Appendix E: U.S. EPA Vintaging Model Framework

Vintaging Model Overview

The Vintaging Model estimates emissions from six industrial sectors: refrigeration and air-conditioning, foams, aerosols, solvents, fire extinguishing, and sterilization. Within these sectors, there are 67 independently modeled end-uses. The model requires information on the market growth for each of the end-uses, as well as a history of the market transition from ozone-depleting substances (ODS) to alternatives. As ODS are phased out, a percentage of the market share originally filled by the ODS is allocated to each of its substitutes.

The model, named for its method of tracking the emissions of annual "vintages" of new equipment that enter into service, is a "bottom-up" model. It models the consumption of chemicals based on estimates of the quantity of equipment or products sold, serviced, and retired each year, and the amount of the chemical required to manufacture and/or maintain the equipment. The Vintaging Model makes use of this market information to build an inventory of the in-use stocks of the equipment in each of the end-uses. Emissions are estimated by applying annual leak rates, service emission rates, and disposal emission rates to each population of equipment. By aggregating the emission and consumption output from the different end-uses, the model produces estimates of total annual use and emissions of each chemical. For the purpose of projecting the use and emissions of chemicals into the future, the available information about probable evolutions of the end-use market is incorporated into the model.

The following sections discuss the forms of the estimation equations used in the Vintaging Model for each broad end-use category. These equations are applied separately for each chemical used within each of the 67 different end-uses. In the majority of these end-uses, more than one ODS substitute chemical is used.

In general, the modeled emissions are a function of the amount of chemical consumed in each end-use market. Estimates of the consumption of ODS alternatives can be inferred by extrapolating forward in time from the amount of regulated ODS used in the early 1990s, adjusted for factors that might affect ODS substitute consumption, such as different charge sizes and lower emission rates. Using data gleaned from a variety of sources, assessments are made regarding which alternatives were used and which alternatives will likely be used in the future, and what fraction of the ODS market in each end-use will be captured by each alternative. By combining this information with estimates of the total end-use market growth, a consumption value is estimated for each chemical used within each end-use. As described above, tracking the consumption in each end-use combined with emission rates over time allows the model to estimate total emissions of each chemical and end-use.

Emissions Equations

Refrigeration and Air-Conditioning

For refrigeration and air conditioning products, emission calculations are split into two categories: emissions during equipment lifetime, which arise from annual leakage and service losses, and disposal emissions, which occur at the time of discard. Equation 1 calculates the lifetime emissions from leakage and service, and Equation 2 calculates the emissions resulting from disposal of the equipment. These lifetime emissions and disposal emissions are added to calculate the total emissions from refrigeration and air-conditioning (Equation 3). As new technologies replace older ones, it is generally assumed that there are improvements in their leak, service, and disposal emission rates. In addition, the charge size assumed for equipment using an ODS substitute may be different than that for equipment using the ODS.

Lifetime emissions from any piece of equipment include both the amount of chemical leaked during equipment operation and the amount emitted during service, including recharges. Emissions from leakage and servicing can be expressed as follows:

$$Es_j = (l_a + l_s) \times \sum Qc_{j-i+1} \quad for\ i = 1 \rightarrow k \qquad Eq.\ 1$$

where:

Es	=	Emissions from Equipment Serviced. Emissions in year *j* from normal leakage and servicing (including recharging) of equipment.
l_a	=	Annual Leak Rate. Average annual leak rate during normal equipment operation (expressed as a percentage of total chemical charge).
l_s	=	Service Leak Rate. Average leakage during equipment servicing (expressed as a percentage of total chemical charge).
Qc	=	Quantity of Chemical in New Equipment. Total amount of a specific chemical used to charge new equipment in a given year by weight.
i	=	Counter, runs from 1 to lifetime (k).
j	=	Year of emission.
k	=	Lifetime. The average lifetime of the equipment.

The disposal emission equations assume that a certain percentage of the chemical charge will be emitted to the atmosphere when that vintage is discarded. Disposal emissions are thus a function of the quantity of chemical contained in the retiring equipment fleet and the proportion of chemical released at disposal:

$$Ed_j = Qc_{j-k+1} \times [1 - (rm \times rc)] \qquad Eq.\ 2$$

where:

Ed	=	Emissions from Equipment Disposed. Emissions in year *j* from the disposal of equipment.
Qc	=	Quantity of Chemical in New Equipment. Total amount of a specific chemical used to charge new equipment in year *j-k+1*, by weight.
rm	=	Chemical Remaining. Amount of chemical remaining in equipment at the time of disposal (expressed as a percentage of total chemical charge).
rc	=	Chemical Recovery Rate. Amount of chemical that is recovered just prior to disposal (expressed as a percentage of chemical remaining at disposal *(rm)*).

j = Year of emission.

k = Lifetime. The average lifetime of the equipment.

Finally, lifetime and disposal emissions are summed to provide an estimate of total emissions.

$$E_j = Es_j + Ed_j \qquad \textit{Eq. 3}$$

where:

E = Total Emissions. Emissions from refrigeration and air conditioning equipment in year *j.*

Es = Emissions from Equipment Serviced. Emissions in year *j* from leakage and servicing (including recharging) of equipment.

Ed = Emissions from Equipment Disposed. Emissions in year *j* from the disposal of equipment.

j = Year of emission.

Aerosols

All HFCs used in aerosols are assumed to be emitted in the year of manufacture. Since there is currently no aerosol recycling, it is assumed that all of the annual production of aerosol propellants is released to the atmosphere. Equation 4 describes the emissions from the aerosols sector.

$$E_j = Qc_j \qquad \textit{Eq. 4}$$

where:

E = Emissions. Total emissions of a specific chemical in year *j* from use in aerosol products, by weight.

Qc = Quantity of Chemical. Total quantity of a specific chemical contained in aerosol products sold in year *j*, by weight.

j = Year of emission.

Solvents

Generally during the solvent cleaning process, a portion of used solvent is assumed to remain in the liquid phase and is not emitted as gas. Thus, emissions are considered "incomplete," and are set as a percentage of the amount of solvent consumed in a year. The remainder of the consumed solvent is assumed to be reused or disposed without being released to the atmosphere. Equation 5 calculates emissions from solvent applications.

$$E_j = l \times Qc_j \qquad \textit{Eq. 5}$$

where:

E = Emissions. Total emissions of a specific chemical in year *j* from use in solvent applications, by weight.

l = Percent Leakage. The percentage of the total chemical that is leaked to the atmosphere, assumed to be 90 percent.

Qc = Quantity of Chemical. Total quantity of a specific chemical sold for use in solvent applications in the year j, by weight.

j = Year of emission.

Fire Extinguishing

Total emissions from fire extinguishing are assumed, in aggregate, to equal a percentage of the total quantity of chemical in operation at a given time (Equation 6). For modeling purposes, it is assumed that fire extinguishing equipment leaks at a constant rate for an average equipment lifetime.

$$E_j = r \times \sum Qc_{j-i+1} \quad for\ i=1 \rightarrow k \qquad Eq.\ 6$$

where:

E = Emissions. Total emissions of a specific chemical in year *j* for streaming fire extinguishing equipment, by weight.

r = Percent Released. The percentage of the total chemical in operation that is released to the atmosphere.

Qc = Quantity of Chemical. Total amount of a specific chemical used in new fire extinguishing equipment in a given year, *j*-*i*+1, by weight.

i = Counter, runs from 1 to lifetime (k).

j = Year of emission.

k = Lifetime. The average lifetime of the equipment.

Foam Blowing

Foams are given emission profiles depending on the foam type (open cell or closed cell). Open cell foams are assumed to be 100% emissive in the year of manufacture, as described in Equation 7 below. Closed cell foams are assumed to emit a portion of their total HFC content upon manufacture, a portion at a constant rate over the lifetime of the foam, a portion at disposal, and a portion post-disposal, as described in Equations 8 through 12, below.[1]

Open-Cell Foam

Manufacturing emissions occur in the year of foam manufacture, and are calculated as presented in the following equation.

$$Em_j = Qc_j \qquad Eq.\ 7$$

where:

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[1] Emissions from foams may vary because of handling and disposal of the foam; shredding of foams may increase emissions, while landfilling of foams may abate some emissions (Scheutz and Kjeldsen, 2002; Scheutz and Kjeldsen, 2003). Average annual emissions are assumed in the model, which may not fully account for the range of foam handling and disposal practices.

Em_j	=	Emissions from manufacturing. Total emissions of a specific chemical in year *j* due to manufacturing losses, by weight.
Qc	=	Quantity of Chemical. Total amount of a specific chemical used to manufacture closed-cell foams in a given year.
J	=	Year of emission.

Closed-Cell Foam

Emissions from closed-cell foams occur at many different stages, including manufacturing, lifetime, disposal and post-disposal. Manufacturing emissions occur in the year of foam manufacture, and are calculated as presented in Equation 8.

$$Em_j = lm \times Qc_j \qquad \text{Eq. 8}$$

where:

Em_j	=	Emissions from manufacturing. Total emissions of a specific chemical in year *j* due to manufacturing losses, by weight.
lm	=	Loss Rate. Percent of original blowing agent emitted during foam manufacture. For open-cell foams, *lm* is 100%.
Qc	=	Quantity of Chemical. Total amount of a specific chemical used to manufacture closed-cell foams in a given year.
j	=	Year of emission.

Lifetime emissions occur annually from closed cell foams throughout the lifetime of the foam, as calculated using Equation 9.

$$Eu_j = lu \times \sum Qc_{j-i+1} \quad \text{for } i=1 \rightarrow k \qquad \text{Eq. 9}$$

where:

Eu_j	=	Emissions from Lifetime Losses. Total emissions of a specific chemical in year j due to lifetime losses during use, by weight.
lu	=	Leak Rate. Percent of original blowing agent emitted each year during lifetime use.
Qc	=	Quantity of Chemical. Total amount of a specific chemical used to manufacture closed-cell foams in a given year.
i	=	Counter, runs from 1 to lifetime (k).
j	=	Year of emission.
k	=	Lifetime. The average lifetime of foam product.

Disposal emissions occur in the year the foam is disposed, and are calculated as presented in the following equation.

$$Ed_j = ld \times Qc_{j-k} \qquad Eq.\ 10$$

where:

Ed_j	=	Emissions from disposal. Total emissions of a specific chemical in year *j* at disposal, by weight.
ld	=	Loss Rate. Percent of original blowing agent emitted at disposal.
Qc	=	Quantity of Chemical. Total amount of a specific chemical used to manufacture closed-cell foams in a given year.
j	=	Year of emission.
k	=	Lifetime. The average lifetime of foam product.

Post-disposal emissions occur in the years after the foam is disposed, and are assumed to occur while the disposed foam is in a landfill. Currently, the only foam type assumed to have post-disposal emissions is polyurethane appliance foam, which is expected to continue to emit for 26 years post-disposal, and are calculated as presented in Equation 11.

$$Ep_j = lp \times \sum Qc_{j-m} \quad for\ m=k \rightarrow k+26 \qquad Eq.\ 11$$

where:

Ep_j	=	Emissions from post disposal. Total post-disposal emissions of a specific chemical in year j, by weight.
lp	=	Leak Rate. Percent of original blowing agent emitted post disposal.
Qc	=	Quantity of Chemical. Total amount of a specific chemical used to manufacture closed-cell foams in a given year.
k	=	Lifetime. The average lifetime of foam product.
m	=	Counter. Runs from lifetime (k) to (k+26).
j	=	Year of emission.

To calculate total emissions from foams in any given year, emissions from all foam stages must be summed, as presented in Equation 12.

$$E_j = Em_j + Eu_j + Ed_j + Ep_j \qquad Eq.\ 12$$

where:

E_j	=	Total Emissions. Total emissions of a specific chemical in year j, by weight.
Em_j	=	Emissions from manufacturing. Total emissions of a specific chemical in year *j* due to manufacturing losses, by weight.

Eu_j = Emissions from Lifetime Losses. Total emissions of a specific chemical in year j due to lifetime losses during use, by weight.

Ed_j = Emissions from disposal. Total emissions of a specific chemical in year j at disposal, by weight.

Ep_j = Emissions from post disposal. Total post-disposal emissions of a specific chemical in year j, by weight.

Sterilization

For sterilization applications, all chemicals that are used in the equipment in any given year are assumed to be emitted in that year, as shown in Equation 13.

$$E_j = Qc_j \qquad \textit{Eq. 13}$$

where:

E = Emissions. Total emissions of a specific chemical in year *j* from use in sterilization equipment, by weight.

Qc = Quantity of Chemical. Total quantity of a specific chemical used in sterilization equipment sold in year *j*, by weight.

j = Year of emission.

Model Output

By repeating these calculations for each year from 1985-2050, the Vintaging Model creates annual profiles of use and emissions for ODS and ODS substitutes. The results can be shown for each year in two ways: 1) on a chemical-by-chemical basis, summed across the end-uses, or 2) on an end-use basis. Values for use and emissions are calculated in metric tons, ozone depleting tons, and in million metric tons of carbon dioxide equivalents (MtCO2eq).