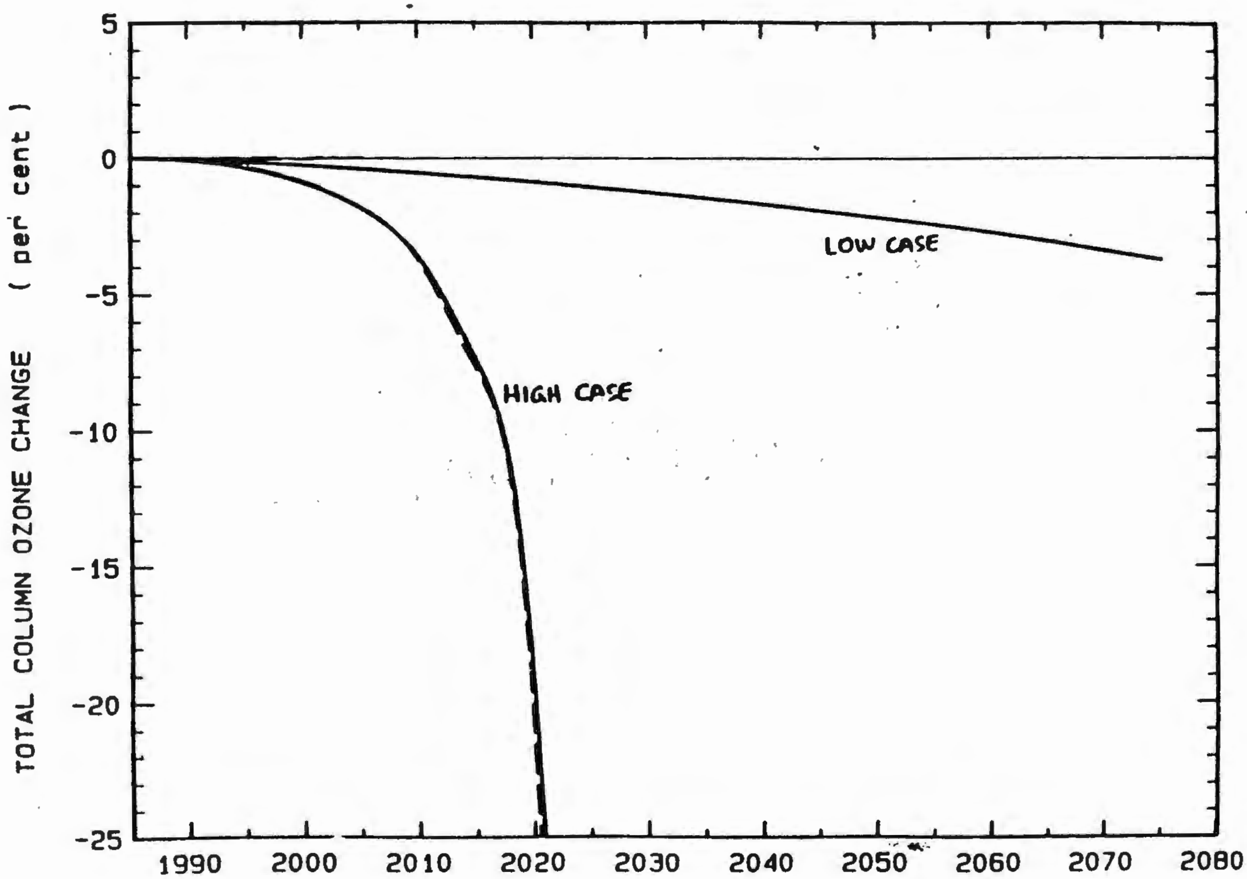


Total column ozone change for "reference case" scenario of trace gases: ~ 2.5% growth in CFCs, concentrations of CH_4 at 1%, N_2O at 0.25%, and CO_2 at ~0.6%.

Source: Connell and Wuebbles (1986).

EXHIBIT 5-37b

Time Dependent, Globally Averaged Change in Ozone for Coupled Perturbations (LLNL 1-D Model)



Total column ozone change for "low" and "high" scenarios of trace gases:

	Low	High	
CFCs	1.4	4.1	(emissions)
CH4	1.0	1.0	(concentrations)
N2O	0.25	0.25	(concentrations)
CO2	~0.6	~0.6	(concentrations)

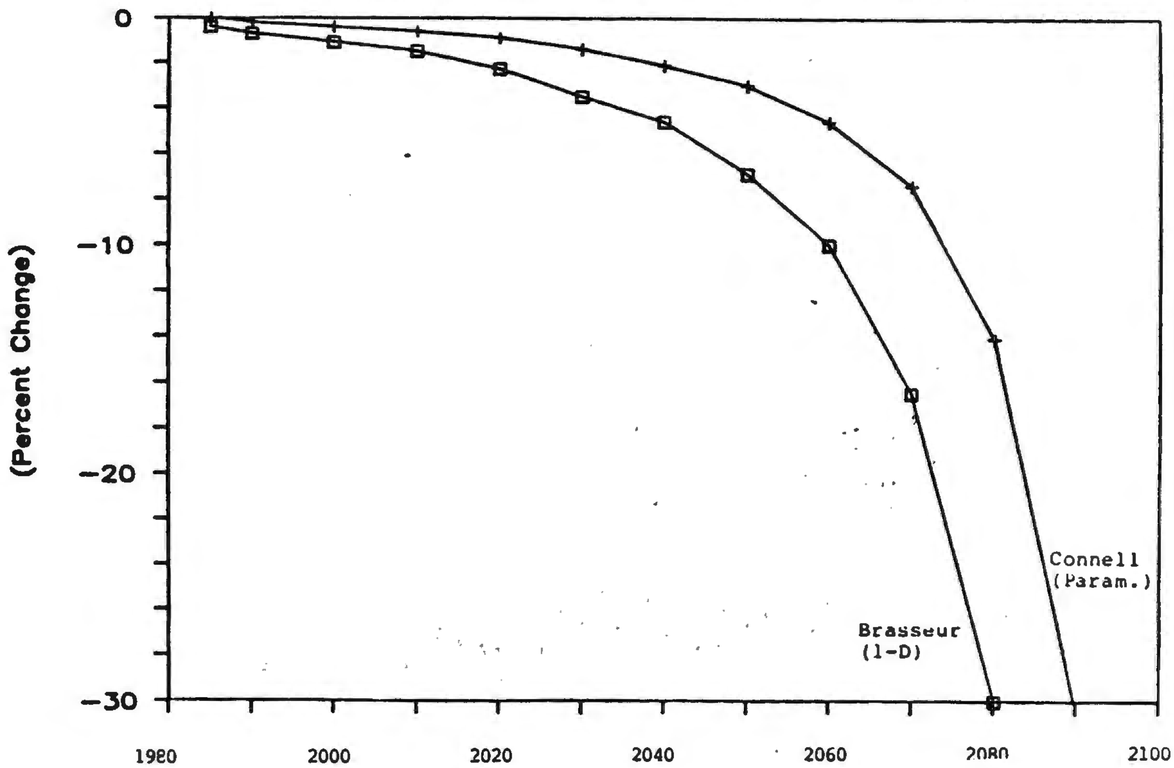
Source: Connell and Wuebbles (1986).

this uses low estim of growth of gases.
~~8%~~ 5% = 15yrs
7% = recent.

*** DRAFT FINAL ***

EXHIBIT 5-33

Model Comparison: Time Dependent Change in Ozone for CFC Growth and Coupled Perturbations



Time dependent change in ozone, as calculated by the 1-D model of Brasseur and DeRudder, (1986) and Connell's parameterization of the LLNL 1-D model. Trace gas assumptions are shown in Exhibit 5-30 and may be summarized as:

Compound	Growth Rate (%/year)	
CFC-11 and CFC-12	1.5% to 2000, 3% from 2000 to 2100	(emissions)
CFC-113	1.0% to 2000, 3% from 2000 to 2100	(emissions)
CC14	constant	(emissions)
CH3CC13	constant	(emissions)
CH4	1.0	(concentrations)
N2O	0.25	(concentrations)
CO2	~0.50	(concentrations)

Note that Connell's parameterization produces lower results than Brasseur's 1-D model.

Source: Brasseur and DeRudder, (1986); and Connell, (1986).