Dioxins and other carcinogenic substances in life-cycle work (assessment of relative risk potential)

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1. Introduction

Dioxins are very strong toxins which arise in low quantities. Many measures were taken during the last 40 years to reduce pollution which decreased emissions, immissions and body burdens of man and animals considerably.

But it is still not clear if dioxins are important carcinogens in the sense that they have a considerable impact on our welfare. We have shown that they do not play an important role compared with other carcinogens (e.g. polycyclic aromatic hydrocarbons (PAH)) in the case of fires [1] or other thermal processes [2]. German EPA has positively checked the basis of this work [3].

Here we examine

* if emission of dioxins can be associated with certain materials more than others (e.g. materials containing Cl atoms such as PVC compared with wood). We do this by adding together the emissions of dioxins along the life-cycle of PVC windows reinforced with steel profiles (shortly PVC windows), and of wood windows.
* if PAH are more important carcinogens associated with the production, recycling of these products compared with dioxins.
* where optimisation of these emissions will most probably be possible.

2. Dioxins, PAH and windows

2.1 Windows are complex products having a long useful life: They consist mainly of PVC , steel or wood frames, glass panes, elastic sealants and metal parts for opening and tilting the windows. PVC and wood are the most widely used frame materials.

2.2 We constrict this study in several directions:

* We do not consider the manufacture and recycling of the glass panes, because they are common to both window systems.
* As carcinogens we consider only dioxins and PAH, because there are data for these two toxic substance groups at least to deduce some first results, to show where data are missing and what can be improved in the future.
* At the moment we do not consider emissions during the use phase, because they are comparable for both window frame materials. We will work out this point for DIOXIN'99. It seems clear that this part of the life-cycle is most important for window systems.

2.3 In a toxicological risk assessment both mass flow of toxins and the relative toxicity is needed. From several studies [4] one finds dioxins (on a TEQ basis) to be 20 times more carcinogenic than PAH (Benzo-a-Pyrene (BaP) equivalents). Both oral and inhalative uptake have to be considered, since oral uptake is most important for dioxins, but inhalative for PAH.

3. **Dioxins and PAH emissions along the life-cycle of window frames**

In general, all thermal processes are sources of dioxins (and of course PAH). So a first search needs to identify all thermal processes along the life-cycle of these materials. Several advanced life-cycle analyses for window systems have been published during recent years [5] and help in this search.

3.1 **Steel profiles:**

Dioxins: Most important source is the iron ore sintering stage, which was recognised as the largest dioxin source in Germany [6]. Emissions have been reduced down to 100 gTEQ/year. Steel-making from primary iron or scrap emits much less (< 1 gTEQ/year).
Because of this only virgin steel is associated with higher dioxin emissions via primary iron; steel recyclates are not.

PAH: There are only very limited data on PAH emissions. From a Swedish investigation [7] we deduce an emission quotient for PAH compared with dioxins of 200, i.e. 200 times more PAH are emitted compared with dioxins on a toxicological basis. This compares well with the fire situation [1] (factors of 100 to 2000). We did not find data on iron ore sintering, but since thermally speaking this is a smoldering type of incineration we assume also much higher PAH emissions (200 times higher or more).

3.2 **PVC profiles:**

Dioxins: Thermal processes during the manufacture of PVC produce dioxins, mainly during VCM-production. These dioxins are concentrated in catalyst residues and in tars. Residues and tars - also from other chemical processes - are thermally treated in high temperature incinerators with low emission limits (0.1ngTEQ/m3) as state of the art. For a typical chlorine using company, also producing some 170 000 t of PVC, these emissions have been published [8] (less 20 ugTEQ/year).
Due to great interest in the production of PVC many other parts of the process have also been investigated, but up to now there is no indication that there are any other important dioxin sources.
Recycling of PVC windows in modern factories is state of the art today. We estimate that for future recycling schemes maximal 10% of such wastes go to incinerators (< 0.1ngTEQ/m3), the rest being mechanically recycled.

PAH: For high temperature incinerators equipped with advanced gas cleaning systems PAH emissions are in the lower ng/m3 range, thus contributing about the same as dioxins on a toxicological basis.

3.3 **Wood profiles:**

Dioxins: There are two important thermal processes in the production of wood profiles: Clean waste wood is burned to dry the profiles, and the most realistic and positive form of recycling is a thermal use of old window profiles. Since clean wood like all biological material also contains chlorine (wood relatively low with 0.001 to 0.01 %) low amounts of dioxins are emitted if clean wood is burned, the amount depending largely on the quality of the incinerator or oven. From different investigations [9] [10] [11] we find a mean (averaged over oven size) of 0.07 ngTEQ/m3, other averages being higher. Smaller ovens which are not perfectly operated tend towards 1 ngTEQ/m3.
Since thermal recycling of wood windows is ecologically preferable but is a significant dioxin source we consider only 10% of wood windows to be thermally recycled with advanced gas cleaning (< 0.1ngTEQ/m3).

PAH: During wood cutting in the forest rather high PAH-emissions have been measured in the exhaust gas of two stroke motorised saws [12] (10 ugBaP/window). Thus in the case of wood only felling trees with saws will contribute a 20-fold higher toxic potential from PAH compared with total life-cycle emission of dioxins.
Drying with clean wood: There is a broad range of emission data of PAH from wood-fired ovens varying over 3 decades [13 14]. Taking lower range data for optimised and larger ovens (8 – 16 ugBaP/kg clean wood) [13] drying operations result in 65 to 130 ugBaP/wood window. Thermal recycling today is not equipped to a great extent with advanced gas cleaning so this source could be most important, at least in the same range as drying actions. Amount of used, painted wood being twice as high and incinerators perhaps more efficient as in drying action.

3.4 **Fires:** Fires are rare events emitting both dioxins and PAH. Dioxins are strongly adsorbed onto soot particles and rarely bioavailable as has been confirmed in many measurements of fire-exposed people [15]. This most probably also holds for PAH.
Dioxins: It is difficult to quantify the amount of dioxins emitted. There is one quantitative investigation of a real PVC fire [16]. From this we deduce some 10 ngTEQ/PVC window taking into account that with PVC windows only a surface layer is burnt (1 kg burnt material is assumed).
In open burning tests of clean wood, dioxin emissions of up to 1 – 1.5 ngTEQ/m3 have been measured [11], resulting in maximal emissions of equally 10 ngTEQ/kg.
PAH: Open burning of wood and biomass has been examined [17]. 10 to 60 ugBaP/kg wood is emitted, not very different from sawing actions. We assume similar amounts of PAH in the open burning of PVC, no data being available.
Conclusion: Due to rarity and comparing fire with life-cycle results in table 1, fires do not play a significant role for dioxins and PAH in the life-cycle of windows. Because of low bioavailability there is no indication even for local risks.

3.5 **Results:**
Dioxins: The various contributions from different life-cycle parts for PVC and wood windows are comparable (figure 1 and table 1). Of course these results depend strongly on several assumptions, e.g. in the case of 100% thermal recycling of wood windows the total emissions would double.
PAH: The data are not as good as in the dioxin case. First do PAH data scatter much more than dioxin data, second there are fewer data published. Taking this into account, PAH emissions from PVC and wood windows are roughly the same. After toxicological weighing they are 100 to 200 times more important as carcinogens compared with dioxins.

4. **Possibilities to reduce dioxin and PAH-emissions**
* There are different activities in reducing the dioxin emissions from iron ore sintering, which will reduce the PAH emissions at the same time.
* Due to the use of high temperature incinerators with advanced cleaning technology in some countries in Europe, dioxin and PAH emissions from waste treatment are already very low.
* Dioxin emissions from the wooden window industry are already low in concentration (0.07 ngTEQ/m3). Reduction will result from optimising the burning conditions, but advanced gas cleaning facilities such as those used in the industry will not be affordable to an industry which is structured on very small units. PAH will also be reduced by optimal burning conditions, but these emissions will stay much higher compared with emissions from units with advanced gas cleaning. Two stroke motorised saws can be substituted by less polluting

but heavy four stroke saws.
* Wood windows will probably be not be thermally recycled with advanced gas cleaning, so these emissions will of course be below legal limits (e.g. 0.1 ngTEQ/m3). They will nevertheless not be as low as thermal recycling units from the chemical industry.

5. Results

5.1 Emissions generated during production and recycling of PVC and wood windows are both about 20 ngTEQ/window (dioxins) and about 50 ugBaP/window (PAH) (perhaps somewhat higher for wood windows).

5.2 Rare fire events do not contribute significantly to total emissions of both toxins. Because of very low bioavailability of toxins adsorbed to soot particles they do not much contribute locally either.

5.3 PAH emissions are much more important carcinogens compared with dioxins in the life-cycle of windows by a factor of about 100 to 200 after toxicological weighing.

5.4 Data on PAH are less abundant compared with dioxins, mainly in the production and recycling of metals.

5.5 Reduction of dioxins and PAH will be easier in industrial systems (incinerators for toxic waste, iron ore sintering etc.) compared with non industrial systems (smaller heat producing units, two stroke sawing machines, etc.).

Fig. 1: Dioxin emissions for steel reinforced PVC and wood windows (ngTEQ/window)

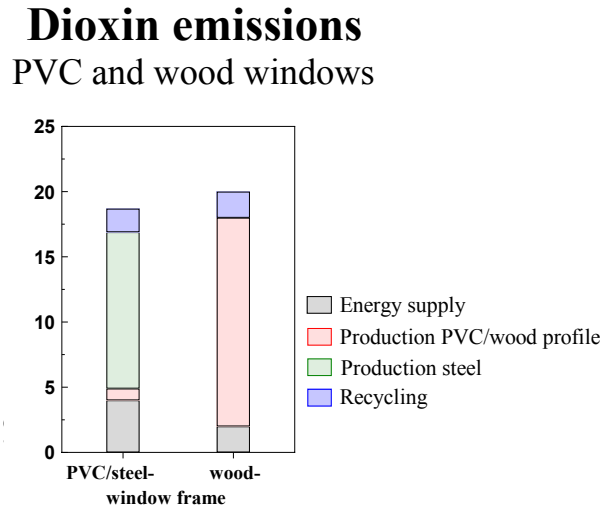

Table 1: Results for dioxin emission in production and recycling of PVC and wood windows.

	ugBaP/window	ngTEQ/window
PVC/steel window		
Energy supply	< 4	
?		
PVC production	0.9	
< 1		
PVC recycling (10% thermally)	< 1.8	
<10		
Steelprod. (Iron ore sintering, 60% virgin material)	12	
48		
		12.9 - 18.7
48 - 59		
Wood window		
Energy supply	< 2	
?		
2-stroke saw tree cutting	< 0.1	
10		
Drying of profiles (clean waste wood)	16	
65 - 130		
Recycling, 10% thermally (100%)	2 (20)	
< 10		
		18 – 20
75 - 140		

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