# Modeling Emissions of HFCs and PFCs in the Fire Protection Sector

Daniel P. Verdonik, Eng.Sc.D.
Hughes Associates, Inc.
3610 Commerce Drive, Suite 817
Baltimore, MD 21227
+1 410 737 8677

## ABSTRACT

In concert with the Greenhouse Gases Emissions Estimating Consortium (GGEEC), the fire protection sector has developed a model to estimate the global emissions of HFCs and PFCs from fire protection applications. The model uses a top-down, tier 2 method based on the estimated global consumption of the former Halon 1301 market for fixed fire protection. The global consumption is apportioned among 13 global regions that have similar fire protection use patterns for halon and halon alternatives, using regional specific factors for the uses of alternatives and percent of global Gross Domestic Product. The results are provided in metric tons of carbon equivalents (MTCE) and can be listed individually for each of the 194 Countries in the model, for each of the 13 regions, or globally. The intent is to employ the model to estimate emissions in lieu of expensive, time-consuming alternative methods that have greater uncertainty and/or to serve as a check of these alternative methods.

## BACKGROUND

At the third Conference of Parties (COP 3) of the United Nations Framework Convention on Climate Change (UNFCCC), the Parties decided in Decision 2/CP3 to allow different methods of calculating greenhouse gas (GHG) inventories with various levels of sophistication. The simplest calculation method, the "Potential Emissions" approach, assumes that yearly emissions are equal to the yearly production or consumption of a given chemical. The Potential Emissions method recognizes that all of a chemical produced or consumed has the potential to be emitted, but this method is extremely inaccurate in predicting *when* these emissions will actually occur. In contrast, Decision 2/CP3 also allows calculation methods that more accurately predict when the emissions will actually occur, the so-called "Actual Emissions" approach. The Actual Emissions approach is much more data intensive, but it is also significantly more accurate as it incorporates the time-dependant delay between production, consumption or sales, and the resulting emission from the end-use.

The simple Potential Emissions approach was the method applied under the Montreal Protocol, and it has proven to be extremely inaccurate in predicting the emissions and remaining bank of halons used in fire protection. For example, halon production in developed countries ceased on 1 January 1994, and yet ten years later halon is still available to support critical needs. The halon is still available because there is a significant time-dependant delay between the production and the emissions of halons that the Potential Emissions method does not account for. This time-dependant delay was recognized by the fire protection community and was an important factor in eliminating halon production before other Ozone-Depleting Substances were eliminated. To support the early phase-out, it was necessary to determine how much halon was still available versus that which had been lost, i.e., emitted.

A model was developed in 1991 to estimate the global emissions of halons, the quantity that had not yet been emitted (the halon "bank"), and the supply that could be available through recovery and recycling efforts. The model, first published in the 1991 Halon Technical Options Committee Report [1], used an Actual Emissions approach based on well-known, worldwide production data, i.e., a top-down, tier 2 approach. The model showed that a major portion of the halon produced had not yet been emitted and was contained in existing fire protection equipment. With proper handling and care, this "banked" halon would be sufficient for meeting critical needs. These results and the approach of the model were widely accepted and played a prominent role in the Montreal Protocol decision to accelerate the phase-out of halon production.

The GHGs of interest to the fire protection sector consist primarily of the hydrofluorocarbon (HFC) and perfluorocarbons (PFC) suppression agents. While these chemicals will never be used in all of the applications where halon was historically used, they are expected to follow similar use patterns to halon in the applications where they are used. Analogous to the case of the halons, the Potential Emission approach will not accurately predict emissions, or conversely the size of the existing bank of HFCs and PFCs. This bank will likely represent the largest source of potential emissions of HFCs and PFCs from fire protection equipment in the future.

Two basic approaches exist for estimating Actual Emissions, and by default, the size of the HFC/PFC bank: a top-down approach based on production or consumption data and a bottom-up approach based on a physical inventory of equipment containing HFCs and PFCs. The bottoms-up approach would require expensive, labor intensive physical inventories of specific fire protection equipment and bulk containers, and would also require accurate data on bulk imports and exports. Such data however, do not exist. For example, customs codes do not adequately distinguish HFCs and PFCs from other fire protection chemicals. This lack of specific data also makes it very difficult for individual countries to apply the top-down method, which would require calculation of consumption from the same non-available customs data. Alternatively, global production data can be estimated with much less uncertainty. The global approach is the same methodology used in the halon model, which has proven useful for tracking and predicting emissions and the size of the bank. A similar Actual Emissions approach using a top-down, tier 2 method for HFCs and PFCs in fire protection could be adapted from the concepts proven in the halon model. Such a global model could be used by countries, particularly smaller consuming ones, to report their Actual Emissions in lieu of expensive, time-consuming alternative methods and/or as a check of these alternative methods.

## ESTIMATE OF TOP-DOWN DATA

The model uses the same approach as that employed by the halon model. It is a top-down approach, based on the annual global consumption of HFCs and PFCs for fire protection. The actual global production or consumption of HFCs and PFCs in fire protection applications is not known, as each of these halon alternative agents is produced by only one or two companies, each regarding any sales related data as highly confidential. Therefore, the consumption of HFCs and PFCs is estimated from the known production of halon 1301 in 1988, adjusting for global market growth and changes in emissions practices and patterns.

According to the data provided in the HTOC halon 1301 model, the global production of halon 1301 in 1988 was 12,795 MT [1]. It must be noted, however, that a significant portion of this production was employed in emissive, non-suppression practices such as discharge testing and personnel training; emissions from testing and training alone in 1988 are estimated to have been as high as 12.5% of the 1988 production. By the time of the halon 1301 production ban on January 1, 1994 and the commercialization of several halon 1301 alternatives, emission practices within the fire suppression community had changed drastically, and discharge testing was discouraged in both local and international fire suppression standards. To account for the changes in emission practices between 1988 and 1994, the halon 1301 emissions listed in the HTOC model for 1988 were subtracted from the 1988 production quantities, and an assumed emission amount, described below, was added back. Having eliminated from consideration production which was simply wasted in non-fire emissive applications, the resulting figure more accurately represents the actual consumption (sales into new systems and recharge of existing systems) of halon 1301 in 1988. Market growth from 1988 onward is then estimated from this emissions-adjusted halon 1301 base as described below.

In order to adjust the 1998 halon 1301 base for the differing emissions practices between 1988 and 1994, it is necessary to know the emission rate in 1994. With the exception of data from the Japan Recycling and Banking Support Committee [2], estimates of emission rates for halons and their alternatives stem mainly from reports based on expert opinion only. The HTOC opined that halon emissions were reduced to five percent of the installed base as a result of actions taken within the fire protection community as a result of the Montreal Protocol [1, 3] and that this same rate would hold true for the halon alternatives. This five percent emissions estimation has been used in much of the literature as the starting point for HFC and PFC emissions as well. For example, a study prepared for the United Kingdom Department of Environment, Food and Rural Affairs (UK DEFRA) estimated current annual HFC emissions at approximately 5% of the installed base per annum based upon consultation with industry experts [4]. Other expert opinion has set the HFC and PFC emission rate significantly lower. For example, Ball opined that the emission rate could be as low as one percent of the installed base [5]. Recently, Verdonik and Robin evaluated publicly available data related to the production and emissions of HFCs and PFCs from fire suppression applications and developed three independent approaches to determine emission rates. The study derived an average emission rate of 2% of the installed base, with an uncertainty range of 1% to 3% [6]. This emission rate range is used in the current version of this model.

Employing an emission rate of one to three percent of the installed base, the equivalent consumption of halon 1301 was calculated for 1988. To account for growth over the period 1988 to1994, the average global growths in Gross Domestic Product (GDP) were applied [7]. The resulting theoretical consumption of halon 1301 in 1994 is thus calculated to be 6801 MT halon 1301 at a one percent emission rate; 7580 MT at a two percent emission rate; and 8360 MT at a three percent emission rate.

## DEVELOPMENT OF PROXY DATA FOR EQUIVALENT HALON 1301 NEED

The equivalent halon 1301 consumption beginning in 1994 is apportioned among 13 global regions that have similar halon alternative use patterns. The 13 regions are indicated below.

- Africa
- Central and South America
- China
- Eastern Europe
- India and Southeast Asia
- Japan
- Middle East
- North America
- Northern Europe
- Oceania
- Russia
- Southern Europe
- United Kingdom

The introduction of halon alternatives into each of these 13 regions was based on data submitted by several HTOC members from various global regions. Regional variations in the relative amounts of each HFC or PFC used to replace halon 1301 are accounted for in the model, as are the relative amounts of other alternatives: HCFCs, inert gases; carbon dioxide, and not-in-kind agents. The exact make-up of these other alternatives is not specified in the model, as they do not lead to any direct emissions of GHGs. The model has the capability of including the new fluoroketone alternative, but no estimates of its current or future use are yet incorporated into the model.

In addition to regional distribution of the halon alternatives, it was also necessary to determine the relative distribution of halon 1301 within each of the 194 countries in the model. Several estimation techniques were reviewed and the best correlation for halon 1301 consumption was found to be the percent of global GDP. As shown in figures 1a and 1b, a fair correlation ($R^2 = 0.727$) exists between the HTOC halon 1301 model results and GDP of the five major regions. An excellent correlation ($R^2 = 0.995$) exists when North America, Europe and Australia are combined.

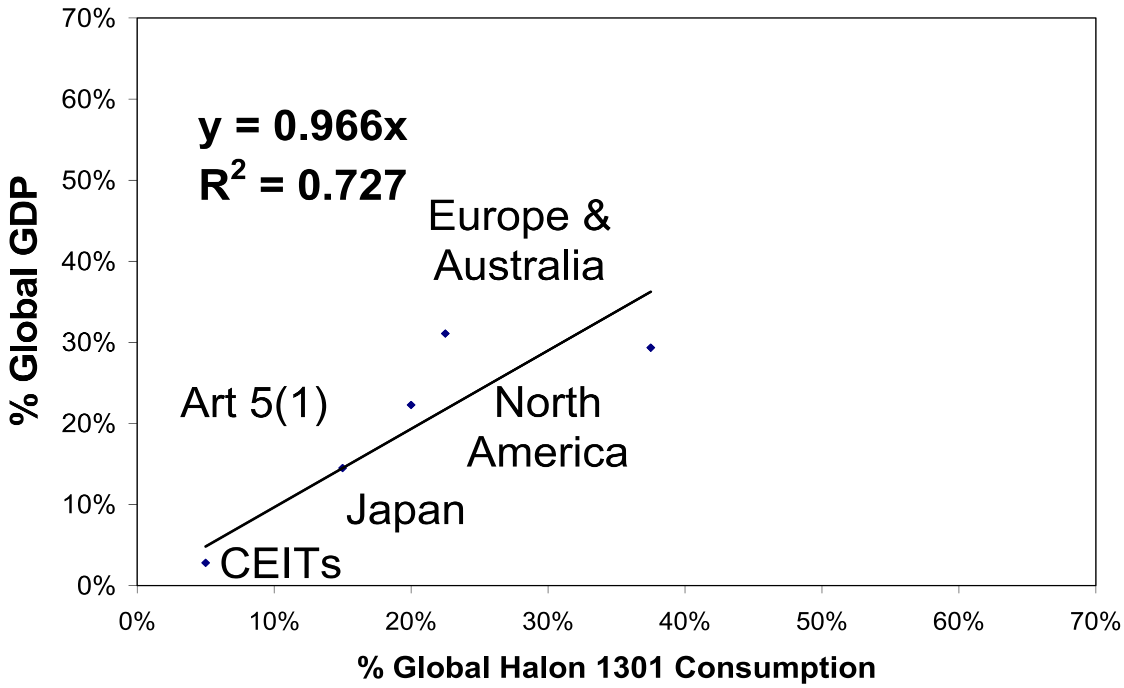


Figure 1a – Correlation of Halon 1301 Use from HTOC Model and GDP

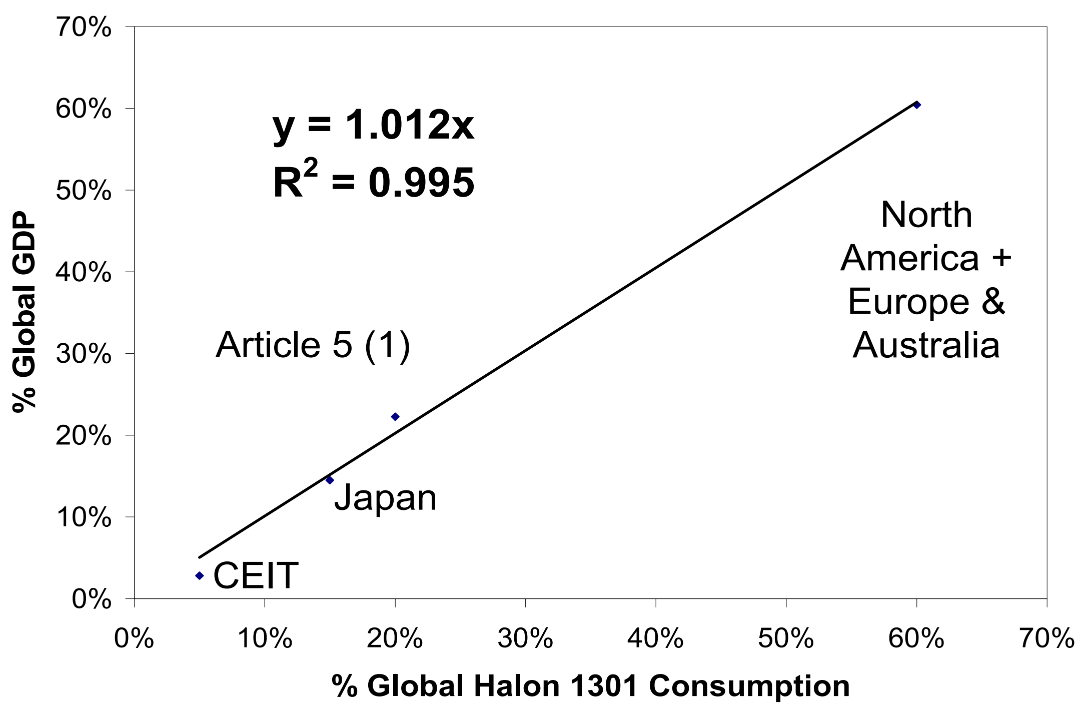


Figure 1b – Correlation of Halon 1301 and GDP combining North America, Europe and Australia.

To further evaluate the potential for using GDP as a proxy for halon 1301 consumption, the Country Reports of halon 1301 consumption submitted under the Montreal Protocol were compared against the GDP of the same five regions in the HTOC model, and for an expanded seven regions to better fit that data. As the country reports are aggregated amounts of all three halons, the Country Reports were also adjusted to remove halon 1211 based on the global production quantities provided in the HTOC halon 1211 model, and for halon 2402 based on the Countries with Economies in Transition ( CEIT) reported production. The correlation coefficient of the several country reported values is 0.86 indicating relatively correlation. The results obtained from adjusting the Country Reports to remove halons 1211 and 2402 produced similar results as for the HTOC model correlation provided in Figures 1a and 1b.

Results for the expanded seven regions are provided in Table 1. There is generally a good correlation for the seven regions but Central and South America (C&SAm) is an obvious outlier. Correlation factors developed with and without C&SAm are $R^2 = 0.898$ and 0.930, respectively. The standard deviation without C&SAm is 17%. These results incorporating the 17 % standard deviation are also shown graphically in Figure 2.

**Table 1: Adjusted Country Reports and Percent of Global GDP**

| | Percent of Global Halon 1301 from Country Reports (adjusted) | Percent of Global Halon 1301 Predicted Based on GDP | Difference (%) |
|---|---|---|---|
| Africa | 2.9 | 2.0 | 0.9 |
| Eastern Europe | 4.3 | 3.9 | 0.4 |
| India / South East Asia | 11.5 | 9.3 | 2.2 |
| Middle East | 3.0 | 2.0 | 1.0 |
| North America | 23.9 | 29.7 | 5.8 |
| Oceania | 18.1 | 16.3 | 1.8 |
| Western Europe | 34.9 | 29.8 | 5.1 |
| *Central & South America* | *1.4* | *7.0* | *5.6* |

In order to gauge the magnitude of the uncertainty of using GDP as a proxy for halon 1301 consumption, the Country Reports of consumption were compared against the manufacturers reports of global production from CEFIC, reported Article 5(1) production and reported CEIT production. The analysis of the difference in yearly reporting between the Country Reports and manufacturer reports was made for Article 2 countries for 1986 and 1989-1993; Article 5(1) countries 1989-1998; and globally 1986 and 1989-1998. The yearly differences were calculated, and a standard deviation was developed to compare the uncertainty in the actual reporting to that of using GDP as a proxy for halon

1301 consumption. The results are a standard deviation of 16% for Article 2 countries, 15% for Article 5(1) countries and 13% globally, suggesting that using GDP as a proxy for halon 1301 consumption has an uncertainty similar to that of actual reporting.

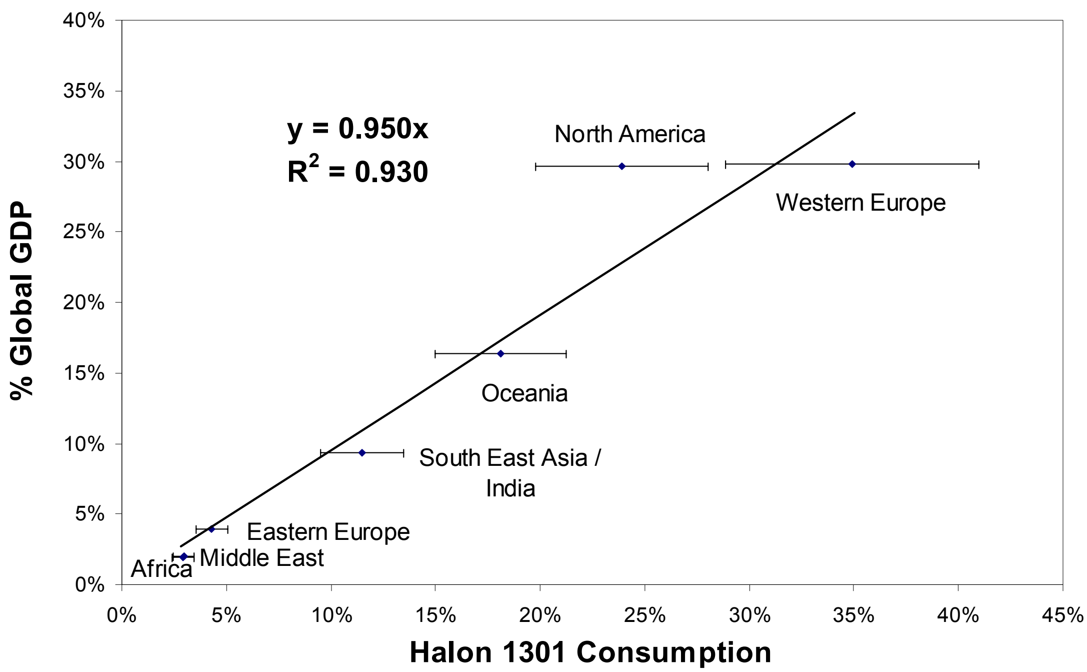


**Figure 2. Correlation of GDP with Country Reports for Seven Global Regions**

The global equivalent halon consumption is apportioned among each country based on that countries percent of global GDP for a given year. Global GDP is calculated each year based on the average GDP growth rate for each country from UN Statistics [7]. Growth rates are stopped in year 2030 because of the large uncertainty in growth rate predictions. The countries' equivalent halon 1301 consumption is further divided amongst all of the halon alternatives, based on the percent uptake for each alternative into their region. For example, using the global percentages of halon alternatives reported by the United Nations Technology and Economic Assessment Panel (TEAP) in 1999 [8], a hypothetical region may fill 50% of the former halon 1301 market with non-in-kind alternatives, 25% with inert gases, 5 % with $CO_2$, >1% with HCFCs, >1% PFCs, and > 20% with HFCs (and more recently with a fluroketone). The HFCs and PFCs are specifically identified by chemical. Using the AEA Technologies reported value developed for the UK [9] as an example, this same hypothetical region uses 97.5% HFC-227ea, 2.5% HFC-23 to make up its 20% of total HFCs, and a trivial amount of PFCs, taken as 0.1% of PFC 3-1-10 for purposes of illustration only.

The model calculates the MTCE for each of the GHGs based on their 100-year Global Warming Potentials (GWPs) from the IPCC Second Assessment Report (SAR), a factor to convert from the $CO_2$ equivalents to carbon equivalents (i.e., 12/44), and the quantity of agent required as compared with halon 1301 from the HTOC Technical Note 1, revision 2 [10] and provides the result as an aggregated value of all of the GHGs. Below is an example using this hypothetical region, a hypothetical country percent of global GDP of 10%, and a two percent emission rate for the year 1994.

**EXAMPLE CALCULATION:**

The global equivalent halon 1301 consumption for the year 1994 is 7,580 MT. The country's equivalent halon 1301 consumption is calculated based on its percent of global GDP, 10% in this case, and hence this country's halon consumption is 7,580 x 0.10 = 758 MT. The percent of this 758 MT replaced by HFCs is 20%, or 151.6 MT in halon 1301 equivalents. Since HFC-227ea comprises 97.5% of the HFCs installed, the amount of HFC-227ea installed is 151.6 x 0.975 = 147.8 MT of halon 1301 equivalents. HFC-227ea requires 1.9 times as much agent as halon 1301 [10] and hence 1.9 MT of HFC-227ea are required where in the past 1 MT of halon 1301 would be required. The metric tons of HFC-227ea installed is thus 147.8 * 1.9 = 281 MT HFC-227ea. Using the SAR 100-yr GWP of 2900, the MTCE for HFC-227ea is 222,245 MTCE, calculated as follows:

$$281 \text{ MT} * 2900 * 12/44 = 222{,}245 \text{ MTCE}$$

As calculated above, the amount of the former halon 1301 market replaced by HFCs is 151.6 MT halon 1301 equivalents. HFC-23 requires 2.0 times as much agent as halon 1301 [10] and makes up 2.5% of the HFC market, hence the metric tons of HFC-23 installed is 151.6*2.0*.025 = 7.58 MT. Using the SAR 100-yr GWP of 11,700, the MTCE for HFC-23 is 24,187 MTCE, calculated as follows:

$$7.58 \text{ MT} \times 11{,}700 \times 12/44 = 24{,}187 \text{ MTCE}$$

PFC 3-1-10 replaces 0.1% of the former halon 1301 market, or 151.6 MT * 0.001 = 0.15 MT halon 1301 equivalents. Since PFC-3-1-10 requires 2.3 times as much agent as halon 1301 [10], the metric tons of PFC 3-1-10 are 0.15 * 2.3 = 0.35 MT PFC-310. Using the SAR 100-yr GWP value of 7,000, the result for PFC 3-1-10 is 668 MTCE, calculated as follows:

$$0.35\text{MT} \times 7{,}000 \times 12/44 = 668 \text{ MT}$$

The total consumption in this scenario is the sum of the three results or 247,100 MTCE.

The model then apportions the MTCE from the GHGs into different lifetimes of equipment as described by the HTOC [1]. The different lifetimes are used to determine when the GHG will be removed from service and will be recovered or recycled. The model assumes a 99.5% recovery rate. Recovery and recycling losses are in addition to the emission rate of the installed base portion of the bank.

The emissions from the installed base are calculated as a fixed percentage of the installed base on the first day of that year plus one-half of the consumption for that year. This accounts for the probability that the consumption in that year will become part of the installed base and cause emissions for an average of six months. The emission is the sum of the emissions from the installed base plus the recovery loses. The total emission is reported for the year, and is then subtracted from the sum of the installed base on the first day of the year plus consumption, to determine the new installed base for the following year. The next year's calculation proceeds in the same way.

Actual data on emissions for the UK for 1997 to 1999, and for the U.S. from HEEP for 2002 were used as a check of the model results. Changes to the market penetration of halon alternatives were made to better fit the actual data. In addition, the following data sources were also employed to update the model from the 2002 version. These data include the following.

- Consumption of HFC-227ea in the U.S. for 1996 [11]
- Composition of HFCs in UK bank [9]
- Consumption of two HFCs in Japan in the year 2000 [12]
- Sales of PFC 3-1-10 into the European Union and estimates of its export into Eastern Europe [13].

One of the checks performed on the model assumptions for the three emission scenarios was to determine the 1999 percent of the former halon 1301 market for HFCs once fitted to the available data for the U.S., UK and Japan. It should be noted that the combined GDP of these three countries is nearly half of the global GDP and therefore would account for half of the halon 1301 equivalent use. For the 2% emission scenario, approximately 19% of the former halon 1301 market was being fulfilled by HFCs, a very good correlation to the 20% maximum value estimated by TEAP [8]. For the 1% emission scenario, only 15% of the former halon 1301 market is being used by HFCs, somewhat lower than estimated by the TEAP. For the 3 % emission scenario, more than 33% of the former halon 1301 market would be HFCs in order to fit the actual emission data of the US and UK and the consumption values of a single year for the U.S. and Japan. This is more than 50% higher than predicted by the TEAP and suggests that the lower emission rates provide a better fit to the actual data.

## RESULTS AND USE OF DATA

The global emissions provided by the updated model for one, two and three percent emissions scenarios are provided in Table 2.

Table 2: Estimated HFC/PFC Global Emissions and Installed Bank: Fire Suppression

| | 1995 | 2000 | 2005 | 2010 | 2015 |
|---|---|---|---|---|---|
| **1% Emission Rate** | | | | | |
| Global Emissions, MMTCDE | 0.06 | 0.60 | 1.20 | 1.99 | 2.87 |
| Global Emissions, MMTCE | 0.02 | 0.16 | 0.33 | 0.54 | 0.78 |
| Global Bank, MT Composite Gas | 1,805 | 19,325 | 38,599 | 63,685 | 92,052 |
| **2% Emission Rate** | | | | | |
| Global Emissions, MMTCDE | 0.11 | 0.85 | 1.64 | 2.74 | 3.95 |
| Global Emissions, MMTCE | 0.03 | 0.23 | 0.45 | 0.75 | 1.08 |
| Global Bank, MT Composite Gas | 1,684 | 13,576 | 26,360 | 43,968 | 63,315 |
| **3% Emission Rate** | | | | | |
| Global Emissions, MMTCDE | 0.11 | 1.10 | 2.13 | 3.46 | 4.91 |
| Global Emissions, MMTCE | 0.03 | 0.30 | 0.58 | 0.94 | 1.34 |
| Global Bank, MT Composite Gas | 1,127 | 11,726 | 22,711 | 37,003 | 52,415 |

It is worthy to note that changes in emission rate do not provide a straight line correlation to emissions. This is due to the fact that for each of the three emission scenarios in Table 2, it is necessary to re-fit the model to the actual emission data. For example, in order to develop the theoretical halon 1301 consumption in 1994, it is necessary to use an emission rate as previously described in the section on the estimate of top down data. The theoretical halon consumption and hence the quantity of halon alternatives in the installed base will change for each emission scenario. Further, in order to fit the model to the actual emissions of the UK and US, it is necessary to change the installed base for these countries to match the data. However, as there is no actual emission data for other countries/regions, the penetration of halon alternatives did not change for the three emission scenarios for all other countries/regions. As a result, each scenario is a unique solution to the data.

It is possible to use these emission results to estimate the size of the bank that caused these emissions. By dividing the emissions in MMTDCE by the emission rate, the bank size in MMTDCE can be calculated. Using the findings of AEA Technologies [9] that for the period 1996-2002 the halocarbon fire suppression installed base in the UK could be estimated as comprised of 97.5 percent HFC-227ea and 2.5 percent HFC-23 and applying that globally, then the emissions and hence bank may be considered as a "composite gas", which is comprised of HFC-227ea and HFC-23 in a 97.5:2.5 weight ratio. Employing the GWP values from the IPCC SAR [14], the GWP of this composite gas is calculated to be 3120. By dividing the MMTCDE of the bank by the composite gas GWP of 3120, the weight of the bank can be estimated. Table 2 also provides the results of this estimation.

The results in Table 2 suggest that, at an average emission rate of two percent of the installed fire protection base, the 2.74 MMTCDE (0.75 MMTCE) emissions level in 2010 represents approximately 0.94% of the TAR [15] estimates of 66 - 93 (79.5) MMTCE for total HFCs emitted in 2010. This also suggests that, at an average emission rate of two percent of the installed fire protection base, the average change in emissions from 2005 to 2010 and from 2010 to 2015 represents approximately 0.4% of the TAR estimates for total HFCs emitted in 2010.

It is also possible to estimate the size of the installed base for the HCFCs using the TEAP estimate that HCFCs comprise less than one percent of the replacements for halon 1301. Accounting for the mass differences between the assumed composite gas of HFCs and the HCFC replacement, over the range of one to three percent emissions, the bank would be 450 to 625 MT of HCFC in 2000 for fixed fire suppression systems. HCFCs are no longer being used for new applications and the bank therefore decreases to approximately 330 to 590 MT in 2005, 280 to 560 MT in 2010 and 240 to 535 MT in 2015 at one, two and three percent emission rates, respectively. While it is known that HCFCs are also used for portable applications, this estimation is only for HCFCs in fixed systems.

## SUMMARY

In concert with the GGEEC, a model has been developed for the estimation of global emissions of HFCs and PFCs from fire protection applications. The model employs a top-down, tier 2 method based on the estimated global consumption of the former halon 1301 market for fixed fire protection. Global consumption is apportioned among 13 global regions, employing regional specific factors for the use of the various halon alternatives and the percent of global GDP. Results are output in metric tons of carbon equivalent (MTCE), and can be listed individually for each of the 194 countries in the model, for each of the 13 regions, or globally. Model results are in excellent agreement with recent emissions and production data available in the open literature. The model can be employed to estimate emissions in lieu of expensive, time-consuming alternative methods that have greater uncertainty and/or to serve as a check of these alternative methods.

## ACKNOWLEDGEMENT

I would like to thank the following for peer reviewing and providing comments on this paper.

David Catchpole
Matsuo Ishiyama
David Koehler
Joseph Senecal
Robert Wickham

## REFERENCES


1. HTOC (Halon Technical Options Committee), 1991: Assessment Report of the Halons Technical Options Committee, Report prepared for the United Nations Environment Programme (UNEP), Ozone Secretariat, Nairobi, Kenya, available from http://www.teap.org/REPORTS/reports.html.

2. HRBSC (Halon Recycling and Banking Support Committee), 2003: Recorded values of installed halon and resupply quantities in Japan 1994 – 2002, email from Matsuo Ishiyama

3. HTOC (Halon Technical Options Committee), 1994: Assessment Report of the Halons Technical Options Committee, Report prepared for the United Nations Environment Programme (UNEP), Ozone Secretariat, Nairobi, Kenya, available from http://www.teap.org/REPORTS/reports.html.

4. AEA Technology Environment, "Emissions and Projections of HFCs, PFCs and SF6 for the UK and Constituent Countries," July 2003, Final Report prepared for the Department for Environment, Food and Rural Affairs (DEFRA).

5. Ball, D., 1999: Keeping the Options Open, Proceedings of the Halon Options Technical Working Conference, Albuquerque, NM, 1999, pp.19-24.

6. Verdonik, D.P. and M.L. Robin, 2004: Analysis of Emissions Data, Estimates, and Modeling of Fire Protection Agents, Proceedings of the Earth Technology Forum, Washington, DC, 2004.

7. World Statistics Pocketbook, Department of Economic and Social Affairs, Statistics Division, Series V No. 20, United Nations Publication, United Nations, NY, 2000.

8. "Meeting Report of the Joint IPCC/TEAP Expert Meeting on Options for the Limitation of Emissions of HFCs and PFCs," ECN-RX--99-029, IPCC, July 1999.

9. AEA Technology Environment, "Emissions and Projections of HFCs, PFCs and SF6 for the UK and Constituent Countries," July 2003, Final Report prepared for the Department for Environment, Food and Rural Affairs (DEFRA).

10. HTOC (Halon Technical Options Committee), Technical Note #1, New Technology Halon Alternatives, Revision 2, 1999, Report prepared for the United Nations Environment Programme (UNEP), Ozone Secretariat, Nairobi, Kenya, available from http://www.teap.org/REPORTS/reports.html.

11. Register, W.D., "Environmental Issues in the Fire Suppression Industry," Eurofeu Fluorocarbon Task Group Meeting, February 7, 2000.

12. Personal correspondence, 2003: email from Matsuo Ishiyama

13. Harnish, J. and Schwarz, W., "Final Report on the Costs and the Impact on Emissions of Potential Regulatory Framework for Reducing Emissions of Hydrofluorocarbons, Perfluorocarbons and Sulphur Dioxide," Report B4-3040/2002/336380/MAR/E1, Ecofys GmbH, February 4, 2003.

14. IPCC (Intergovernmental Panel on Climate Change), 1995: Climate Change 1995: The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change J. T. Houghton et al. (ed.), Cambridge University Press, Cambridge, UK and New York, NY.

15. IPCC (Intergovernmental Panel on Climate Change), Third Assessment Report – Climate Change 2001, Climate Change 2001: Mitigation, available from http/www.ipcc.ch.