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Feasibility Study of the Salt Mines Storage Route

Step 2 report

Comparison of the salt mines storage with competing routes for MSWI residues management

Study intended for ECVM (European Council of Vinyl Manufacturers)

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1. CONTEXT AND OBJECTIVES

1.1 General Objectives of the study

This study is aimed at evaluating the present situation of MSW incineration in terms of management of the residues as well as of corresponding quantities involved, with a special attention to the route for storage in salt mines and to the influence of PVC.

The salt mine question is presented in step 1 report. It shows the present situation and discuss its possible evolution in the next years. Deep underground storage is done only in Germany (3 active mines : Herfa-Neurode, Heilbronn, Zielitz, 1 project : Borth), in France (1 mine : Wittelsheim), and is intended in the UK (1 project in Bostock). A lot of other mines (coal and salt mines) in Germany practising mine-valorisation can accept ultimate residues from incineration, although these residues are classified as hazardous. While deep storage should continue for a long time without difficulties, and may be developed, the future of mine-recycling practices highly depends on permanence of German legal situation and local authorisations.

The second part of the present study concerns the evaluation of the technical and economical interest of this way to manage the residues from MSW incineration.

It begins by a synthesis of various data on MSW incineration in Europe, on quantities of residues, and on the effect of PVC on the amounts and composition of residues. A large collection of data was used and checked to obtain the most relevant average figures, and their usual ranges.

A cost comparison is presented to estimate the competitivity area for salt mines in comparison with alternative surface landfilling possibilities.

1.2 Specification of the Step 2 study

STEP 2 : COMPARISON OF THE SALT MINES STORAGE WITH COMPETING ROUTES FOR MSWI RESIDUES MANAGEMENT :

This step of the study is aimed at evaluating the different competing routes already exploited :

- landfill storage (type of class to be identified) after stabilisation as in France, Belgium and Italy
- landfill storage without stabilisation (Great Britain, Belgium (Flandres), Denmark (temporary storage...)
- Salt mines storage (mainly in Germany, but also in Denmark, France, Austria, Switzerland)
- Reutilisation in mine-filling (mainly in Germany)
- Storage/Quarry-filling (Langøya in Norway, where a part of the residues from Denmark are sent) (difficult to classify)
- Building and road construction.

For this purpose, an average composition of MSW and its PVC content will be identified to determine the nature, composition and quantity of residues. The impact of PVC content in the MSW will then be evaluated in terms of quantity, quality and corresponding cost of the residues in given scenarios for their final destination.

Then the different routes for MSW residues management will be compared in terms of specification requirements and cost (apart from transportation). Transportation costs will be further considered and the maximum distance from the incinerator to the mines determined for keeping the competitiveness of salt mines storage. This will also enable the evaluation of the corresponding capacities of residues production to be possibly addressed to the different salt mines.

1.3 Detailed specifications for the STEP 2 study

1. MSWI data

1.1. Capacity produced, corresponding quantity incinerated in Europe (most recent datas)

1.2. MSWI location in CE and corresponding capacities

1.3. Residues produced in Europe (tons/year)

- Bottom Ash
- Fly Ash
- Salts
- Fly Ash + Salts when mixed
- Liquid effluents

1.4. Final destination of the residues (type by type) and quantities involved in Europe

- Landfill
- Road application
- Salt mines
- Other storages

2. Impact of PVC on the quantity and hazardousness of the residues (type by type)

3. PVC producers involved in salt mines storage activity

4. Technico-Economic comparison of salt mines storage with the competing routes

4.1. Specification of the residues for each destination

4.2. Cost comparison

- apart from transportation
- current transportation cost for each type of destination
- maximum transportation cost to salt mines for keeping this route competitive

5. Conclusion : overall appraisal of the salt mines storage for MSWI residues

1.4 Preliminary warning *(read me first)*

This study being focused towards obtaining best useful data, comments and explanations are limited and much place is given to tables and numbers. Accuracy of values is not expected to very high in the MSW domain (10% to more than 100% deviations may be found), and evolution is continuous. A great part is thus given to comparisons and possible ranges, and choice of good average values. Wider explanations can be found in various sources given as references.

We hope the reader can directly find the useful values and bases of calculations, and could easily correct values and corresponding conclusions if updated or more accurate data (especially cost data) become available.

2. MSWI Data

2.1 MSW production, and part incinerated in Europe

Considering the whole European Community, overall key figures from recent data [Oec97] are :

- Amount of MSW produced : **155 000 ktons/year**.
- for a population of **375 Millions**

This gives an average amount of **400 kg / year / capita.**

- **21%** of MSW are incinerated

Table 1 gives details per country, with additional data on Switzerland and Norway, considered in overall "EC17" figures.

Details on incineration per country will be further discussed, after general data on MSW nature and content.

European statistics						
Country	Abb.	Area km^2	Population Million inhab.	density inhab./km^2	MSW(*) kt/year	MSW kg/inhab.
Austria	A	83857	8,0	95	3841	480
Belgium	B	30518	10,2	334	4781	469
Germany	D	357046	82,1	230	25777	314
Denmark	DK	43092	5,2	121	2788	535
Spain	E (SP)	504782	39,3	78	14296	364
Finland	SF	338145	5,1	**15**	2100	412
France	F	543965	58,7	108	28000	477
United Kingdom	UK	244129	58,5	240	20000	342
Greece	GR	131957	10,4	79	3200	**308**
Ireland	IRL	70283	3,7	53	1550	419
Italy	I	301225	57,6	191	27000	469
Luxembourg	L	2586	0,4	164	218	514
Netherlands	NL	41160	15,7	**380**	8956	**572**
Portugal	P	92389	10,0	108	3500	351
Sweden	Sw	449964	8,8	20	3900	443
EC15 countries		**3235098**	**373,6**	**115**	**149907**	**401**
Max		*543965*	*82,1*	*380*	*28000*	*572*
Min		*2586*	*0,4*	*15*	*218*	*308*
Switzerland	CH				2660	
Norway	Nw				2637	
EC 17 countries					**155204**	

Area and population : January 1999 ("INTERPLAN" diary 2000)
(*) MSW amounts OECD 1995 - ratio in kg/inhab is calculated from these data.
EC 17 = EC 15 + CH + Nw

Table 1 - European Statistics and MSW production

2.2 MSW composition in Europe

The composition of domestic wastes is usually described from three different points of view :

- typological MSW composition (nature of raw elements, e.g. plastic content)
- Immediate analysis (combustion characteristics, e.g. combustible part)
- Elemental composition (chemical elements, e.g. Cl and HM contents)

2.2.1 Typological MSW Composition

The composition of MSW depends directly on the evolution of the MSW management practices and especially on the extension of the sorting at source. It is submitted to high fluctuations according to countries and versus time, due to differences in the definitions of MSW and to the different conditions encountered in countries (social conditions, location, season...).

In general, MSW includes household waste, bulky waste, small commercial and non-hazardous industrial wastes (trade waste), and market and garden residuals when not sorted at source.

Table 2a gives contribution of main elements : putrescibles (= organic matters), papers, plastics, glass, metals, miscellaneous (textile and others), based on 1995 OECD data [Oec97].

Country	Amount of MSW OECD 1995		Putrescibles / fines	Paper	Plastic	Glass	Metals	Miscell (textiles incl.)
	k tons / yr	kg/y/capita	Wgt %	Wgt %	Wgt %	Wgt %	Wgt %	Wgt %
A	3841	480	50	22	7	9	5	8
B	4781	470	37	16	7	7	4	29
CH	2660	250	38	29	15	3	3	12
D	25777	320	44	24	7	9	6	10
DK	2788	530	36	20	5	4	2	35
E (SP)	14296	370	44	21	11	7	4	13
F	28000	470	29	25	11	13	4	18
GR	3200	310	49	20	9	5	5	13
I	27000	470	40	22	7	8	3	20
IRL	1550	430	29	33	9	6	3	20
L	218	530	44	19	8	7	3	20
Nw	2637	620	18	31	6	4	5	36
NL	8956	580	38	26	6	6	3	21
P	3500	350	35	23	12	5	3	23
Sw	3900	440	44	30	7	8	2	9
SF	2100	410	32	26	6	6	3	29
UK	20000	340	19	37	10	9	7	18
EC 15	149907	398	36,1	25,1	8,6	8,8	4,4	17,0
EC 17	155204	396	35,9	25,3	8,7	8,6	4,4	17,3

Source = OECD (1995) - EUROSTAT (1993)
France composition data from ADEME Waste characterization campaign of 1993 (published in 1996).

Table 2a - Amount and composition of MSW in Europe and for each country

Values per capita are slightly different than the value given in table 1 but should be more consistent, because table 1 uses population in 1998 instead of 1995. Average for Europe is nevertheless identical (400 kg/y/capita).

Some compositions given in this table should be valid only for "raw" MSW, i.e. before possible separation of some materials for recycling and composting. Compositions for "incinerated MSW" can thus be slightly different.

Table 2b gives a comparison of average compositions of MSW in EC according to different sources [Eur97, Isw97, Rij93, Gro93, Oec97, Apm96]. Main Differences are due to evolution and to particular methods of classification.

MSW fractions in EC % by weight	EUROSTAT 1993	TNO 1992	AOO 1993	OECD 1995	APME 1996
Putrescibles/Fines	37	33	33.1	36.1	35
Paper	27	30	27.1	25.1	25
Plastics	8.5	7.4	12.2	8.6	8
Glass	9	8	3.9	8.8	9
Metals	4.7	8	5.7	4.4	4
Miscellaneous (textiles incl.)	13.8	13.6	18 (*)	17.0	19
Total	100	100	100	100	100
% PVC in Plastics		***10***			***10.7***
% PVC in MSW		***0.74***			***0.86***

(*) includes 6,2%wood, 6,5%combustible, 4,3%non-combustible
[AOO 1993] = as quoted by Rij99 "composition of the waste to be processed in an MSWC facility".

Table 2b - Average composition of MSW in EC and evolution

2.2.2 MSW Immediate analysis

The immediate analysis can be useful for combustion analysis, especially for incinerator monitoring. It gives the 5 main characteristics of a waste considered as a fuel, as given in table2c from French, European and US data :

- composition in combustible (Volatile Matter + Fixed Carbon) and non-combustible (Inert, water)
- Calorific Heat value (LHV = Lower Heat Value).

MSW identification	Water %	VM %	FC %	Inert %	LHV MJ/kg
France MODECOM	35	34.3	6	24.7	8.25
European data	25.2	49.2	3.4	22.2	8.83
Tno99 data (see table 13c)	30.8	49.6		19.6	9.46
Tkn94 Thermische Abfallbehandlung	30	45		25	6 - 10
US Mean 1988	20	53	7	20	10.5
US Max 1988	40	60	15	30	-
US Min 1988	15	30	5	6	-

Table 2c - Composition of MSW as a fuel (immediate analysis)

Water content (humidity) is now typically under 35% in European countries, due to hermetic collection in plastic bags. Higher humidity may be found in some Asiatic countries (Korea : up to 60%). Low humidity ensures a better combustion and allows for higher heat recovery.

The inert part (usually assumed to be ≈ 25%) contains mainly sand (SiO2), iron and other metals.

LHV is usually in the range 5.9 – 10.5 MJ/kg [Blo95].

2.2.3 MSW Elemental composition

The elemental composition is a more detailed composition giving the repartition per atomic element (organics and metals), coming either from combustible part (MV+CF, containing organic elements) or from inert part (containing main metals).

An estimation of the average MSW composition is given in the following table, on the basis of a recent compilation of data published by PWMI/TNO in 1993 [Gro92, Gro93, Rij93, Apm96] : this table is restricted to Chlorine, Sulphur and Heavy Metals contents, derived from bulk composition in putrescibles, paper, plastics, glass and metals.

A more complete elemental analysis, giving contents in organics (C, H, O, N, S, P, Cl, F, Br), and metals (Hg, Cd, As, Co, Cr, Cu, Mn, Ni, Pb, Sb, Se, Sn, V, Zn), is given in table 13c (from [Tno99]).

MSW fractions in EC	APME 1996 % by Weight	Chlorine g/kg	Sulphur g/kg	Heavy Metals g/kg
Putrescibles/Fines	35	7.56	2.85	2.108
Paper	25	3.69	2.52	0.561
Plastics	8	23.64	0.23	1.241
Glass	9	0.1	-	0.9665
Metals	4	0.32	0.11	18.491
Miscellaneous (textiles incl.)	19	10.0	3.6	4.4
Total	***100***	***7.38***	***2.33***	***2.64***

Table 2d - Main elements distribution in MSW from EC in 1996

According to table 2d, Chlorine, Sulphur and HM basic contents, in g/kg are :

- **Cl : 7.4 g/kg** usual range 5 to 10 g/kg
- **S : 2.3 g/kg** usual range 1 to 4 g/kg
- **HM : 2.6 g/kg** (including 0,7 g/kg Pb, see below)

These values can be compared to values given in table13c, and values measured on a set of selected incinerators [Ber99], all values in g/kg :

	Table 2d	range	[Tno99]	[Ber99]	[Ber99] range	[Veh97a] range	Tnk94 range (g/kg dry)
➢ Cl	7.4 g/kg	5 - 10	5.9 g/kg	7.2 g/kg	6 - 8.6	5 - 8	1 -10
➢ S	2.3 g/kg	1 - 4	1.9 g/kg	3.0 g/kg	1 - 4	1 – 3	0.3 - 5
➢ HM	2.6 g/kg		3.8 g/kg	2.0 g/kg	0.4 - 4.2	Cu : 0.2 – 1 Zn : 0.6 – 2	Pb : 7 - 20 Cd : 0.1 - 0.5

The Cl content is in fact much dependent on the plastic content, especially of PVC. These data must be considered as including the average effect of PVC (effect discussed in §3).

Usual Pb Content in MSW

Lead is the main heavy metal present in PVC products. It is thus is important to know its average content in MSW for assessing the effect of PVC on MSW behaviour (question discussed in §3). Miscellaneous values can be found in the literature :

Average	range	unit	Source	Country	Comments
455	430 - 1200	mg/kg	[Rei89]	Germany Switzerland	
1350	700 - 2000	mg/kg dry	[ThK94]	Europe	Unusually high. Old? source Dr.Leman [Lem92]
466	456 - 476	mg/kg wet	[Tno96]	The Netherlands	
653	648 - 657	mg/kg dry	[Tno96]	The Netherlands	
817		mg/kg dry	[Pol96]	France	(3% from plastics, 65% from metals, 5% from glass → Less than 3% Pb comes from PVC)
700	400 - 1000	mg/kg	[Veh97b]	Europe	major sources = pigments, stabilizers, alloys, accumulators (*)
670		mg/kg wet	[Tno99]	The Netherlands	Derived from Krajenbrink 1996

(*) according to various sources (International Ash Working Group 1995, Handbook 1995, Jonhke 1994).

Table 2e – Lead content in MSW

The value of **670 mg/kg** seems to representative of the average value.

2.3 Part of incineration and other MSW treatments in Europe

The distribution of Municipal Solid Wastes according to the different ways of treatment in Europe (incineration, landfill, compost, recycling) is shown in table 3.

Sources of data :

- EEWC report published 1997 (Juniper study) [**Eew97**]
- European Statistics from 1993-1996 published in 1997 by ISWA [**Isw97**]
- Last data published by OECD for 1995 [**Oec97**]
- Eurostat report corresponding to data from 1993 [**Eur97**] (EUROSTAT 93)

MSW ANNUAL PRODUCTION AND WAYS OF TREATMENT IN EUROPE								
Country	MSW total Amount* k tonnes / yr	incinerated Wgt %	Landfill Wgt %	Compost Wgt %	Recycling Wgt %	Amount incinerated kt/yr	*Amount incinerated kt/y*	*Amount incinerated kt/yr*
	OECD 95	OECD 95				OECD 95	*ISWA 96*	*Juniper 97*
A	3841	**17**	40	18	25	653	*407*	*510*
B	4781	**31**	55	6	8	1482	*-*	*2151*
D	25777	**25**	34	8	33	6444	*9569*	*13121*
DK	2788	**56**	21	11	12	1561	*2593*	*2814*
E (SP)	14296	**5**	83	12	0	715	*672*	*1072*
Fr	28000	**37**	55	7	1	10360	*9542*	*10830*
GR	3200	**0.5**	92.5	-	7	1	*-*	*0*
I	27000	**5**	95	-	-	1400	*2100*	*3407*
IRL	1550	**-**	92	-	8	0	*-*	*0*
L	218	**58**	4	4	34	126	*-*	*150*
NL	8956	**25**	38	22	15	2234	*2348*	*3600*
P	3500	**-**	88	12	-	0	*-*	*0*
Sw	3900	**41**	40	3	16	1600	*672*	*2094*
SF	2100	**2**	62	3	33	50	*-*	*50*
UK	20000	**12.5**	82.5	-	5	2500	*1713*	*2140*
CH	2660	**76**	7	5	12	2021	*2844*	*2722*
Nw	2637	**17**	68	1	14	448	*417*	*440*
EC 15	**149910**	**19,4%**	**64,5%**	**6,4%**	**9,7%**	**29130**	*35474*	*40193*
EC 17	**155200**	**20,4%**	**63,5%**	**6,3%**	**9,8%**	**31600**	*38735*	*45101*

EC17 = EC15+CH+Nw

Table 3 - MSW Production and ways of treatment

Fairly similar figures are given by [Bon99]. Other data on current situation and trends can be found in [Fzk97].

This table shows that incineration is much more a common practice in Northern European countries, as it can be seen on the European map (figure 1) :

- **> 40%** for Switzerland, Luxembourg, Denmark, Sweden,
- **25% to 40%** : France, Belgium, Netherlands, Germany
- **12 to 21 %** for Norway, Austria, United Kingdom (atypical low % for Northern countries)
- **< 8 %** for Italy, Spain, Portugal, Greece

With the exception of Finland (2%), for relatively small amounts.

These percentages were almost the same in 1991 [Jhn92], excepted for NL (46% - now 25%) and Sweden (55%, now 41%). If exact, it means a sharp decrease of incineration part in these countries, probably in advantage of recycling.

For all Europe, MSW treatments are distributed by the following average percentages (values calculated in above table) :

MSW Treatments in Europe
(1995-1997)

- ❖ **6% composted**
- ❖ **10% recycled**
- ❖ **20% incinerated**
- ❖ **64% landfilled**

Other data

Above percentages are based on OECD95 data. ISWA96 and Juniper97 (last columns of table 3), given for comparison purpose, have higher overall amounts than OECD data (38735 and 45101 kt/year instead of 45100). This is due not only to evolution from 1995 to 1997, but also to the nature of these values : part of “Juniper data” are in fact based on capacities of incinerators and not on effective quantities, and this explains a overall amount 16% higher than ISWA96 and 45% higher than OECD95, although these last data take into account a greater number of incinerators (see below). Clearly, these statistics do not include accurate enough information to distinguish the various origins of differences.

Overall value for EC15

Various overall value can be found for Europe (EC15) :

- OECD 95 (table 3): 29130 kt/yr
- ISWA96 (table 3) : 35474 kt/yr
- Juniper97 (table 3) : 40193 kt/yr
- Jun.97+correction (table 4) : 43784 kt/yr
- Laurent Bontoux [Bon99] : 43700 kt/yr

We shall further base various estimations on a forfeit base of **40 000 kt/year** incinerated MSW.

2.4 MSWI location and corresponding capacities

Table 4 gives the number of plants and capacities of MSWI units in Europe.

(From Juniper 97 data, with corrections from various source)

There are around **230** MSW incineration units, mainly located in Northern Europe, as shown on the map (figure 2).

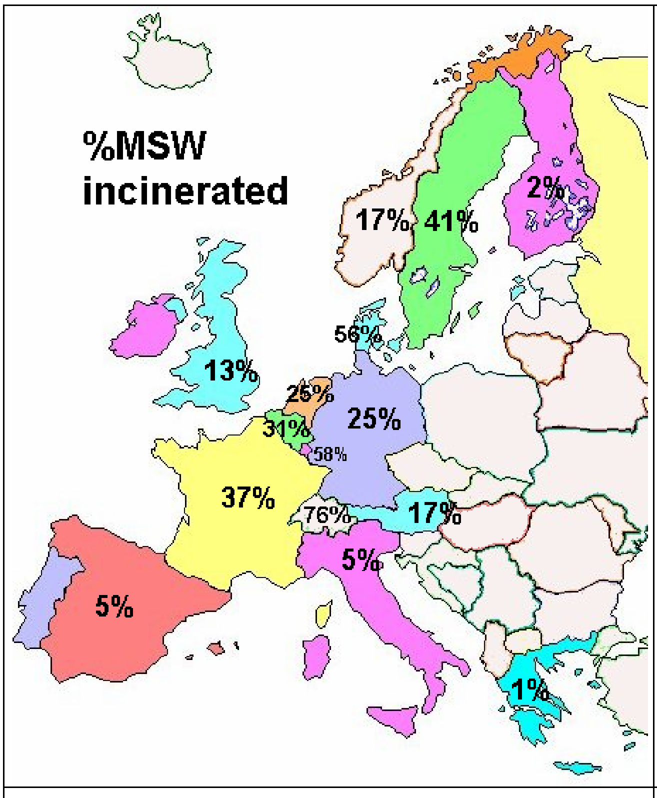

Figure 1 - % MSW incinerated per country

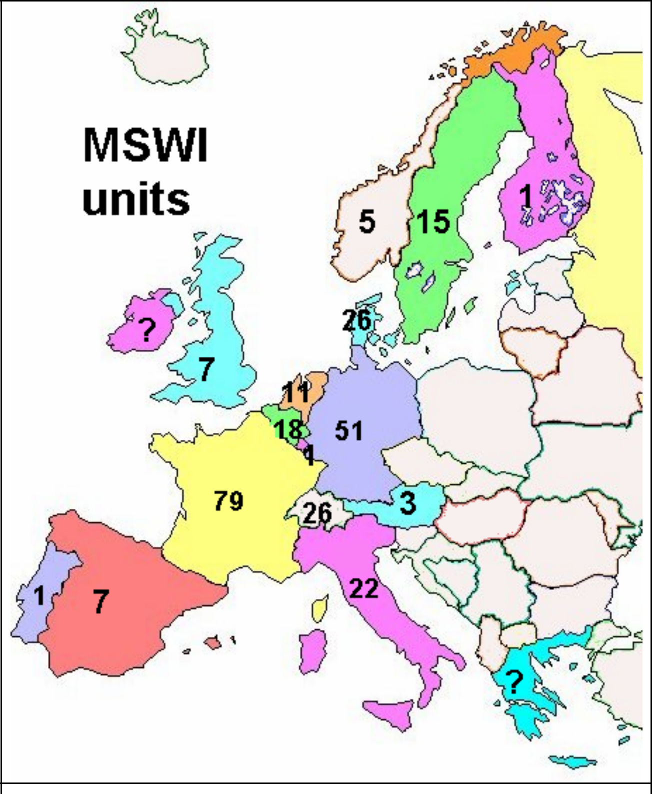

Figure 2 - Number of plants per country

COUNTRY	Number of plants	Capacity (kt/year)	Mean capacity per unit (kt/year/plant)
AUSTRIA	3	510	170
BELGIUM	18	2406	134
DENMARK	26	2854	110
FINLAND	1	50	50
FRANCE	79	10771	136
GERMANY	51	13462	264
GREECE	1?		
ITALY	22	2197	100
LUXEMBOURG	1	150	150
NETHERLANDS	11	5638	513
PORGUGAL	1		
SPAIN	7	1242	177
SWEDEN	15	2094	140
UK	7	2140	306
Other	3	270	90
NORWAY (*)	9	470	52
SWITZERLAND	26	3002	115
TOTAL EC15	**244**	**43784**	**179**
TOTAL EC17	**279**	**47256**	**169**

(*) Norway : 1998 data. Two more plants opened in 1999.

Table 4 - Number of Plants and capacities per country in Europe

There are great differences in the numbers of plants and their capacities according to different sources, as shown in table 5a (comparison of 4 sources).

SOURCE	JUNIPER 1997 Plants > 30 kt/year		ISWA 1996 Plants > 10 kt/year		OECD 1995		1991 [Jhn92]	
COUNTRY	Number of plants	Capacity (kt/year)	Number of plants	Capacity (kt/year)	Number of plants	Capacity (kt/year)	Number of plants	amounts (kt/year)
AUSTRIA	3	510	2	407	22	1630	2	300
BELGIUM	17	2151	-		18		27	720
DENMARK	26	2814	34	2593	32	2400	48	1500
FINLAND	1	50	-				1	
France	77	10830	95	9542	297	11408	260	6350
GERMANY	43	13121	36	9569	138	???	49	9300
ITALY	32	3407	15	2100	204	1912	54	2000
LUXEMBOURG	1	150	-		1		1	140
NETHERLANDS	11	3600	6	2348	12	2700	11	2805
NORWAY	5	440	5	417	12		50	440
SPAIN	7	1072	6	672	20	625	22	697
SWEDEN	15	2094	21	1827	21	1700	22	1550
SWITZERLAND	26	2722	28	2845	30	2488	48	2300
UK	7	2140	12	1713	214		33	2780
TOTAL EC 15	**230**	**40285**	**211**	**29361**	**970**	*20675*	**530**	**28142**
TOTAL EC 17	**271**	**45101**	**260**	**34033**	**1021**	*24863*	**628**	**30882**

Table 5a - Comparison of 3 sources giving statistics on MSWI plants in Europe

This is due to different capacities criteria used for the data collection (Juniper [**Eew97**] and ISWA sources take into account only the plants with capacities greater than 10 or 30 kt/year), and also to a constant evolution of the incinerators park.

Other data may be found in [Bon99], which also uses Juniper1997 as a basis, with corrections from various sources. It obtains a slightly higher overall amount for Europe (EC15) of 43 700 kt/year.

2.5 Classification according to Gas Treatment Systems

The type of GTS (Gas Treatment System) has a direct influence on the quantity and composition of the APC residues (Air Pollution Control residues, including solid residues and liquid effluents generated during the Gas Treatment), in relation with the concentration of the acid compounds to neutralise (mainly HCl and SOx).

Following EC's classification, the Gas Treatment Systems have been distributed among 3 categories : Dry, Semi-Dry and Wet Processes. Semi Wet/wet processes (wet + evaporation of liquid effluents) are included in Semi-Dry GTS.

Each GTS has specific characteristics in terms of Neutralisation Agent nature, required excess quantities, and corresponding generation of residues.

Table 6 shows the distribution of incinerators in EC as a function of GTS [**Eew97**].

COUNTRY (nb = number	Totals	Gas Treatment Systems			
		Dry process	Semi-dry process	Wet process	Others
	Capacity	Capacity	Capacity	Capacity	Capacity

of MSWI)	nb	kt/year	nb	kt/year	%	nb	kt/year	%	nb	kt/year	%	nb	kt/yr	%
AUSTRIA	3	510							3	510	100%			
BELGIUM	17	2151	1	55	3%	8	741	34%	8	1355	63%			
DENMARK	26	2741	8	482	18%	7	790	29%	11	1469	54%			
FINLAND	1	50	1	50	100%									
FRANCE	63	9209	16	1439	16%	18	2277	25%	29	5493	60%			
GERMANY	57	13427				19	4217	31%	38	9210	69%			
ITALY	32	3407	13	1106	32%	1	84	2%	18	2217	65%			
LUXEMBOURG	1	150	1	150	100%									
NETHERLANDS	11	5223	1	60	1%	4	1683	32%	6	3480	67%			
NORWAY	5	440	2	225	51%				3	215	49%			
SPAIN	7	1200				2	515	43%				5	685	57%
SWEDEN	15	2088	6	778	37%				9	1310	63%			
SWITZERLAND	24	2722				1	85	3%	23	2637	97%			
UK	7	2140	4	1140	53%	3	1000	47%						
TOTAL EC17	269	45458	53	5485	**12%**	63	11392	**25%**	148	27896	**61%**	5	685	**2%**
TOTAL EC15	240	42296	51	5260	12%	62	11307	27%	122	25044	59%	5	685	2%

Table 6 - MSWI capacities and numbers of plants for the 3 types of GTS.

Source : Updated Juniper 1997 (Plants capacities >30 kt/year) [**Eew97**] , updated from several sources.

Notes that semi-wet/wet processes are included in the semi-dry processes. We have identified 41 such plants in Europe :

Belgium	5 plants	480 kt/yr
France	3 plants	480 kt/yr
Germany	33 plants	7700 kt/yr (*)
Total	41 plants	8660 kt/yr

(*) including 5 plants with pure wet scrubbing for 1510 kt/y.

The distribution of APC systems when related to the amount of incinerated MSW leads to the following percentages for all Europe (line EC17 in above table) :

- **Dry processes : 12%**
- **Semi-dry processes : 27%**
- **Wet processes : 61%** (including wet/semi-wet)

Comments.

Compared to our different sources, partial updating of these results was attempted, but it is difficult to improve estimations. Juniper 1997 data are not always consistent with other sources, and there is a constant evolution of GTS processes due to the more and more severe regulation for gas emission, and also to the evolution towards suppression of liquid residues in some countries (in Germany, all new incinerator must be effluent free).

This constant evolution is illustrated by the French evolution from 1992 to 1997 shown on figure 3.

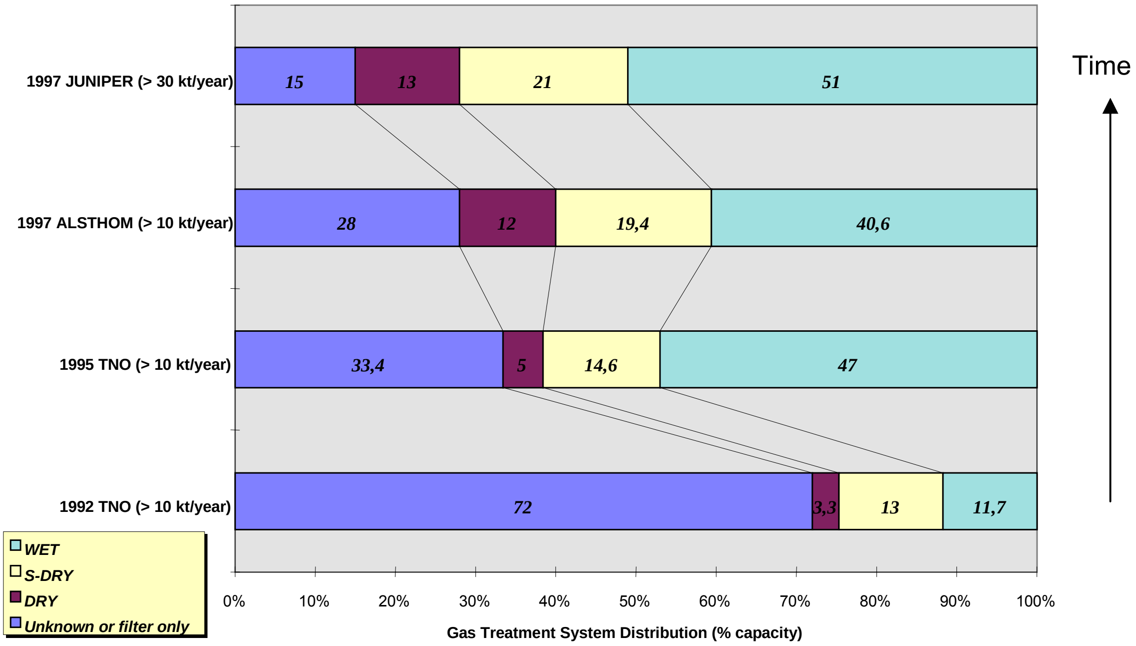

Figure 3. Evolution of GTS Process distribution in France

2.6 Residue production in Europe

2.6.1 Sorts of residues

The residues from incineration can be divided into 3 main ways (figure 4) :

- Primary residue from combustion : Bottom Ash or Slag (coarse ash)
- Residue from gas treatment : APC residues (solids + possible liquid effluent)
- Emissions at the stack (gas effluent + some residual solids)

Bottom ashes represent the highest amount (around 30% of incinerated mass, see next paragraph). Their typical composition is 30 to 50% glass, 30 to 60% sand, 10 to 20% scrap iron and other metals, 5 to 20% water.

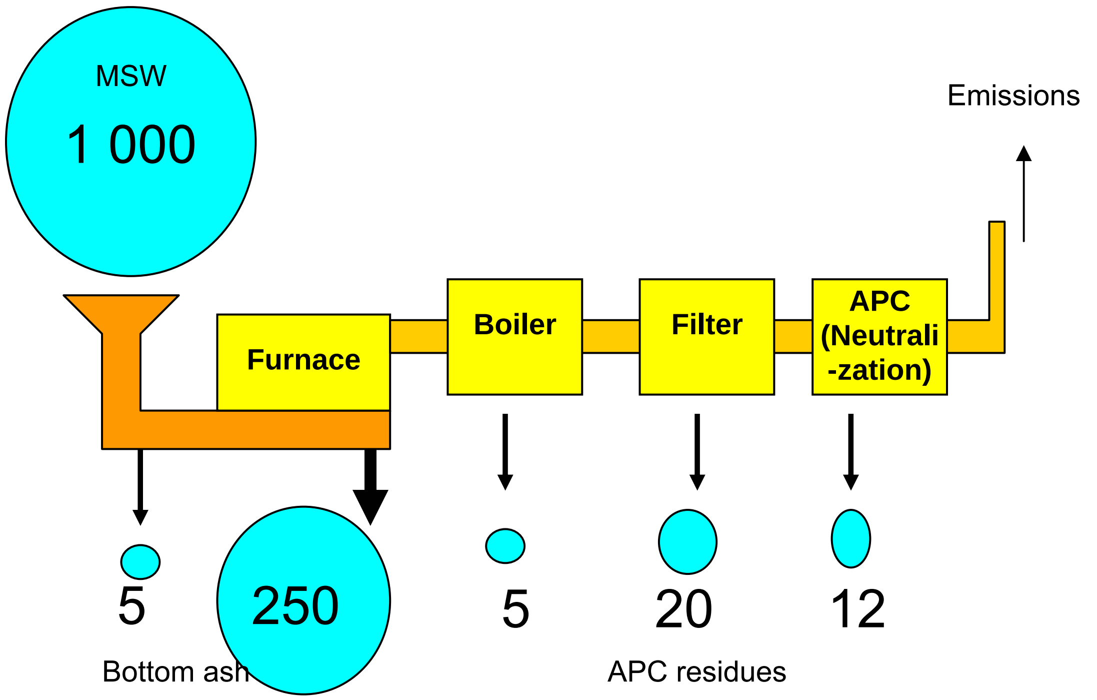

Figure 4. Mass Flow-chart in incineration of MSW

According to the possible Gas Treatment Processes employed to meet the gas effluent specifications, the APC final residues may have different nature and composition. They include the following residues, in separate of combined form :

- Boiler Ash
- Cyclone Ash
- Filter Ash (fly ash from filtration steps (fabric filter or ESP)
- Neutralisation residues : solid residues
- Liquid effluent (containing salts if not treated)
- Filter cakes from treatment of liquid : solid residues

Fly Ash (solid residues)

Neutralisation residues

Gas treatment process	Reactant	Nature of APC residues	Type of APC residues
Dry Semi-Dry Semi-wet	Lime $Ca(OH)_2$ Bicarbonate	Solid	[Fly Ash + salts] (mixed) or Fly Ash / Salts
Wet	Lime NaOH	Solid + liquid	Fly Ash / Liquid effluent / Filter cake
Semi-wet Wet	Lime + NaOH	Solid	Fly Ash / Salts or Fly Ah + Salts */ Filter cakes*

Table 7a - Nature of APC residues as a function of GTS.

Neutralisation residues are mainly composed of the Neutralisation salts (NaCl, $CaCl_2$, CaOHCl, …) according to neutralisation agent employed as well as to its required excess (NaOH, $Ca(OH)_2$, Na_2CO_3).

2.6.2 Amounts of residues per incinerated mass

Quantities of residues are usually expressed in mass ratios "residues/incinerated waste", or mass percentage of incinerated MSW.

The production of **bottom ash** should correspond to the inert part in MSW, which is around 20% to 30% (see §2.2.2), plus some unburned material (< 3%). It is often assumed that the average production is 300 kg/ton (30%), or more commonly **250 kg/ton** (25%) of MSW incinerated. [Rij99] gives a wider range of 20% to 35% but accepts a lower representative value of 215 kg/ton (with 15% humidity) in overall evaluations.

The production of **pure fly ash** depends on the primary combustion set-up. They are mainly related to the carry-over of particles from the waste bed, and are thus dependent on the grid type and mixing system, on the primary air distribution, and on gas circulation (co-flowing or opposite flowing, depending on the flue gas outlet position). For example, a reduction of speed of primary air flowing through the waste layer can reduce the amount of fly ashes. Some particles are produced in the flame (ZnO, soot,…) and their generation (or destruction) depends on other parameters (HM contents, secondary air distribution). It can explain differences between units, although no statistics are published on that question, to our knowledge.

The production of other **APC residues (neutralisation residues)** highly depends on the GTS system.

Following ranges are usually considered for residue ratios :

- fly ash (boiler ash + filter ash) = 14 to 34 kg/t
- salts (neutralisation products) = 0 to 60 kg/t depending on the S and Cl contents of MSW, on the nature of the reactant, and on the type of GTS (no solid salts to be considered with wet processes with effluent release, 14 to 50 kg/t for other Gas treatment systems)

Some processes (dry or semi-dry) do not have specific filtration for Fly Ash which are collected with the neutralisation products.

Slightly different figures are given by [FZK97] (table 7b), which makes a more detailed distinction between different types of residues (bottom ash = grate ash + grate sifting, fly ash = boiler ash + filter ash). This reference gives a lower amount of fly ash, attributed to a recent evolution towards a "more gentle combustion", in Germany. This "more gentle" combustion should mean a lower carry-over of particles from the waste layer (e.g. optimized air blowing system).

type of residue	kg per ton MSW	Comments
grate ash	200-350	*(or 250 - 400?)*
grate sifting	1-5	*usually mixed with grate ash*
boiler ash	5	
filter ash	10-15	*decreased from 30 (more gentle combustion) (20 in below diagram)*
wet scrubber (APC)	12	*mostly used in Germany. Salts have to be evaporated (in Germany).*
dry system	no data	

Table 7b - Amounts of residues according to [FZK97]

Depending on the gas treatment system, average solid residues amounts have been estimated from chemical calculations assuming a Chlorine content of 7g/kg and a sulphur content of 2g/kg in MSW (table 7c) (see details below, in table14a and comments, and in annexe B). A similar analysis is presented in [Ber99]. These values are compared to [Rij99] recent values.

Gas treatment process	APC residues	kg/ton of MSW *our evaluation*		kg/ton of MSW *for comparison [Rij99]*	
Dry	Salts (Neutralisation residues) + fly ash (commonly mixed)	51.7	= 25 + 26.7	40.6 (D)	= 15.2 + 25.4
Dry with Bicar	"	38.1	= 25 + 13.1		Not evaluated
Semi-Dry	Neutralisation residues + fly ash (commonly mixed)	50.3	= 25 + 25.3	35.5 (C)	= 15.2 + 20.3
Wet	filter cakes + fly ash	29.3	= 25 + 4.25	16.8 (A)	= 15.2 + 1.6
Semiwet-Wet	filter cakes + fly ash	39.4	= 25 + 14.4	30.2 (B)	= 15.2 + 6.9 + 8.1
Simple Filtration	Fly ash	25		15.2	Not considered

Table 7c - Amounts of APC residues for different GTS.

[Ber99] "fly ash" basic value or 25 g/kg is an average value (in a range of 10 to 34 g/kg for a set of 8 European facilities).

Our "Wet GTS" values are in the [FZK97] range of 27 - 32 kg/ton for boiler ash + filter ash + wet scrubber residues.

The calculated overall range for APC residues is 30 to 59 kg/t, which is consistent with the range given above for salts and fly-ash (30 to 60).

The [Rij99] values are 20 to 30% lower, because they are based on 39 % less fly ash, and a lower Cl content in MSW (Cl = 5.9 g/kg and S = 1.9 g/kg). The basic value of 15.2 for fly ash (dry value) seems rather low to be representative of the whole Europe. It corresponds to a value measured on the Alkmaar facility (NL) which can be considered as an advanced facility (14 g/kg, according to [Ber99]). It could be representative of the more modern units but not of the current average.

Furthermore, if boiler ash are added to bottom ash, as suggested by the flow chart of [Rij99] figure 3, the value of 15.2 is in agreement with the German values of 15 g/kg for "filter ash" for an advanced facility (table 7b). According to the same source, boiler ash is 5 g/kg. Total fly ash (boiler ash + filter ash) is then 20 g/kg. Our value of 25 for European average is slightly higher.

Anyway, no better precision may be expected from available statistics.

2.6.3 Estimation of overall amounts of residues in Europe

Overall estimation of **APC residues** production in Europe can be obtained from distribution of GTS in Europe (table 6) and ratios of residue production given in table 7c. Calculation shown in table 7d gives respective average productions from 24.2 to 39 kg/ton$_{MSW}$ for the three sets of estimated ratios.

GTS	% in Europe	kg/ton of MSW		
		Ber99D	*Ber99E*	*Rij99*
Dry	14%	58.7	51.7	40.6
Semi-Dry	22%	52.5	50.2	35.5
Wet	64%	30	29.3	16.8
Simple Filtration	neglected	25	25	15.2
Total or average	100%	**39**	**37**	**24.2**

Table 7d - APC residues production ratios in Europe

Detailed estimation for production of APC residues for each country is given by table 7e, with calculation based on the second estimation of [Ber99E], and on overall incineration capacities (thus overestimated). It gives a production of residues of 1690 kt/year.

GTS	Dry process	Semi-dry process	Wet process	Others	Mean APC ratios	Incinerated MSW	Estimated amounts	Available data	Ultimate storage
APC ratios kg/ton	51,7	50,2	29,3	25	kg/ton	Capacity	APC	APC	APC
COUNTRY	% MSW processes by GTS types					kt/year	kt/year	kt/year	kt/year
AUSTRIA			100%		29,3	510	15	12	0,6
BELGIUM	3%	34%	63%		37,1	2151	80		
DENMARK	18%	29%	54%		39,3	2741	108		
FINLAND	100%				51,7	50	3		
FRANCE	16%	25%	60%		38,0	9209	350	255	255
GERMANY		31%	69%		35,9	13427	482	400	
ITALY	32%	2%	65%		37,1	3407	126		
LUXEMBOURG	100%				51,7	150	8		
NETHERLANDS	1%	32%	67%		36,3	5223	190		
NORWAY	51%		49%		40,8	440	18		
SPAIN		43%		57%	35,8	1200	43	40	40
SWEDEN	37%		63%		37,6	2088	79		
SWITZERLAND		3%	97%		30,0	2722	82		
UK	53%	47%			51,0	2140	109		
TOTAL EC17	**12%**	**25%**	**61%**	**2%**	**37,2**	45458	1690		

Table 7e - Mean APC residues production per country in Europe

For further calculations, owing to the fact that the mean calculated APC ratios seems somewhat lower than our estimation (depending on the country, see next paragraph), we have chosen a rounded estimation of **33 kg/ton** (which is between our estimation and [Rij99] estimation).

We also have to base the calculation on actual incinerated amounts of MSW, which are lower than incineration capacities. For all Europe, it thus gives the following rounded amounts :

- **40 000 kt/yr incinerated MSW**
  (average estimation from available data, see tables 3 and 5a)
- **10 000 kt/yr bottom ash** (average 250 kg/t$_{MSW}$)
- **1 320 kt/yr APC residues** (base 33 kg/ t$_{MSW}$)

2.6.4 Comparison to some particular situations

The accuracy of the estimations of APC ratios and amounts can be evaluated from comparison with available data for some countries, especially when overall production of residues can be known and compared to overall incinerated amounts.

France

In France, annual storage of APC residues in CSDU (ultimate waste disposal centres) is 255 kt/yr (source: ADEME, see annex in step1 report, and additional data on France in annex to this report), for an overall mass of 10 800 kt of MSW incinerated : it corresponds to an overall APC/MSWI ratio of 24 kg/t_{MSW} instead of the above estimation of 38 kg/t_{MSW} (60% higher).

Our calculated APC ratio seems overestimated as compared to overall ratio. No explanation was found apart from a possible effect of temporary storages (a part of amounts is temporary stored in incineration facilities), and that in some cases, fly ashes can be mixed with bottom ashes and thus don't go to class I disposal sites. This can explain that the amount going to disposal centres would be lower than the actual amount produced. But this last practice should not represent a significant proportion, as it is not allowed in France and may only concern some small units.

Example of a French MSWI plant equipped with a wet system (see annex), shows that this ratio can actually be reduced to **19 kt/ t_{MSW}**, salts rejected in rivers or sea being around the same amount.

Germany

In Germany, liquid effluents have to be evaporated to prevent the release of salts in the rivers. Above estimation of 482 kt/yr (based on 36 kg/t_{MSW}) should not be far from real value. It is nevertheless 20% higher than the German value given by [Dpu97] (400 kt/yr, which corresponds to 30 kg/t_{MSW}). Amounts of residues may be lower due to optimised gas treatment, according to [Fzk97].

Spain

From Spanish statistics giving overall productions of residues (see data on Spain in annex), the following APC ratios per type of GTS are derived :

- ESP only 23 to 30 kg/t_{MSW}.
- with semi-dry 50 kg/t_{MSW}.
- Mean value 40 kg/t_{MSW} (overall amount of 40 kt for 1000 kt_{MSW} in 1998)

These values are in agreement with the mean ratios used in above calculations, and the overall ratio of 40 is slightly higher than the above estimation of 36 kg/t_{MSW} for Spain.

Austria

For Vienna-Spitttelau plant, main incinerator in Austria, APC residues are around **22 kg/t_{MSW}**.(see table "Austria Data"). It is lower than the estimated value of 30 kg/t_{MSW} given above, based on usual wet systems. It may be due to the well-advanced flue gas treatment for this unit, as it is claimed to be.

Filter cakes residues, which represents only **1,1 kg/t_{MSW}**., are sent to Heilbronn in Germany, while slag and fly ash are used for making special concrete in disposal centres :

"After separate transport of slag (in covered wagons) and filter ash (in silo transporters) to a special processing plant, these two residues are sieved, scanned to remove any ferrous scrap, mixed with cement and water, and used in landfill construction for border walls as a slag-filter ash concrete with an eluate (leaching) quality approaching that of drinking water.

The ferrous scrap removed from the raw slag at the plant itself is returned to the material cycle (steel production). The filter cake is transported to Germany by rail in big bags, and used there as infill in a disused salt mine."

For all Austria (3 plants over 30 t/h), it gives a fair estimation of 560 t/year sent to German Mines.

(Current cost for transportation and storage : 490 € / ton).

Comments on Norway & Denmark

In Norway, the Langøya center receives an annual amount of 40 kt of fly ash, mainly from Norway and Denmark (see Step1 report). Taking the calculated amounts of 20 kt/year for Norway + 114 kt/year for Denmark, it should mean that Denmark sends around 17% of APC to Langøya, if Norway sent 100%. Denmark sends the other part to German mines or to local temporary storage (see additional details hereunder).

Comments on The Netherlands

Proportion of wet systems in The Netherlands is slightly higher than France, and practice is the same : salts can be eliminated with the liquid effluent , especially for plants located near the sea. We don't have data on overall production.

2.6.5 Comparison to German mine-valorisation amounts

Overall figure of 1500 kt/yr APC residues can be compared to total amount of residues sent to German mines for mine-valorisation :

- **676 kt/yr hazardous residues** (APC + other residues) disposed of in mine-valorisation in Germany (in 1997).

This amount should mainly includes APC residues, but also some other hazardous wastes. Part coming from MSWI is not known (90%?), and amounts going to underground storage are not included. Main part of APC residues should logically be accepted in mine-valorisation centres (which are cheaper), depending on their quality (HM content, leachability). Low quality APC residues should be sent to underground storage (e.g. Austrian filter cakes residues are sent to Heilbronn).

Estimation of APC involved in mine valorisation

Assuming the percentage of 90%, it gives a rough estimation of :

- **600 kt/yr APC residues** are used in mine-valorisation sites in Germany

It represents **45%** of the whole European production of APC residues (above estimation of 1320 kt/yr).

We can note that owing to the current capacity of German mines, the whole European APC residue production could be sent to Germany if it were economically and politically viable.

Comparison to production from Germany and nearby countries

Amounts of APC produced in Germany and neighbouring countries are :

- **400 kt/yr APC residues** for Germany
- **394 kt/yr APC residues** for Switzerland + Denmark +Netherlands

It shows that only a part (around 50%) of APC residues from neighbouring countries are sent to German mine-valorisation facilities.

2.7 Final destination of the residues

The management of the residues depends of the practices, regulation and site availability as a function of the country considered. In any case the residue has to fulfil with the regulation in force prior to be stored in its final destination.

2.7.1 Solid residues (bottom ash or APC residues)

Solid residues are possibly addressed either to landfills to be stored with possible stabilisation treatment, road construction applications or salt mines storage.

Different types of final destination of the solid residues have to be considered :

1) Valorisation
   - Road application (incorporation in filling or covering material)
   - Mine-valorisation (incorporation in filling or building material), in salt or coal mines (Germany only)

2) Landfill for hazardous wastes
   - Landfill in Underground storage (Salt mines)
   - Landfill in surface sites equipped for hazardous wastes (CET or Class I type in France)

   (Langøya in Norway is classified as such a landfill site but is also doing valorisation).

Usually, bottom ash go to valorisation in road application (provided they respect quality criteria) (see example of French situation in below frame), and APC residues (Salt+Fly ash) to landfills - after being packed in "big bags" or transported in special tankers for powdered products - where they can be mixed with cement for stabilisation.

French classification of bottom ash
As given in the French regulation “circulaire de mai 1994”.

- **Catégorie V : leachability < 5%** : can be directly utilized (valorized)
- **Catégorie M : leachability < 10%:** can be utilized after temporary storage for aging (maximum 1 year) or stabilization. It goes to catégorie V if leachability is correct, catégorie S if not.
- **Catégorie S : leachability > 10%:** no possible utilization, must be sent to CET2 landfills

See for example some leaching test in [Sch94] (with a method for improving the quality of bottom ash).

Very few utilisation of APC residues takes place, except :

- in the Netherlands, where 30 to 50% of fly ash is used as a filler in asphalt [Bor94, Van99]
- In Germany, where APC residues are used for mine-filling in mine-valorisation sites (probably more than 90% of these residues, 10% going to deep storage mines). In coal mines, APC residues are pumped as a cement grout admixture used as mine building material.
- In Norway, where the disposal of fly ash (in the Langoya centre) contributes both to neutralisation of acid residues and to the filling of an old quarry. In that site, alkaline dry and semidry residues are mixed with waste sulphuric acid and landfilled in a deep, former limestone quarry as an impure gypsum product (see step1 report).

Landfills for hazardous waste must normally be equipped with leachate collection systems. In some countries, residues have to be stabilised (by solidification and/or chemical stabilisation) prior to disposal.

Future and current landfills will have to apply the recent European Directive on landfill (discussed in the Step1 report), which has to be adapted to each European country before 2001.

Some countries, e.g. Denmark and the Netherlands, are currently considering residue management options and investigating various treatment concepts and processes. In the meantime, the residues are placed in temporary storage facilities or landfills or exported to the German underground facilities or the Norwegian treatment and storage facility at Langøya.

2.7.2 Liquid residues

Liquid residues are released in the environment (in rivers, or in the ocean for some units in The Netherlands), after being treated for pollutants removal (HM, acids, solids, pH control to 7).

The possibility to release liquid effluents in the environment becomes more and more limited. Most of the wet gas treatment previously exploited in Belgium and Germany have been replaced by dry, semi-dry, semi-wet or mostly semi-wet/wet systems.

2.7.3 Quantities involved

No other data on quantities involved per type of destination and residues were found, except for the figures presented in §2.6.

Next paragraph gives complementary details on residue management.

2.8 Discussion on the various residues management policies in Europe

2.8.1 Fly ash

Fly ash, i.e. the particulate material collected by electrostatic precipitators or fabric filters upstream of the neutralisation systems, is generally classified and treated in much the same way as the dry and semidry residues are.

They are placed in hazardous waste landfills with or without prior treatment. The most common treatment form in the EU member states is probably solidification/stabilisation with Hydraulic binders (cement or cement-like substances) often supplemented with the admixing of various proprietary additives. This is done e.g. in Austria, Belgium, Germany and France (**Veh97c**, **Vra99**, **Fly97**). In some cases the fly ash is washed prior to solidification/stabilisation to remove the readily soluble salts (mostly chlorides). This is done in Switzerland (**Veh97c**). Methods for chemical stabilisation of fly ash with phosphates, carbon dioxide, ferrous sulphate and other chemicals (with or without prior washing of the ash) are under development but not yet in general use. In some member states, e.g. Germany and Denmark, fly ash pre-collected at incinerators with wet scrubbing systems is mixed with the sludge from treatment of the scrubber liquid effluent and landfilled (**Fly97**). The purpose of this treatment should be for the fly ash to absorb excess liquid from the sludge and for the sludge to bind/reduce some of the potentially soluble trace elements in the fly ash, thereby reducing their leachability. More sophisticated treatment methods such as the 3R process in which the fly ash is extracted with the acid scrubber liquid effluent from the wet scrubbing process and subsequently fed back on the grate to be sintered, are only in use at very few incinerators (**Veh99**). High temperature treatment methods such as melting and vitrification are currently not being applied to fly ash in full scale in Europe due to the high Energy requirements and the technical difficulties involved.

2.8.2 Residues from dry and semidry processes

There is no qualitative difference between the composition and the management options and practices for residues from the dry and semidry processes, respectively. The only difference concerns the excess of neutralisation agent : due to higher stoechiometric ratio , the residues from dry processes generally have a higher content of unreacted neutralisation agents than the semidry residues have. Dry and semidry residues will therefore be discussed together.

It is quite common to collect the excess reactants and the reaction products from the dry and semidry processes together with the fly ash. In some countries, e.g. Belgium, the fly ash is filtrated upstream of the neutralisation systems, and the dry and semidry residues consists of reaction products and excess neutralisation agents with only very small amounts of fly ash. With few exceptions (most notably Hg), most of the contaminants and trace elements are associated with the fly ash, and the fly ash containing residues from the dry and semidry processes may therefore be regarded as fly ash diluted with reaction products and excess neutralisation agents.

Several processes have been designed to recover calcium chloride and sodium chloride from the dry and semidry APC residues, but to our knowledge few or none of these processes are currently used commercially (**Fly97**).

The dry and semidry residues are generally placed in hazardous or special landfills with or without solidification/stabilisation (Belgium, France, Great Britain, Sweden) or they are stored in excavated salt mines (Germany). In the Netherlands and Denmark, the residues are placed in temporary storage, awaiting the development of appropriate technology and new regulations. As mentioned previously, part of the residues produced in Denmark are exported to a Norwegian treatment and landfilling facility (Langøya). The same solidification/stabilisation methods (cement and other additives) that is used for fly ash are also applied to the residues from the dry and semidry processes. Because of the high contents of soluble salts, the amounts of cement and other additives necessary are higher and the results in terms of stability and reduction of the leachability of contaminants as well as economics are less satisfactory than for fly ash (**Fly97**, **Veh97c**). The most promising stabilisation processes for dry and semidry residues are based on initial or simultaneous removal of the soluble salts by an aqueous extraction followed by the actual stabilisation step. This washing operation produces a saline extract with a content of trace elements, which must be treated prior to discharge.

The technical and economical problems associated with high temperature treatment (melting and vitrification) of dry and semidry residues are even more pronounced than for fly ash and no such processes are in commercial operation.

Particular case of dry process using sodium bicarbonate

Using NaHCO3 as neutralisation agent, it is possible to find an industrial utilisation of the neutralisation residues. Such unit is already in operation in Italy (Rosignano) , and another unit with a capacity of 50 kt is under construction in Nancy (France) for strartup in summer 2001.

Such practice can clearly reduce the amount of residues from incineration to send to landfill.

2.8.3 Residues from the wet process

In the wet process the fly ash is always pre-collected upstream of the wet scrubbers. The waste streams from the process may consist partly of sludge from treatment of the wastewater and partly of treated wastewater containing the soluble salts, mostly the chlorides. The purpose of the wastewater treatment is to reduce the content of trace elements in the wastewater to a very low level.

In some EU member states (e.g. Denmark), where most of the MSW incinerators are located near the sea, the discharge of treated, saline wastewater with a low content of trace elements presents no problem. In other member states where most or all incinerators are located inland, far away from the sea, the discharge of saline wastewater may not be acceptable, and in those cases the wastewater from the scrubbing System is evaporated to produce a dry residue consisting of salts and various impurities. This is e.g. common practice in Austria, Germany and the Netherlands. On few incinerators, HCl is recovered from the acid scrubber effluent by distillation (**Veh97c**). It is also possible to recover gypsum by separate treatment of the wastewater from the second scrubbing stage in two-stage scrubbing systems (e.g. in Spittelau, Austria, see annexe).

The dry Solids from the evaporation of the liquid effluent is treated similarly to the dry and semidry residues (without fly ash). The sludge from treatment of the wet scrubber effluent will often appear as a filter cake, which may be landfilled at a special or hazardous waste landfill after stabilisation or mixing with fly ash. The treated wastewater is discharged to the sewage System or directly into a receiving water body.

3. Impact of PVC on the quantity and hazardousness of the residues

3.1 General aspects on PVC composition and main applications

PVC is a chlorinated hydrocarbon polymer consisting of a linear carbon chain for which alternate carbon atoms have one of their hydrogen atoms replaced by a chlorine atom. The chlorine in PVC represents 57% of the weight of the pure polymer without any additives. Pure PVC will be designed as "resin" and the term "polymer" will be used for the different types of PVC compounds.

According to the targeted application the PVC polymer formula can vary in large proportions because of additives incorporated into the polymer as filler, stabiliser, lubricant, plasticiser, pigment or flame retardant. PVC products can be classified in two major categories, rigid PVC and soft (or plasticised) PVC.

Building and construction	:	mainly rigid PVC
Packaging	:	plasticised and rigid PVC
Wire, cables and elec.	:	plasticised PVC
Leisure	:	plasticised and rigid PVC
Transport	:	mainly rigid PVC
Furniture, office equipment	:	plasticised and rigid
Clothing footwear	:	plasticised
Domestic appliances	:	rigid and plasticised

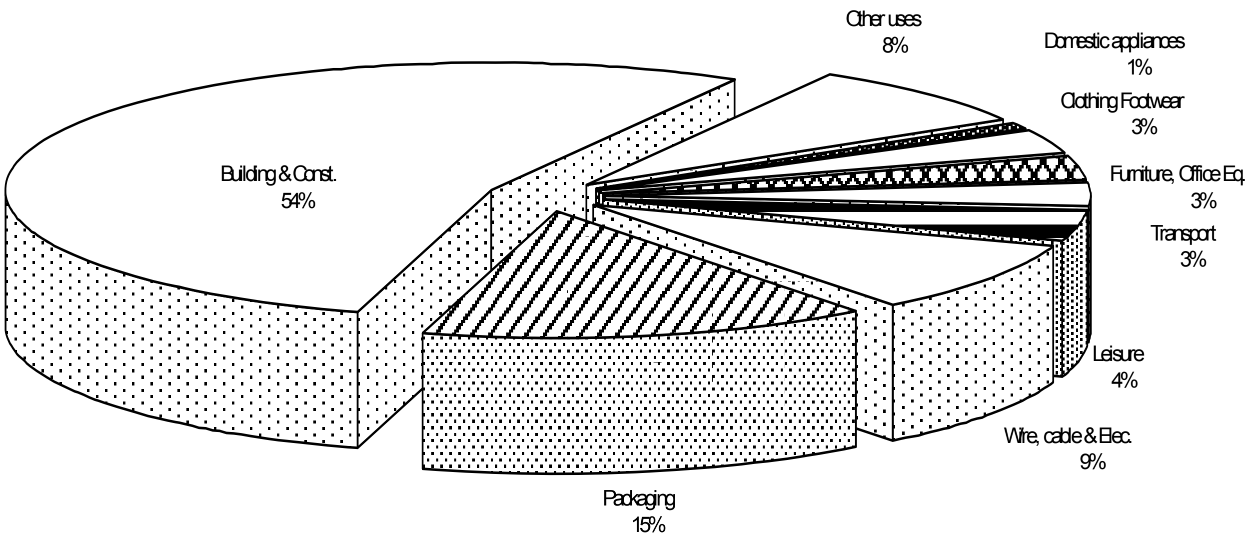

Figure 5 - PVC use per destination

Hazardouness of PVC incineration may come from two problems :

- **Effect of Chlorine content (main effect)** : production of Chloride Acid HCl, which has to be neutralized in the APC system and can influence combustion conditions, especially heavy metals partitioning, dioxines production, and leaching properties of residues

➢ **Effect of Heavy Metal content (minor effect) :** mainly Cd, and also Sn, Pb, V, Zn.

3.2 Chlorine content

3.2.1 Chlorine content in PVC products

Chlorine content in pure PVC resin is 57% (exact value for C_2H_3Cl is 56.8%).

The resin content of PVC products - and consequently the Chlorine content - are highly dependent on the formulation of the polymers.

Chlorine concentration therefore varies from 53% in rigid products (93% PVC resin) to 34% in films (60% PVC resin) and 25% in cable covering (44% PVC resin). This concentration can go down to 14% in flooring applications (25% resin).

57% Cl	**in pure PVC**
14% - 53% Cl	**in PVC products**
37% - 50% Cl	**in incinerated PVC**

PVC Chlorine contents

3.2.2 Chlorine content in PVC incinerated

Industrial wastes (e.g. cable covering and flooring applications) are not to be incinerated with domestic Waste ; only a part of the PVC production is devoted to incineration for end-of-life products. For the effect of PVC on MSW, we have to consider the average composition of incinerated PVC, and not the average composition of PVC produced.

Following table gives the average chlorine content in PVC incinerated, according to various sources. It ranges from 37% to 50%, calculated from estimation of part of soft PVC and Rigid PVC in MSW.

Sources	Nieuwenhuysen 1996 [Nie96]	De Groot 1993 [Gro93]	Reimann 1991 [Rei91]	Rijpkema 1993 [Rij93]	Rijpkema 1999 [Rij99]	Rasmussen 1995 [Ras95]	Mark 1995 [Mar95]
% Soft PVC	50	34	30	50	28.6	50	
% Rigid PVC	50	66	70	50	46.0	50	
%Cl in incinerated PVC	41	45	50	41	37.3	48	40

Table 9a – Composition in soft or rigid PVC, and Chlorine contents in incinerated PVC

A mean value of 45 % can be accepted for calculations of Cl contribution (Calculation presented in [Ber99] are based on 50%). Note that recent analysis by [Rij99] results in a Cl content of 37.3%, lower than all previous estimations.

3.3 Heavy metal content in PVC

3.3.1 Origin of Heavy Metals

Heavy metals in PVC only come from additives used for particular products such as Pipes, Fittings, profiles and Cable covering.

Table 9b [Buh98, Ecv98, Ber99] gives typical ranges for Pb, Sn, Cd, Ba, Zn, Ca, contents in PVC products (packaging or other products), depending on stabiliser types added to resin.

Stabiliser Type	Main Metal		Metal Content (%) in PVC	
			Packaging	Other Products
Lead compounds	Pb	Lead	Not used	0.5-2.5
Organotins	Sn	Tin	0.1-0.2	0.3-0.5
Cadmium compounds (usage restricted by EC/91/338)	Ba Cd Pb	Barium Cadmiu m Lead	Not used “ “	0.1-0.2 0.1-0.3 1.0-1.8
Barium/Zinc compounds (only for plasticised applications)	Ba Zn	Barium Zinc	Not used “	~ 0.1 < 0.1
Calcium/Zinc compounds	Ca Zn	Calcium Zinc	0.1 < 0.1	~ 0.1 < 0.1

Table 9b - Typical Metal Contents in PVC Products

3.3.2 HM in average PVC products

Table 10 gives a calculation of the mean HM contents for PVC in the Netherlands, from percentages of different PVC manufactured products. It considers only Sn, Zn and Pb.

It is based on TNO values [Tno96] for annual production and composition (which is slightly different from the above pie chart composition).

Overall PVC production in the Netherlands, and Heavy metals contents												
Product and classification		NL-market		Composition (%)			Heavy metals contents (mg/kg)			Heavy metals production (t/year)		
	soft/rigid	kt/ year	%	PVC	Organic (plasticizer)	inorganic (filler)	Sn	Zn	Pb	Sn	Zn	Pb
Rigid foil	rigid	6	4%	90	7	3	30			0,18	0	0
Soft foil	soft	5	3%	60	30	10		400		0	2	0
Vinyl carpets	soft	13	8%	53	33	14		600		0	7,8	0
Cable isolation	soft	15	10%	46	28	26			14000	0	0	210
Boots	soft	1,2	1%	43	51	6		500	1500	0	0,6	1,8
Roof lining	soft	4,8	3%	50	35	15		350		0	1,68	0
Construction Elements	rigid	7	5%	80	6	14			2000	0	0	14
Pipes	rigid	103	66%	91	6	3			10000	0	0	1030
Total PVC		155	100%	80,3	12,5	7,3	1	78	8102	0,2	12,1	1255,8

Table 10 - Calculation of mean HM content (Sn, Zn, Pb) in PVC in the Netherlands

It shows that :

- Sn is present in rigid foil (30mg/kg), but is only 1 mg/kg on the total PVC production.
- Zn content can go up 600 mg/kg and represents only 78 mg/kg on the average.
- Pb content can go up to 14 g/kg (=1,4%) and represents 0,81% of the total PVC production. This percentage corresponds to the use of 1256 tonnes of Pb for producing 155 ktonnes of PVC per year (overall cross-checking could be done with values obtained from the PVC industry).

The composition of the PVC incinerated in MSW is different : only some types of PVC have to be considered, as shown further on.

3.4 Effect of PVC on the composition of MSW

3.4.1 PVC content in MSW

PVC content in MSW from 0,4 to 1,6%, depending on the country (table 11) and also on sources. Differences between countries can be due to recycling policy and also to quality of statistics methods.

Minimum values (0.4% to 0.6%) are found for Netherlands, Norway and Italy.

Maximum values are found for France (1.2%) and Switzerland (1.35%).

Average PVC content in MSW in Europe

- 0,74% (TNO 1992, Mar95)
- 0,86% (APME 1996)
- 0,64% (TNO 1996, Rij99)
- 0,70% (ECVM, EVC99) [Pcv99]
- 0,73% (Rasmussen Ras95)
- 0.9 % (current calculation)

PVC in French MSW in 1993
ADEME data, on dry MSW [Pol96]

- 1,5% PVC bottles/packages
- 0,4% other PVC packages
- 0,3% other PVC products

Total PVC 2.2%
1.6% if 40% packages are recycled

Debate on France data

Value given for France has been modified.

In fact, raw data from ADEME 1993 [Pol96] gives a surprisingly higher value of 16 % PVC in the plastic fraction of MSW instead of an average value of 10%. But this value was supported by [Rij93] (1990 data : 21% PVC in plastics, 6% plastics in MSW, thus > 1.3% PVC in MSW). An even higher value of 2.2% can be derived from [Pol96], for MSW before recycling. It turns into 1.6% assuming 40% recycling for PVC bottles and packages.

Due to development of recycling practices in France, and especially to replace of many PVC packages by PET (peak change in 1997/98), real PVC percentage should now be much lower than this value. That is why we replaced the value of 16% PVC in plastics by 12% (highest percentage of other countries), which gives a value of 1.2% PVC in MSW.

Part of plastics and PVC incinerated with MSW						
				Percentages en %wgt		
Country	MSW annual amount kt/yr	% MSW incinderated wgt %	Incinerated MSW kt/y	% plastics in MSW	% PVC in plastics	% PVC in MSW
A	3841	17	653	7%	9%	0,63%
B	4781	31	1482	7%	10%	0,70%
CH	2660	76	2021	15%	9%	1,35%
D	25777	25	6444	7%	10%	0,70%
DK	2788	56	1561	5%	12%	0,60%
E (SP)	14296	5	715	11%	12%	1,32%
F	28000	37	10360	10%	12%	1,20%
I	27000	5	1400	7%	8%	0,56%
L	218	58	126	8%	10%	0,80%
Nw	2637	17	448	6%	8%	0,48%
NL	8956	26	2234	6%	7%	0,42%
UK	20000	12,5	2500	10%	10%	1,00%
total and Average	140954	21,3	29944	8,7%	10,5%	0,92%
without CH and Nw	135657	20,3%	27475	8,3%	10,8%	0,90%
without France	112954	17,3%	19584	8,1%	9,6%	0,77%

Source : values of percentages (%plastics, and share of PVC in plastics) are taken from ISWA 1996, excepted for France (see above explanation).

Table 11 - Parts of plastics and PVC incinerated with MSW

Average percentage for Europe is calculated in table 11 by weighing percentages by annual amounts incinerated, from OECD 95 data, excluding countries for which no data on PVC content are available. It results in the following mean percentages for PVC :

- 1.1% using the original French value of 1.6% PVC in MSW (ADEME1993 value)
- 0.9% using the corrected value of 1.2% (result shown in the table)
- 0.77% by eliminating France from calculation (result shown in the table)
- 0.70% by eliminating France and Switzerland (not shown)

Accuracy of original data per country is questionable, as other sources give average PVC content for Europe between 0.64 and 0.86% (see above frame).

It may come from differences of composition between raw MSW and incinerated MSW (composition after extraction for recycling), and also from the general evolution.

For further calculations, we have considered an average value of **0.8 % PVC** in European incinerated MSW.

3.4.2 HM in average PVC incinerated

Table 12 (from [Tno96, Nie96]) gives corrected calculation for HM content in incinerated PVC, using above composition, and estimated TNO values for the part incinerated for each category of PVC products.

PVC Contents in Municipal Solid Wastes in the Netherlands							Average concentrations in MSW						
Product and classification		NL-market	Processed in MSWC				Composition (%)			Heavy metals contents (mg/kg)			Chlorine content
	soft/rigid	kt/ year	% product	kt/year	%		PVC	Organic (plasticizer)	inorganic (filler)	Sn	Zn	Pb	% Cl
Rigid foil	rigid	6	100%	6	**41%**		90	7	3	30			51,3
Soft foil	soft	5	100%	5	**34%**		60	30	10		400		34,2
Vinyl carpets	soft	13	10%	1,3	**9%**		53	33	14		600		30,2
Cable isolation	soft	15	0,5%	0,075	**1%**		46	28	26			14000	26,2
Boots	soft	1,2	100%	1,2	**8%**		43	51	6		500	1500	24,5
Rooflinings	soft	4,8	0%	0	**0%**		50	35	15		350		28,5
Construction Elements	rigid	7	1%	0,07	**0%**		80	6	14			2000	45,6
Pipes	rigid	103	1%	1,03	**7%**		91	6	3			10000	51,9
Totals		155	9%	14,7	100%		**72,5**	**20,8**	**6,8**	**12,3**	**230,3**	**905,6**	**41,3**

Table 12 - Heavy metal content in incinerated PVC in the Netherlands

It gives the following HM contents in PVC incinerated, that can be compared to contents in PVC produced :

- Sn 12 mg/kg PVC incinerated 1 mg/kg PVC produced.
- Zn 230 mg/kg PVC incinerated 78 mg/ kg PVC produced.
- Pb 906 mg/kg PVC incinerated 8102 mg/ kg PVC produced.
  (0,09 % PVC incinerated 0,81% kg PVC produced).

Main Pb contributors are items "cable isolation" and "Pipes". Less than 1% of these categories of PVC are incinerated. It explains the lower average Pb content in incinerated PVC. On the opposite, Sn and Zn have higher contents in incinerated PVC than in produced PVC.

Note that we have taken 0,5% instead of 0% for cables processed in MSWC. This explains a slightly higher value than given by TNO [Tno96b] (**750 mg/kg**).

This value can be compared to the average value of **500 mg Pb/kg plastic** in MSW fractions, from other TNO data : PVC is a higher Pb contributor than other plastics.

Table 12 gives also a calculated mean chlorine value of 41,3% in the PVC incinerated in MSW, consistent with the mean value of 45% given above.

3.4.3 PVC effect on Cl and HM content of MSW

Effect of PVC can be evaluated by comparing the contribution of PVC to the average contents in Chlorine and lead in MSW.

PVC contributions

(base: 45% Cl /PVC and 0.8% PVC in MSW, 45% Cl in PVC, 906 mg Pb per kg MSW, 230 mg Zn)

- PVC contribution to Cl in incinerated MSW : **3.6 g/kg**
- PVC contribution to Pb in incinerated MSW : **7.2 mg/kg**

Usual content in incinerated MSW (see § 2.2)

- Cl content: **7.4 g/kg**
- Pb content: **670 mg/kg**

PVC shares

PVC contributes to **49%** of Cl content in MSW, and to **1.1%** of Pb content in MSW, on the basis of 0.9 % PVC in MSW.

Respective shares given by [Rij99] are **41%** for Cl and **0.74%** for Pb, on the basis of 0.64 % PVC in MSW (see table 13b).

These values are in the range given in [Ber99] (38% to 66%).

Our value for Pb (1.1%) may be overestimated, but other sources mention quite higher values :

- **10 %** (in the Netherlands) [Min97]
- **6 %** (in Denmark) [Depa98, Rei91]
- **3 %** (in Sweden) [Mer99]

The values of 6% and 10% are however clearly overestimated. 10% would correspond to the hypothetical case in which all sorts of PVC (including cable isolation and pipes) would be put in domestic incineration. Pb influence of 6% given in [Rei91] was obtained with a very large rigid PVC content (U-PVC ≈ 0.7%) in MSW.

Anyway, accuracy of these estimations is low because it cumulates all uncertainties on PVC content in MSW, composition of PVC found in MSW, and average composition of MSW. It highly depends on the collecting and recycling policies in different countries.

3.4.4 Other HM, Cl, S, data for comparison

Table 13a, from [Ber99/Rij93] data, presents the PVC influence on the MSW composition, determined for 0.7% PVC in MSW, PVC being a 50/50 mixture of rigid (U-PVC) and flexible PVC (P-PVC).
This source is consistent with the above values for the share of Cl and Pb (respective contributions of 39% and 1%).
More recent TNO results [Rij99] give a more complete analyse including other metals (table 13b).
From both results it appears that the influence of PVC on heavy metal content in MSW is significant only for cadmium, for which it represents a contribution of 7% (table13b) or 11% (table 13a).
This contribution is much higher than for lead and tin (Pb ≈1%, Sn ≈2%, V≈1%). Contributions to other HMs (Hg, As, Co, Cr, Cu, Mn, Ni, Sb, Se, Zn,...) are lower than 1%.
The situation for Cadmium is being changing, because Cadmium additives are now only permitted in PVC profiles and not in other products. The lower contribution of 7% can be considered to be more representative of current situation.

1st evaluation , from Rij93 data							
Elements from MSW		standard MSW	PVC - U (rigid)	PVC -P (flexible)	PVC waste (50% U)	Contribution of 0.7%PVC in MSW	Influence in %
Cl	g/kg	7,4	510	320	415	2,905	39%
S	"	2,4	0	0	0	0	0%
Cd	mg/kg	6,4	100	100	100	0,7	11%
Pb	"	570	1470	240	855	5,985	1,1%
As	"	8,3	0,5	0,5	0,5	0,0035	0,04%
Sn	"	4,4	25	0	12,5	0,0875	2,0%
Zn	"	710	0	450	225	1,575	0,2%
Other Metals	"	1354	396	370	383	2,681	0,2%

- PVC-U : Unplasticised (e.g. pipes, windows frame) (rigid, strong, weather proof)
- PVC-P : Plasticised (e.g. cable covering, floor covering, some packaging) (flexible)

Table 13a - PVC contribution to elementary composition of MSW (partial)

2nd evaluation , from Rij99 data							
Basic percentages for calculations				PVC-P/total=	50%	PVC/MSW=	0,64%
Elements from MSW wet		standard MSW	PVC - U (rigid)	PVC -P (flexible)	PVC waste (50% U)	Contribution of PVC in MSW	Influence in %
C	g/kg	274,4	357,3	420,4	389	2,49	0,9%
H	"	38,3	45,4	54,6	50	0,32	0,8%
O	"	165,1	9,7	48,2	29,0	0,19	0,1%
N	"	9,1					
Cl	"	5,9	459,7	286,3	373	2,39	40,5%
S	"	1,9	0	0	0	0,00	0,0%
P	"	1,0					
F	"	0,11					
Br	"	0,15					
ash	"	196,1	28	90,5	59,25	0,38	0,2%
water	"	307,94	100	100	100	0,64	0,2%
LHV	MJ/kg	9,46	16,17	19,98	18,075	0,12	1,2%
Hg	mg/kg	0,6	0,09	0,09	0,09	0,0006	0,10%
Cd	"	8,5	90	90	90	0,58	6,78%
As	"	7,4	0,45	0,45	0,45	0,0029	0,04%
Co	"	13	0,9	0,9	0,9	0,0058	0,04%
Cr	"	190	23	23	23	0,15	0,08%
Cu	"	1630	230	230	230	1,47	0,09%
Mn	"	110	23	23	23	0,15	0,13%
Ni	"	100	9	9	9	0,06	0,06%
Pb	"	670	1320	220	770	4,93	0,74%
Sb	"	31	9	9	9	0,058	0,19%
Se	"	4,8	no data			0	
Sn	"	4,5	23		11,5	0,074	1,64%
V	"	26	45	45	45	0,29	1,11%
Zn	"	1000		410	205	1,31	0,1%
total HM	"	3795,8	1773,44	1060,44	1416,94	9,068	0,2%

Table 13b - PVC contribution to complete elementary composition of MSW
Source : [Rij99] (TNO study R99/462)

Recap

♦ **Cl** contribution **50 %**	(**3.6 g/kg**	for a usual content of	**7.4 g/kg Cl**	in MSW)
♦ **Cd** contribution **7 %**	(**0.6 mg/kg**	for a usual content of	**8.5 mg/kg Cd**	in MSW)
♦ **Pb** contribution **1 %**	(**7.2 mg/kg**	for a usual content of	**670 mg/kg Pb**	in MSW)
♦ **HM** contribution **0.2 %**	(**9 mg/kg**	for a usual content of	**3800 mg/kg HM**	in MSW)

3.5 Impact of PVC on the quantity and hazardousness of the residues

3.5.1 Main effects of PVC

As already mentioned, the hazardousness of PVC incineration comes from two points :

- **Effect of Chlorine content (main effect)** : production of Chloride Acid HCl, which has to be neutralized in the APC and can influence combustion conditions, especially heavy metals partitioning and dioxines production, and finally leaching properties of residues
- **Effect of Heavy Metal content (minor effect) :** mainly Cd, and also Pb, Zn, Sn.

PVC thus can change composition and amounts of residues from combustion :

- Increase of the amount of APC residues, due to the increase in neutralisation agents needed for neutralisation of HCl, proportionally to the amount of Cl coming from PVC
- Increase of the chlorine content of fly ash
- Changes in HM partitioning between residues (less HM in bottom ash, more HM in APC residues).

This last effect (transfer of HM from bottom ash to Fly ash and other APC residues) is due to the formation of HM chlorides or oxi-chlorides in the combustion, which are highly volatile at combustion temperatures. This effect could be favourable, as it may improve the quality of bottom ash for recycling purpose (better leaching characteristics). However, according to [Ber99], this effect is not significant in usual MSWI combustion conditions.

3.5.2 PVC influence on the Neutralisation residues

The presence of PVC in MSW has a direct effect on the quantity of chlorine in the raw gas and therefore on the corresponding necessary gas treatment efficiency. The higher chlorine content in the gas requires additional neutralisation agent supply and therefore affects the quantity of residues or effluents generated by the different Gas Treatment Systems.

Gas Treatment Residues relating to the use of PVC are mainly composed of chlorine salts and neutralisation agent excess. According to the Gas Treatment System these can be either sodium salts NaCl, Na_2CO_3 (dry process with sodium bicarbonate, wet process with sodium hydroxide), or calcium compounds $CaCl_2$, CaOHCl, $Ca(OH)_2$ (for processes using lime).

Due to the lack of availability of APC residues representing situations where no PVC would be incinerated, no direct comparisons of the quantities and hazardousness of the various types of residues produced with and without incineration of PVC can be made.

Instead of such direct data, an estimation can be done in terms of the amounts of residues depending on the APC. This approach includes four APC types : the dry process, the semidry process, the wet process and the semiwet-wet process.

1) Effect on the amount of residues per type of APC

The estimated amounts of APC residues components for 4 types of gas treatment systems have been estimated within the study presented in [Ber99].

The quantities of residues attributable to PVC were calculated in scenarios where the most severe emission limits for HCl (10 mg/Nm3) are met, except for the standard dry process with standard grade lime which is not likely to meet this specification.

Results are listed in table14a. It shows the amounts of residues produced, in kg per tonne of incinerated waste, with and without PVC. It also gives the absolute increase in kg/t MSW, and the share of PVC (increase divided by the "with PVC" case) ; note that percentages expressed in terms of increases instead of shares would result in slightly higher percentages. Data with PVC correspond to data already presented in table 7c (our estimation).

	Amount produced (kg per tonne of waste incinerated)		**Effect of PVC**	
Gas treatment process and respective residues	**Without PVC**	**With PVC**	**kg / t MSW**	**% share (w/w)**
Dry process:				
• Acid gas cleaning residue	19.5	26.7	+ 7.2	*26%*
• Fly ash	23.8	25.0	+ 1.2	
Total	**43.3**	**51.7**	+ 8.4	16 %
Dry process with Bicar:				
• Acid gas cleaning residue	9.1	13.1	+ 4.0	*30%*
• Fly ash	23.8	25.0	+ 1.2	
Total	**32.9**	**38.1**	+ 5.2	14 %
Semidry process:				
• Acid gas cleaning residue	19.8	25.3	+ 6.5	*26%*
• Fly ash	23.8	25.0	+ 1.2	
Total	**43.6**	**50.3**	+ 6.7	13 %
Wet process:				
• Fly ash	23.8	25.0	+ 1.2	*4.8%*
• Filter cake	4.3	4.3	+ 0	
Total	**28.1**	**29.3**	+ 1.2	4.1%
Semiwet-wet process:				
• Acid gas cleaning residue	10.0	14.4	+ 4.4	*31%*
• Fly ash (total)	23.8	25.0	+ 1.2	
Total	**33.8**	**39.4**	+ 5.6	14 %

Table 14a - Estimated amounts of residue components in APC, and effect of PVC

These calculations are based on rounded values, slightly different than above values :

- Cl content in MSW : 3.5 g/kg without PVC, 7 g/kg with PVC (⇔ 0.7%PVC in MSW ∗50%Cl) (PVC is assumed to double the Chlorine content in MSW)
- S content in MSW : 2 g/kg
- 66 Cl and 50% S neutralized in gas treatment step (other part goes to bottom ash and for a lower part to fly ashes)
- Stoechiometric ratios from 1.10 to 2 for HCl according to GTS (table14b)
- Stoechiometric ratios from 1.10 to 4 for SO_2 according to GTS (table14b')

GTS	N.A. (formula)	Products (formula)	Basic S.R. ratio	N.A. kg N.A./ kgCl	Neutr. residues kg / kgCl
Dry with lime (standard grade lime)	$Ca(OH)_2$	$Ca(OH)Cl, H_2O$	2	2.08	3.11
Dry with Bicar	$NaHCO_3$	$NaCl, Na_2CO_3$	1.05	2.48	1.72
Semi-dry	$Ca(OH)_2$	$Ca(OH)Cl, H_2O$	1.7	1.77	2.80
Wet:	NaOH + $Ca(OH)_2$	NaCl + $CaCl_2$	1.1	1.14	1.96 (effluent)
Semiwet-wet	$Ca(OH)_2$	NaCl + $CaCl_2$	1.1	1.14	1.91

Table 14b – Stoechiometric ratios for HCl treatment

GTS	N.A. (formula)	Products (formula)	Basic S.R. ratio	N.A. kg N.A./ kgS	Neutr. residues kg / kgS
Dry with lime	$Ca(OH)_2$	$CaSO_4,2H_2O$	4	9.25	12.32
Dry with Bicar	$NaHCO_3$	Na2SO4, Na_2CO_3	1.2	6.30	5.09
Semi-dry	$Ca(OH)_2$	$CaSO_4,2H_2O$	4	9.25	12.32
Wet:	$Ca(OH)_2$	$CaSO_4$	1.1	2.54	4.25
Semiwet-wet	$Ca(OH)_2$	$CaSO_4,2H_2O$	1.1	2.54	5.61

Table 14b' – Stoechiometric ratios for S treatment

These stoechiometric ratios are typical values based on chemical analyses, validated by comparison with experimental data gathered on a set of selected incinerators. Actual stoechiometric ratios can be different, and may vary according to type of unit and country emission standards (decreased thanks to recycling of excess neutralisation agent or optimising system, increased for obtaining lower pollutant emission levels).

Details on these calculations are given in annexe B.

Table 14 a shows that the influence of PVC on the amount of acid gas cleaning residues ranges from **4% to 31%** , according to the type of Gas Treatment System.

PVC Influence on pure fly ash (without neutralisation products) is less than **5%.**

Influence on overall residues amounts ranges from **4% to 16%.**

These percentages are fairly equivalent to PVC allocations given by [Rij99] (14.5% for scrubber residue, 16.4% for semi-dry scrubber residue, 11.6% for filter cakes in wet system) (and 34% salt residue in wet system with effluent evaporation). Detail comparison is presented as follows.

Comparison to PVC effect in [Rij99]

Table 14d gives comparative results from Rijpkema [Rij99].

He assumes fly ash mass ratio of 15.2 g/kg_{MSW}, and respective contents of 37.3%Cl in PVC, and 0.64%PVC in MSW. He also assumes a reduced stoechiometry for extra Cl associated with PVC, due to some compensation by SO_2.

The lower amount of fly ash (15.2 instead of 25 g/kg_{MSW}) was discussed above (corresponds to the Alkmaar MSWI unit, while we consider a rough average value for Europe, see comments on table 7c in § 2.6.2).

GAS TREATMENT		BOTTOM ASH	FLY ASH	DRY (D)		SEMI-DRY (C)	WET (A)	SEMI WET – WET (B)
Neutralisation Agent.				Lime	BICAR	Lime	Lime	Lime
Stoechio. ratio. for HCl				2.5	-	1.8	1.1	1.1

Stoechio. ratio. for HCl from PVC				1.5	-	1.3	1.1	1.1
Our stoechio. for HCl				*2*	*1.05*	*1.7*	*1.1*	*1.1*
Residue usual amounts (kg/tonne MSW)		215	15.2	25.4	-	20.3	1.6	15
Our usual amounts, kg/t MSW		*250*	*25.0*	*26.7*	*13*	*25.7*	*1.2*	*14.4*
Cl effect (kg/kgCl) for Cl from PVC PVC effect (kg/kgPVC) Allocation to PVC	x x*.37	0.18 0.066 0.19%	0.012 0.005 0.19%	1.55 0.580 14.5%	- - -	1.39 0.520 16.4%	0.08 0.029 11.6%	1.23 0.458 19.5%
Our Chlorine effect (kg/kg neutr. Cl) *Our Chlorine ratio (kg/kg Cl in MSW)* *Our PVC effect (kg/kgPVC)* *Our allocation to PVC*	*y/.66* *y* *y*0.5*	 *0.46* *0.23*	 *0.34* *0.17* *4.8%*	*3.11* *2.05* *1.02* *26%*	*1.72* *1.14* *0.57* *30%*	*2.80* *1.85* *0.93* *26%*	*1.96(*)* *1.29 (*)* *0.65 (*)* *4.8%*	*1.91* *1.26* *0.63* *31%*

(*) in liquid effluent (kg dry matter/kg ref.)

Table 14d - Influence of PVC on the quantity of residues : comparison to TNO [Rij99] results

We obtain quantities of APC residues around 1 kg residue per kg PVC (0.57 to 1.02), while [Rij99] gives around 0.5 kg residue per kg PVC (0.46 to 0.58). We thus obtain higher allocations to PVC.

This is not only due to a lower Cl content in PVC in [Rij99] (37.3% instead of 50%), but to different approaches of the stoechiometry linked to Cl from PVC :

- We assume that for dry and semi-dry systems, stoechiometry must take into account the formation of Ca(OH)Cl, H2O rather than CaCl2 (see annex B). Formation of CaOHCl is discussed in [All97] and [Joz95]. Such effect explains the high stoechiometric ratio (around 2) usually needed for dry and semi-dry treatments.
- We don't take into account the SO_2 compensation effect, because SO_2 neutralisation reactions are slower than HCl neutralisation reactions.
- From data on experimental behaviour, we assume that only 66% of Cl is neutralised by Gas treatment, other part being absorbed in bottom ash and fly ash (accuracy of such percentage is of course questionable but it is in the range of uncertainties) ; [Rij99] gives a percentage of 74% neutralised in Gas treatment (see §A.5. Chlorine Balance).

2) Effect on the amount of residues in overall European production

From European statistics on Gas Treatment System given above (12% dry, 25% semi-dry, 61% wet), we have computed the average effect of PVC on the amount of APC residues in overall European production. Table14b gives amounts of residues values calculated with and without PVC, from a first evaluation [Ber99D], and from updated values given in table 14a (2nd evaluation, [Ber99E]). Semi-Wet wet processes are included in semi-dry processes in both evaluations.

GTS	Dry process	Semi-dry process	Wet process	Others	Mean APC ratios	Incinerated MSW
	% MSW processes by GTS types				kg/ton	kt/year
TOTAL EC17	12%	25%	61%	2%		45500
APC amounts	in kg per ton of MSW					in kt/year
1st evaluation [Ber99D]						
With PVC Without PVC	58,7 44,9	52,5 41,3	30 28,7	25 23,7	39,0 33,7	1776 1535
PVC share	24%	21%	4%	5%	14%	241
2nd evaluation [Ber99E]						
With PVC Without PVC	51,7 43,3	50,7 43,7	29,3 28,1	25 23,8	37,3 33,8	1697 1537
PVC share	16%	14%	4%	5%	9%	160

Table 14c - Estimated average amounts of residues, and effect of PVC

It shows the allocation of PVC for each type of Gas Treatment System :

- 16% share for the dry process
- 14% share for the semi-dry process
- 4% for the wet process
- 5 % for the simple filtration process → not relevant (negligeable part of APC systems)

In wet systems, the amount of solid residues is lower, because some liquid residues (salt water) can be rejected into rivers and seas, depending on the country and the location.

Taking into account proportions of each GTS in Europe (12%, 25%, 61% 2%), it gives an overall effect due to the PVC of **10%** share in amounts of residues.

Assuming this average value of 10%, overall European production of solid residues directly due to PVC can then be estimated to **130 kt/year** on a total of **1 320 kt/year**, on the basis of 40 000 kt MSW incinerated per year.

3) Effect on hazardousness of residues

The effect of PVC on APC residues is directly related to the effect on the MSW composition, which has been shown to be a substantial increase in the chlorine contents, a significant increase in Cadmium content (≈ 11%), and less significant increases in other heavy metals contents (Pb ≈1%, Sn ≈2%, V≈1%). A large part of these elements are found in APC residues, mainly in chloride form).

Bottom ash

As already stated (and explained in [Ber99]), in the current temperature range of combustion conditions for MSW incineration, the higher chlorine content has no significant effects on the transfer of other Heavy Metals and trace elements from bottom ash to gas treatment residues, although some studies show such a possibility, which would improve the leachability characteristics of bottom ashes.

PVC has thus an negligible effect on the amount and composition of bottom ash.

Fly ash (primary filter ash)

Fly ash (from primary filter step) contributes between 11% to 15% of the neutralisation of the HCl. Its chlorine content is consequently subject to variations following the Cl content in the waste.

Recent studies [Ber99] show that the Cl content in fly ash varies between 1.8 to 13.2 % (or 4 to 10.2 % according to other studies).

All APC residues

The increase in chloride salts content of fly-ash and APC residues has a direct influence on leaching properties of the residues.

Table 15a gives an attempt to quantify this effect from laboratory experiments on leachability of residues [Ber99]. It gives the amount of leachates corresponding to a period of 50 years, for each type of residues, without and with PVC (basic Liquid to Solid ratio L/S = 1 l/kg). It is based on the assumption that the waste contains 7.0 kg Cl/tonne in the presence of PVC and 3.5 kg Cl/tonne without PVC.

The corresponding relative increases due to PVC are given in table 15b.

For all residues, the incineration of PVC (which concentration in MSW is 0.6 to 0.8 %) appears to increase the content of leachable salts (primarily chlorides of Ca, Na and K) up to a factor of about 2.

Effect on the leaching of trace elements/heavy metals (-7% to +5% for Cd, 0% Pb in table 15b) is not significant. This is supported by the fact there isn't any available data showing that the leaching of trace elements/heavy metals would increase significantly as a result of the incineration of PVC.

Component	**Dry residue (incl. FA)**		**Semidry residue (incl. FA)**		**Wet + fly ash**		**Fly ash (FA)**	
	without PVC	**with PVC**	**without PVC**	**with PVC**	**without PVC**	**with PVC**	**without PVC**	**with PVC**
	g/t	g/t	g/t	g/t	g/t	g/t	g/t	g/t
Chloride	119000	200000	65000	130000	29000	55000	49000	94000
Sulphate	1300	1300	140	140	2400	2400	3000	3000
Ca	53000	89000	32000	56000	3500	5400	5900	5800
Na	8900	15000	7700	13000	9900	19000	15000	29000
K	13000	22000	10000	17000	9900	19000	19000	37000
Cd	0.46	0.43	0.17	0.16	0.00038	0.0004	7.0	7.3
Pb	3400	3400	15	15	0.00045	0.00045	9.1	9.1

Table 15a - Estimated average amounts of leachates in 50 years, and effect of PVC

Components	Dry residue (incl. FA)	Semidry residue (incl. FA)	Wet + fly ash	Fly ash (FA)
Chloride	68%	100%	90%	92%
Sulphate	0%	0%	0%	0%
Ca	68%	75%	54%	-2%
Na	69%	69%	92%	93%
K	69%	70%	92%	95%
Cd	-7%	-6%	5%	4%
Pb	0%	0%	0%	0%

Table 15b - Effect of PVC on leachability of residues

Source :
Leachability results come from column leaching tests carried out by VKI on dry residues from I/S Nordforbrænding, semidry residues from I/S Amagerforbrænding, wet scrubber sludge mixed with fly ash from Göteborg [Hje92] and fly ash from I/S Vestforbrænding [Hje93].

3.6 PVC producers involved in salt mines storage activity

Solvay SA will be involved in such activity, by Solvay Salz (+ associated partners) when the new underground storage site is opened in Borth.

4. Technico-Economic comparison of salt mines storage with the competing routes

4.1 Final destination of the residues in Europe

According to the national policies and corresponding regulations in force, the solid residues from Gas Treatment can be stabilised by a cement-based binding, and then stored in different final destinations as shown below:

- Belgium : Class 1 special landfill for non-stabilised residues in Flanders
  Class 2 landfill for stabilised residues in Wallonia
- France : special landfill disposal (class 1) after stabilisation to meet the leaching criteria
- Netherlands : landfill
- Germany : salt mines storage or reutilization (mine-recycling)
- Austria : salt mines storage in Germany for filter cakes (Heilbronn), special landfill disposal for others
- Italy : landfill after stabilisation
- Great Britain : landfill
- Denmark : on-site landfill (situation at Kommunekemi) or sent to Norway (Langøya)

No stabilisation is required for salt mine storages (as practised in France or Germany).

4.2 Specification of the residues for each destination

In any case, the characteristics of residues have to be determined before being accepted in landfills or recycling sites.

Specification of quality of residues (leachability, HM content) should mainly be taken into account for recycling purpose, or for allowing disposal in landfill for non-hazardous wastes. In these case, it is important to know all characteristics which could have an environmental effect or change the quality of the final product (concrete, filling material, road material).

These specifications less concern the usual case when residues are sent to landfills for hazardous wastes (as in it is the case for all APC residues in France), apart from the need for stabilisation. The amount of binding product needed for stabilisation increases with the soluble content, but this parameter doesn't seem to be taken into account in acceptance or cost criteria by disposal site operators.

Particular case of salt mines deposit

For underground deposit in salt mines, criteria for acceptation are lower than for other sites, as no stabilisation is required. Usual criteria are [Uev00] :

- not explosive
- not spontaneous combustible
- no generation of toxic or explosive gases
- no reactions between the wastes or with the rock salt
- no spreading of diseases

- no penetrant smell
- sufficient stability

Fulfilment of such criteria should rise no problem for residues from incineration. Incinerator fly-ash and flue-gas cleaning residues were the first categories of waste for Heilbronn deposit. Salt mines are considered to be an ideal disposal place for these kinds of waste.

Particular case of salt mine-filling valorisation sites

For mine-filling, main additional criteria for acceptation of residues is that the compressibility under the maximum overburden pressure may not be higher than 22% [Uev00], in order to obtain the best resistance and avoid any collapse of the mine (which is the purpose of the filling). Such a criteria may be achieved by a proper mixing of the waste with some mine salt residues (covering of big bags with salt tailings), or with incineration slag (bottom ashes), or other mine techniques.

Another acceptation criteria is that residues are in a form which is easy to handle.

All residues from incineration of domestic wastes should fulfil these criteria.

Note that stabilisation is not required in salt mines, but is required in other mines, mainly coal mines (firstly in order to increase resistance, especially if the residue is used in building material ; secondly to limit leachability).

New legal base

All current practices, excepted mine-valorisation, will have to comply to the April 1999 European Council Directive 199/31/EC, which gives general principle for waste acceptance criteria and procedures for landfill of waste. According to that directive, a special classification is given to salt mine deep storage, but acceptation criteria are still to be defined by a technical committee. But this should not bring basic changes to current practices.

4.3 Cost comparison

Cost for disposal of residues has to include :
- transportation cost
- storage or disposal costs
- stabilisation cost if necessary and not included in disposal costs

Handling and packaging are included or not considered in the analysis .
Typical costs will be estimated, and an estimation of maximum transportation cost to salt mine for keeping this route competitive will me assessed.

4.3.1 Costs for Storage or disposal

Costs for disposal have been estimated from literature data and from direct contact with some companies.

Prices depends on quantities (price is higher for small quantities because of analysis and handling procedures), on type of residues and on type of storage.

The table 16 shows the different costs for the management of the solid residues from Gas Treatment (fly ash, neutralisation salts, filter cake) up to their final destination. This includes the cost of stabilisation when required.

Country	Nature of the residues	Stabilisation required	Type of final storage	cost (€/tonne)	Source
Belgium (Wallonie)	Fly ash and Salts	Yes	Landfill Class 2	155	Ber99
France	All solid residues	Yes	CET Landfill Class 1	215 - 260	(Δ)
	"	No	Salt mine storage	200	Sto99
Italy	All solid	Yes	Landfill Class 2	135 - 160	Ber99
Netherlands	Fly ash	No		110	Ber99
	Neutralisation Salts	No	Landfill	100	
	Filter cake	No		100	
Germany	Any	No	Salt Mine storage	225 - 450	Oko98,UEV
	Any	No (*)	Mine recycling	50 - 150	Oko99 (*)
	Other (non hazardous ?)	No (*)	"	15	
Austria	Fly ash	No (*)	Landfill	130 (*)	Ber99, Spi00
	Filter cake	No	Salt Mines	460 (see comment)	
Great Britain	Fly ash and Salts	No	Landfill	75	Ber99
Belgium (Flandres)	Fly ash and Salts	No	Landfill Class 1	120 to 130	Ber99
Denmark	Fly ash and Salts	No	Landfill	80	Ber99
Norway	Fly ash and Salts	No	Quarry recycling/storage	Unknown(◊) 80 ?	

Table 16 - Solid residues storage costs (€/tonne)

(Δ) For France, see data on French Class I and some interviews in annexe. Prices given by phone without stabilisation are 110 -183 €/t. Prices with stabilisation are in the range 229 -259 €/t. Salt mine price is 216 €/t. All prices including French special tax on pollutant activities of 18 €/t. Range given by [Ber99] is 210 – 240 €/t.

(*) From Mr. J.Mügge :The price for the « Bergversatz » (mine recycling) is extremely dependent on the characteristics of the material itself (Chemical nature, kind of additional work which has to be used to convert it in a building material suitable for mine filling, legal classification...) Although minimum price given for some mines is 15 €/ton, no mine will accept APC residues at such a price. Usual price for APC residues is in the range of 100 € to 140 € (this is in the range given by the Green Öko-Institut 50-150).

(◊) but "quite competitive with the prices to German salt mines" (see annex on Norway disposal site in previous report)

Main source of cost values is [Ber99], which is based on information given by operators from each country.

UEV/Heilbronn : basic price given for underground deposit is 230 €/t (450 DM/t). Price can be higher for low density packages, from 230 to 269 € (450 to 920 DM/t), with a minimum weight of 1 tonne. [UEV00].

K+S recycling : last price found in newspapers [Sud00] is 600 to 700 F/t (91 to 108 € /ton) for French APC residues coming from Angoulème MSWI (152 to 305 €/t with transport). This exceptional case in France has just been accepted by the French government but causing some problems. Authorization was cancelled on March 24th [Sud00b].

The table shows a large range for the cost for residue disposal, from 50 to 460 €/ ton.

The highest cost, given for Austria, is the price for storage of filter cakes (490 €/ton, rail transport included). This contract was signed 10 years ago, and should be renegotiated in 2000. Price will certainly be lowered, due to recent price drop for residue storage in Germany. It currently corresponds to the highest price given by Oko98 and Oko99.

Other costs range from 50 to 240 €/ton.

Usual prices should be closer to the French price (200 €/ton, transport not included).

Apart from salt mines, the cost mainly depends on the need to stabilise the residue prior to storing, and we can thus consider two categories :

- with stabilisation : **175 €/tonne** (range : 135 – 240, exceptionally up to 460)
- without stabilisation : **105 €/tonne** (actual range : 50 - 130)

Extra cost for stabilisation around **70 €/tonne** can be attributed to PVC for 25 % (average leachability increase).

For mine disposal, as practised only in Germany (see previous report), stabilisation is mainly done in recycling sites, where fly ash or APC residues are mixed with other materials for making building material, especially in coal mines. No stabilisation is basically necessary in salt mines (recycling or storage sites), as leachability is not to be considered in a salt layer : residues can be stored in big bags or in various mixture forms. In that case, the "with stabilisation" case may be cheaper, due to the fact it is practised in cheaper mine-valorisation sites (provided highly leachable residues are really accepted). The main difference is the classification of storage :

- salt mine deep storage : **200 €/tonne to 450 €/tonne**
- salt mine recycling : **100 €/tonne** (range 90 - 140 €/tonne)

Higher costs for deep storage can be attributed to stronger management criteria (obligation to fulfil local and European Directives on landfill of residues).

Lower costs for mine recycling can be attributed to the fact that residues (especially fly ashes) are well-adapted materials for mine-filling, and that it reduces costs for assuring security and safe closing of mines. Management practices refer to mining regulations, which have looser environment obligations (especially for leachability controls and book-keeping).

4.3.2 Transport costs

Transport costs highly depend on the way of transportation and on the quantities involved.

- For road transport, a typical cost is 0.06 €/t-km for quantities around 23 t (one truck). Range derived from [Sud00] is 0.06 to 0.20 €/t-km. Ranges obtained by questioning different transport companies in Europe (see annexe A : transport data) is 0.04 - 0.12 €/t-km. We can assume a mean cost of 0.10 €/ton/km.
- For rail transport : should have equivalent or lower costs for large quantities, but prices are difficult to be obtained (no price obtained from French Railways (Ecorail) or Spanish Railways (Renfe). Price obtained from a German company (Schenker-BTL) is 0.07 €/t-km for transport in 4 wagons. Each wagon can carry around 40 t residues in big bags (maximal mass 50 t).
- For ship transport : lowest cost for large quantities. Range 0.015 to 0.03 €/t-km for 300 to 1000 km and quantities 250 t or 500 t. Temporary storage of APC residues, and regrouping should be needed.

Compared to current disposal costs, transport prices are negligible for usual distances. For road transport on a distance of 800 km, its share is around 15% in overall disposal cost.

Usual distances between incineration plants and disposal centres are lower than this distance.

4.3.3 Example of price estimation for residue disposal in France

This example concerns a MWSI plant located in southwest France, and sending residues to a long-distance disposal centre for ultimate wastes.

CET (Class 1) disposal centre (usual price including stabilisation)	240 €/t
Transport (700 km) by road	40 €/t
Total (VAT not included)	280 €/t
Total per mass of MSW incinerated (assuming 33 g/kgMSW)	9 €/t

The estimated price for CET is in the usual range of 215 – 260 €/t in France (see above table).

The transport price assumes bulk transport with lowest handling costs. It represents 14% of overall costs.

For usual situation, distances are lower than these values. In France, such long distance is forbidden if nearer CET1 centres exist, except in special cases with legal authorization (*).

This shows that the main cost is usually the disposal cost.

(*) Exceptional recent authorization for Angoulème MSWI (see above comment) (*cancelled before application*) has been possible only by classifying APC residues as mine material. This classification is logic when sending residues to mine-valorisation sites, but raised some questions (if really accepted, why not allow such practise in France ? – why considering two different classifications for the same residues ?…), apart from other political or ecological, or industrial issues….

4.3.4 Costs for disposal in a salt mine storage

Assuming a basic price of 200 €/t (official price StocaMine – negociated prices may be lower), overall disposal cost to this mine would be (for distance from 200 to 1500 km) :

$$P = 200 + \text{Distance (km)} * 0.10 \text{ € /t}$$

It would be competitive to sent residues to this mine rather than a nearby centre assumed to offer a price 40 €/t higher, up to a additional distance of 400 km.

Of course, this depends highly on negotiation contracts, and on the regulation dispositions which could impose using use nearby centres (according to a proximity principle) or would not allow transport on too long distances.

Long distance transport by ship should much easily be accepted (*), and is basically adapted to such wastes (transport time is out of question) but would mean extra cost for handling from MSWI plants to rivers and from rivers to mines, and temporary intermediate storage in order to “massify”.

(*) for example, such transport was practised for German MSW to an incineration plant in Bordeaux (France) (distance > 2000 km) but should now be forbidden for MSW, although a new technique of MSW wrapping (clearly authorized but with no legal classification) could now allow such transport in very good conditions.

4.3.5 Costs for disposal in a mine recycling site

In the case of disposal in German mine recycling sites, much lower cost would make long distance transport competitive.

Assuming a price of 100 €/ton for disposal, it gives a overall price of (for distance from 200 to 1500 km) :

P = 100 + Distance (km) * 0.10 € /t

To reach the same level as deep storage (200 €/t), distance may be increased by 1000 km.

At these conditions, it would be advantageous for all countries around Germany to send their whole production of residues to the German mines. The main obstacle comes from both political and environmental points of view (well illustrated by the recent example on the question of export of APC residues from France to Germany [Sud00] (copy in annexe).

For this case, the distance from Angoulème to German mines is of the order of 1000 km, and K+S offered the lowest cost conditions (or at least the best overall economical option).

Note that all values are based on a transport price of 0.10 €/t/km, and that could change depending on fuel price.

Contrary to the exagerated point of view of the [Sud00] newspaper article, APC transport must not be considered as highly dangerous. The classification of APC residues as hazardous wastes is mainly from a disposal point of view.

Lower transport costs by ship or rail would be limited by extra handling costs, negligible for long distances (> 1000 km), and that could make German mines competitive for any incinerators in Europe.

4.3.6 Incineration costs for comparison

Costs for elimination of final residues can be compared to the incineration cost for MSW in Europe.

Usual range is 67 to 100 €/t.

Assuming a APC residue ratio of 33g/kg_{MSW} and an elimination cost of 180 €/t, this elimination cost represents around 6.6 €/t_{MSW} and around 8% of total incineration cost.

5. Conclusion

In this conclusion, we gives a recapitulation of average key typical values concerning the situation of APC residue disposal in Europe.

Attention should be given to uncertainties : precision of these values can not be better than 20%.

No high overall precision can currently be expected on the question of MSW, due to large discrepancies and continuous evolution in practises, type of classification, composition, incineration techniques and residue management for domestic wastes around Europe.

MSW production in Europe

- Amount of MSW produced in Europe >**150 000 ktons/year.**
- average individual amount **400 kg / year / capita**.

MSW incineration in Europe

Incineration is mainly practised in Northern Europe, where it can represent up to 76% of MSW, while it is lower than 5% in Southern countries (Spain, Italy, Greece). For the European average, it gives around 20 to 25% incinerated.

- **230** large incinerator plants (over 30 t/h)
- **20-25%** of MSW are incinerated (range 1% to 76% for different countries)
- Overall incineration capacity **45 000 ktons / year**
- Amount of MSW incinerated **40 000 ktons / year**
- Gas Treatment systems (GTS) : **61% wet, 25 % semi-dry, 12% dry**
- **10 000 kt/yr bottom ash** produced from MSW (250 kg/ t_{MSW})
- **1 320 kt/yr APC residues** (fly ash + neutralisation products) (33 kg/ t_{MSW})

Disposal costs (average or more probable values) for APC residues

- Overall range for landfill **50 to 460 €/ton**
- Surface disposal site : ≈ **200 €/tonne** but highly variable
- salt mine deep storage : same
- salt mine recycling : ≈**100 €/tonne**

Assuming that **45%** of the whole European production of APC residues goes to mine-valorisation in Germany, it gives :

- average disposal cost ≈ **180 €/tonne**.
- **238 Million €/yr** for disposal of APC residues
- Disposal of APC residues represents around **8%** of total incineration costs.

Effect of PVC in MSW

The influence of PVC on MSW composition is mainly related to the chlorine content of the waste sent to incineration : PVC is responsible for 38 to 66 % of the chlorine content in MSW (total Cl in MSW containing PVC : 6.4 to 10.5 g Cl / kg MSW, average 7.2 g Cl/kg).

PVC also influences some Heavy Metals content in the MSW : mainly Cadmium, as 7 to 11% of Cd in MSW is attributable to PVC. Its share is 1.7% for tin (Sn), 1% or less for other HMs (Pb, V, Zn, …). Average typical values are :

- **0.8 % PVC** in MSW (**320 kt/year**)
- **45 % Cl** in the PVC incinerated with MSW
- **Cl** contribution **50 %** (**3.6 g/kg** in a usual content of **7,4 g/kg Cl** in MSW)
- **Cd** contribution **7 %** (**0.6 mg/kg** in a usual content of **8.5 mg/kg Cd** in MSW)
- **Pb** contribution **1 %** (**7.2 mg/kg** in a usual content of **670 mg/kg Pb** in MSW)
- **HM** contribution **0.2 %** (**9 mg/kg** in a usual content of **3800 mg/kg HM** in MSW)

Effect of PVC on APC residues from incineration of MSW

The presence of PVC in MSW has a direct effect due to the higher quantity of chlorine in the raw gas, which requires additional neutralisation agent supply and therefore affects the quantity of residues or effluents generated by the different Gas Treatment Systems (GTS) or Air Pollution Control (APC).

PVC effect represents :

- **19 %** increase of residues from dry APC
- **18 %** increase from semi-dry APC
- **5 %** increase from wet APC without evaporation (major part of salt residues being rejected with the liquid effluent)
- **5 to 31 %** higher leachability of APC solid residues (due to neutralisation salts).
- **10%** of overall solid APC residues (fly ash + neutralisation products) from MSW incineration in Europe, i.e. **130 kt/year.**

Effect of PVC on disposal costs of incineration residues

- Extra costs due to higher leachability : the higher need for stabilisation results in possible extra costs for disposal < **65 €/ton**, a priori included in landfill prices

- No extra cost in case of disposal in salt mines (no stabilisation required)
- main cost increase is due to the increased amount of residues (+10%) : ≈ **24 Million €/year**

Salt Mines storage

- Good solution, from a technical point of view, for ultimate storage of APC residues (long-term viability, no stabilization required, costs currently comparable or lower than surface Class 1 landfill for hazardous waste).
- Enough capacity : the whole European APC residue production could be sent to Germany if it were economically and politically viable. Currently around **40% to 45%** (rough estimation) is sent to salt mines.
- For special landfill storage, main cost is the disposal cost (transport < 15% of overall price up to 800 km distance)
- Low cost practised in mine-recycling sites would make their use competitive up to long distances. Assuming 0.10 €/ton/km (road transport, mean price), we can consider following possible cost decrease :
  - - 40 €/ton (200 instead of 240) : competitive up to 400 km.
  - - 140 €/ton (100 instead of 240) : competitive up to 1400 km.
  - - 190 €/ton (50 instead of 240) : competitive up to 3200 km.

Conclusion for mine-recycling sites

Cumulating lowest costs for mine-recycling and lower transport costs (ship for long distances) with optimized handling could make storage in German mines economically competitive for any incinerator in Europe. But such a solution is clearly bounded to the sustainability of the mine-recycling sites, which is not yet clearly sure, for political reasons. It should nevertheless continue at least for the next 7 years, but with a narrow market, restricted to Germany and some neighbouring countries. A recent attempt of a French plant to send APC residues to such sites failed, due to political pressures, although it was possible to classify APC residues as mine-material, thus by-passing the legal restriction on long-distance and international transport of wastes.

Conclusion for underground storage sites

If the international market was opened to the transport of APC residues to deep underground landfill storage sites, it will not be competitive up to long distances, because storage costs are not significantly lower than for usual surface landfills. And transport of APC residues on long distance can be forbidden, especially in France where residues must be sent to the nearest storage site (proximity principle).

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Notre prix de stockage pour les REFIOM est de 1300 F H.T. la tonne".

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ANNEXE A

Miscellaneous data on MSW incineration and ultimate waste storage

- France
- Austria
- Spain

Ultimate Waste Data for France (1998)

CSDU : Centres de Stockage de Déchets Ultimes (Ultimate Waste Disposal centre)

REFIOM : Résidus d'Epuration des Fumées de l'Incinération d'Ordures Ménagères (APC from MSWI)

Waste	France	Imports	Total
Hazardous Industrial Waste	802 576	562	803 138
• *Stabilised part*	*432 746*	*562*	*359 301*
• *APC (REFIOM)*	*261 454*		*261 454*
Sewage Sludge	3428		3 428
Common Industrial Waste	87 975		87 975
Inert Waste	23 734		23 764
Municipal Wastes	104 790		104 790
TOTAL	**1 022 503**	**562**	**1 023 095**

These values don't take into account additives such as binders used for stabilisation.

For hazardous Industrial Waste, binders represent 20% added mass to total waste.

For the part which is stabilised, binders represent 80% added mass. For the total of hazardous Industrial Waste, they represent 20% added mass.

Classification of CET ("Centres d'enfouissement technique")

- CET de **classe I :** destiné à recevoir les déchets industriels spéciaux ultimes, il doit être implanté sur un site imperméable (perméabilité < 10^{-9} m/s sur une épaisseur de 5 m)
- CET de **classe II** : destiné à recevoir les ordures ménagères et les déchets assimilés, il est situé sur un site semi-imperméable, (perméabilité < 10^{-9} m/s sur 3 m ou < 10^{-9} m/s sur 1 m et 10^{-6} sur 5 m)
- CET de **classe III** : destiné à recevoir les déchets inertes, il peut être implanté sur un site perméable

Some regulation aspects

- Arrêtés du 18/02/92 : Stockage de certains déchets industriels spéciaux ultimes et stabilisés. Installations existantes J.O. du 16 avril 1993, installations nouvelles J.O. du 30 mars 1993
- Arrêté du 18/02/94 :Modification de l'arrêté du 18 décembre 1992 relatif au stockage de certains déchets industriels spéciaux ultimes et stabilisés pour des installations existantes J.O. du 26 avril 1994

According to these acts, stabilisation is compulsory for hazardous industrial wastes, Waste of category A (REFIOM/APC, powdered waste from metallurgy, mineral wastes from chemical treatment), and category B.

- Loi du 13/07/92

Each French region must have a Class I site for ultimate waste disposal before 2002.

After 2002, ultimate wastes which cannot be valorised (≈ recycled) or treated will be the only ones which can be stored.

Ultimate Waste Disposal Centres in France (1999)

CSDU : Centres de Stockage de Déchets Ultimes (Ultimate Waste Disposal center) ("Class 1" disposal site)

13 CSDU are now open in France (see map) (11 of which were already opened in 1996).

• Argence (calvados)	CGEA-ONYX	02.31.73.04.50
• Bellegarde (Gard)	France-Déchets	01 42 91 66 66
• Champteusse sur Baconne (Maine et Loire)	SEDA (France-Déchets)	
• Changé	Laval Service (ou Séché?)	
• Guitrancourt (Yvelines)	EMTA	01.34.97.25.65
• Jeandelaincourt(54)	France-Déchets	
• Laimont (Meuse)	DECTRA	03.26.04.82.62
• Pontailler sur Saône (Côte d'or)	France-Déchets	
• Saint-Cyr des Gâts (Vendée)	TOP Ouest	
• Tourville la Rivière (Seine Maritime)	SERAF (France-Déchets)	
• Vaivre (Doubs)	ECOSPACE	03.80.72.91.11
• Villeparisis (Seine et Marne)	France-Déchets	
• Wittelsheim-Mine Joseph Else (68).	StocaMine (EMC + TREDI + MDPA)	03.89.57.84.00

A project for a new site in region "Rhône-Alpes" (Marboz(01) or Sury Le Comtal(42)) was presented in
October 1998.

Sources :

- Data from ADEME Angers, fax from Katia Becaud, Département Industrie, Milieux et Technologies, 02 41 91 40 58 Fax 02 41 91 40 02, Stockage de classe I, 8 dec.1999.
- Updated map given by ADEME Angers, fax from Christian Militon, tel 02 41 20 41 22.
- List given by Bertin documentation department, and updated according to data from France Déchets and ADEME

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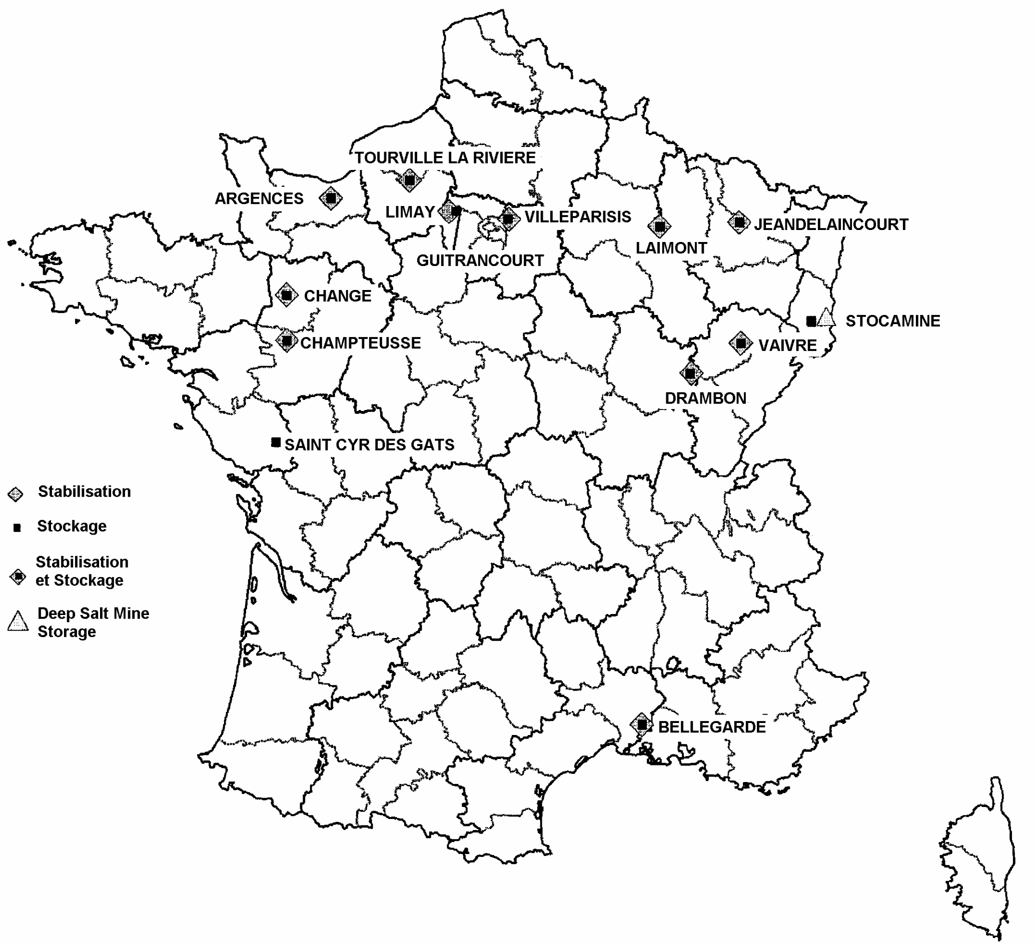

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Miscellaneous answers from companies managing ultimate wastes for storage in CET Class 1 in France

1) France Déchet - 01 42 91 66 66 – map of French site sent by Internet. No answer to price questions (answer yet expected).

2) SocaMine : see preceeding report (1300 F/t). No answer to last mail on legal problems, but some answers by phone, only on technical questions (answer probably delayed by legal departments of mother companies)

3) CGEA-Onyx, Argences (14) - 02.31.73.04.50, CET 02.31.23.92.68.

All residues have to respect criteria given by "Arrêté du 18 décembre 1992", such as soluble fraction < 10%. Usual parameters concern leachability (levels of Pb, Ni, Cd, As, Hg, DCO, soluble fraction, pH…). No usual problems for acceptation of APC residues.
Wastes must come from nearest CET1 in France, excepted with special authorization, in case of unavailability of another CET. Effect of ratio of stabilisation agent? No such parameter, but preliminary analysis is compulsory, before acceptation or before any price estimation.
Need for stabilisation depends on APC type :

- Wet → Filter cake : can almost be accepted without treatment
- ESP → Filter ash : powdered form (stabilisation required anyway for powders)
- lime APC residues → high soluble fraction

Price dependant on salt quantities ? not really. Depends first whether stabilisation is required or not. Also whether it is delivered in bulk or big bag (higher price).

- No stabilisation (pure storage) : 1000 to 1200 F/t (152 €/t to 183 €/t)
- With stabilisation : 1500 to 1700 F/t (229 to 259 €/t) (42 to 51% higher)
- Added tax (taxe sur les activités polluantes : 120 F/t (18 €/t extra cost)

4) Dectra, Laimont (55)- 03.26.04.82.62 answer yet expected

5) Ecospace, Vaivre (70) - 03.80.72.91.11 - answer yet expected

6) EMTA, Guitrancourt (78) -- 01.34.97.25.65 → take wastes only after stabilisation, done by another company (SERP Industrie, 01 34 97 25 00).

- Price without stabilisation 600 à 700 F/t → 92 à 107 €/t (special tax and TVA not included).

7) SERP Industries, 01 34 97 25 10.
The cost depends on nature (lower for sludge, higher for pasty or powered products)
Acceptation criteria are such as organic matter <2500 mg/l, phenol < 50 mg/l.
No parameter concerning salt content, neither ratio of stabilisation agent. This is included in package price of 1480 F for APC (226 €/t), lower price for sludge being 1080F/t. An additional tax is 120 F/t (taxe sur les activités polluantes)

- Without stabilisation : 720 à 820 F/t → 110 à 125 €/t
- With stabilisation : 1600 F/t → 244 € /t

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Transport of wastes in France
Miscellaneous data

Wastes in France (1998)

- 883 Millions tons per year

29.5 Mt	MSW (déchets ménagers et assimilés) (434 kg/hab)
22.5 Mt	City Wastes (déchets des collectivités locales) (ex Sewage treatment sludges)
50.0 Mt	Common Industrial Wastes (déchets industriels banals, DIB)
7.0 Mt	Hazardous Industrial Wastes (déchets industriels spéciaux, DIS)
420.0 Mt	Agriculture and Food Industry Wastes
0.7 Mt	Hospital Wastes
354.3 Mt	Builder's yard wastes

Source : L'Officiel des transporteurs n°2013 – 9 janvier 1999.

Transport costs for Wastes

- OM (raw MSW), distance 50 km : 15F/m3 → 1 F/t-km (0.15 €/t-km)
- DIS (Special Industrial Wastes): 120 - 735 F/t (1998) or 150 - 900 F/t (1999) (7 to 42% of elimination costs) → 0.86 to 4.6 F/t-km (0.13 to 0.70 €/t-km), average distance 195 km
- DIB (Common Industrial Wastes): 250 F/t (50% of elimination costs) 3 F/t-km (0.46 €/t-km), average distance 80 km

Source : Quels coûts pour les déchets? L'Officiel des transporteurs n°2013 – 9 janvier 1999.

- Transport of waste from Angoulème to Germany (1000 km) [Sud00] : 400 – 1300 F/t (61 €/t to 200 €/t, ie. 0.06 €/t-km to 0.2 €/t-km).
- Average road price : 1F/t-km (0.15 €/t-km). Lower cost 0.40 F (0.06 €)/t-km ? - Possible with large amounts and long distances [Christian Riper, ADEME, 04 93 95 79 73].

Collection cost (for comparison)

Average	360 F/t	
Range	200 – 400 F/t	(simple collection)
	350 – 400 F/t	(selective collection by the people)
	550 – 700 F/t	(organised direct selective collection)
Additional transport	40 – 60 F/t	
Average total	500 F/t	

Source : Environnement & Technique, janvier 2000 n°193

Transport of Wastes

Transport of waste : 0.85% by boat

Ecorail : subsidiary of French Railways (SNCF/CTT Sceta), created in 1997 for doing transport of Domestic and Industrial Wastes, in mixed rail/road form. 50MF annual turnover, expected to increase to 200 MF by 2002. For REFIOM transport, contact Mr.Vincent Combrouze, 01 44 85 86 75, secr. 01 44 85 86 87 (doesn't want to give any estimation : SNCF is not known to be particularly « transparent » on the question of prices).

Source : L'alternative à la route, La réplique d'Ecorail. L'Officiel des transporteurs n°2013 – 9 janvier 1999 + phone contact.

Bibliography : Book written by Mr. Christian Riper (ADEME Valbonne Sophia Antipolis) on transport of waste in France *("Guide sur la gestion des déchets ménagers et assimilés : transport et logistique" 150 pages. Editions ADEME Angers. Référence 3010, Prix 250F).*

Average distances for wastes according to way of transportation

- Road : 36 km
- Rivers : 87 km
- Railways : 310 km (average distance for scrap iron : 400 km)

Source : Transports Actualités n°652, 29 mai1998.

Fluvial Transport

According to VNF (Voies Navigables de France), (M. Philippe MAUGE, Région Ile de France 01 40 58 27 40) :
Tranport costs are from 0,10 to 0,20 F /tonne-km (**0.015 to 0.03 €/ton-km**) for short distance.
For long distance, say 1000 km on a 250 t barge, it will be the lowest price 0,10 F/tonne-km.
It depends on handling cost, which are lower for bulk transport (which is current for bottom ash) ("*faible délai de planche*"), and higher for big bags (transport costs include immobilisation costs).
Organisation of this transport must be regular and well organized to be cheeper.
Bulk transport for APC residue is possible with special barge for powered products (i.e. fluidized bed barge for cement or smelting slag). (Loading time reduced to 200 –300 tonnes/h)

- Barge 250 tonnes for usual transport in France
- Barge 500 tonnes for transport to Germany : possible by the Northern canal way.

Legislation

Proximity principle restricting long distance transport of wastes.

If destinated to mine re-utilization in Germany, APC residues could be classified as mine materials and get round the proximity principle [Sud00]. But such recent authorization was recently cancelled [Sud00b], after strong reaction of competitors, green movements and press.

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Price data for transport of wastes in Europe

Kobenhavn (Denmark) -> Frankfurt (850 km) : (1 € = 1.96 DM)

- 2100 – 2350 DM for a 24.5 ton truck : 0.052 – 0.058 €/t-km (oral answer from a German company).
- 6000 DM for 50 tonnes by truck : 0.072 €/t-km (+85 DM per hour wait) (Internationale Spedition KRUG)
- 5500 DM per wagons (for 50 ton in 1 or 4 wagons) : 0.066 €/t-km (or x 4 ? not clear) (in big bags, Schenker-BTL, Abtl Railcargo, Heidelberg)

Birmingham (UK) -> Frankfurt (850 km) : (1 € = 0,61 £)

(by Road + train or ferry)

• 750 £ for a 23 t truck : 0.063 €/t-km	(European, Dover)
• 850 £ for a 25 t (13.6m long) truck : 0.066 €/t-km	(Churchill Freight, London)
• 2600 £ for ≈ 20 t containers	(Carrols Transport, Hounslow)
• 1400 £ per truck	(Chiltern Air Freight Ltd, Slough)
• 2000 £ per container	(J.C.A. UK, London)
• 1 £/kg in container 80 m^3	(Eagle, London)
• 3000 £ for 50 t (0.116 €/t-km)	(Worldwide International, London)
• 2950 £ for 50 t in 2 trucks (0.113 €/t-km)	(Fleet Shipping International, London)
• 485 £/kg for 10 t , 2450 £ for 50 t (0.095 €/t-km)	(Davies Turner&Co, Kent)

Overall range : 0.06 - 0.12 €/t-km

Madrid (Spain) -> Frankfurt (1500 km) : (1 € = 166 pstas)

• train : at least 6 wagons	no answer yet (RENFE)
• 470 000 pstas in 2 trucks, for 50 t (0.038 €/t-km) no transport in tank trucks (bulk form)	(Transfesa)

Overall ranges for the 3 cases : 0.04 - 0.12 €/t-km

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MSW in France (1998 data)

					Other data for comparison			
MSW incineration in France in 1998					*Juniper97*		*OECD95*	*ISWA 96*
Capacity range	<48 k/yrt	48 à 80kt/yr	> 80 kt/yr	total	*> 30 kt/yr*	*corr.*		*> 10 kt/yr*
MSWI number	186	24	38	248	*79*	*77*	*297*	*95*
MSW amounts (kt/yr)	2500	1300	7000	10800			*10360*	
Overall capacity (kt/yr)					*10771*	*10830*	*11408*	*9542*

MSW incinerated in France				**Ratio to MSW incinerated**		
Annual Mass incinerated	bottom ash	APC including fly ash	total BA+APC	Bottom ash	APC ratio	total BA+APC
débit déchets	*mâchefers*	*REFIOM*	*sous-produits*	*mâchefers*	*REFIOM*	*sous-produits*
tons/an	*tons/an*	*tons/an*	*tons/an*	kg/tons	kg/tons	kg/tons
10 800 000	2 926 000	254 500	3 180 500	270,9	23,6	294,5

Residues per category		*tons (1998)*
Total déchets incinérés	MSWI	10 800 000
mâchefers	bottom ash	2 735 000
ferraille	Scrap iron	175 000
REFIOM	APC	249 000
cendres seules	Fly Ash alone	5 500
autres	Others	16 000
total sous-produits		3 180 500

Main part of fly ash is included in APC, but some fly ash can also be included in bottom ash (bottom ash and fly ash can be mixed in small units)
Source : ADEME Février 2000 (Jean-Louis Bergey)

Ultimate Waste Data for France (1998)

Stockage des déchets en CSDU : les tonnages 1998				
Waste	France	Imports	Total	
Dangerous Industrial Waste	802 576	562	803 138	
· *Stabilised part*	*432 746*	*562*	*359 301*	
· *APC (REFIOM)*	*261 454*		*261 454*	(equivalent to above figure)
Sewage Sludge	3428		3 428	
Common Industrial Waste	87 975		87 975	
Inert Waste	23 734		23 764	
Municipal Waste	104 790		104 790	
TOTAL	1 022 503	562	1 023 095	

These values don't take into account additives such as binders used for stabilisation.

- For dangerous Industrial Waste, binders represent 20% added mass to total waste.
- For the part which is stabilised, binders represent 80% added mass.
- For the total of dangerous Industrial Wastes, they represent 20% added mass.

Source : ADEME Décember 1999 (Katia Becaud)
(original table in ..\France\MSWFrance.xls)

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Example of a French MSWI (UIOM) equipped with a wet system

Caractéristiques générales	Overall caracteristics	
Capacité	*capacity*	6 t/h
Tonnage annuel	*Amount*	45000 t/yr
Traitement de fumées (GTS)	humide avec lavage des cendres (wet scrubbing + ash washing)	

Residus	Residues			Ratio to MSW incin.	
1) mâchefers	*Bottom ash*	-			
2) Cendres sous refroidisseur (humidité 2 à 2,5%)	*Fly Ash*	255 t/yr	A	5,7	kg/t
3) REFIOM lavés (CV+boues de STEP)	*filter cake+ thick sludge*	583 t/yr	C	13,0	kg/t
humidité	humidity	30 à 35 %	D	4,2	kg/t
4) Liquide	*liquid effluent*	4 m3/h			
concentration Chlore	*Cl concentration*	30 g/l			
concentration sel (total)	*Salt conc.(total)*	32 g/l	B	19,8	kg/t

Bilan des résidus de traitement de fumées				
Total solid APC residues (humid)	sent to CET (Class I)	A+C	18,6	kg/t
Total APC residues, dry, including salt in liquid effluents		A+C+B-D	34,2	kg/t

Source : Benesse-Marenne, personnal communication

Price estimation for residue disposal				
CET (Class 1) disposal center	(N/B)	1600 FHT/t		244 Euro/t
Transport (700 km)		260 FHT/t	14%	40 Euro/t
Total (VAT non included) per mass of residues		1860 FHT/t		284 Euro/t
Total per mass of MSW incinerated				5,3 Euro/t

1 Euro = 6.55957 FF

(N/B) Nîmes/Bellegarde (France Déchets)

NB. Owing their high quality, residues could be put in Class II landfill (lower disposal price)

(original table in ..\France\MSWFrance.xls)

Austria Data

Wien - Spittelau

Overall caracteristics		
Nominal capacity (for 2 lines)	36	t/h
Annual nominal capacity	250 000	t/yr
Annual Amount (1999)	263 625	t/yr
GTS : ESP + Wet scrubber + DeNOx by SCR (see figure)		
Year built	1971	
Flue gas scrubber	1986	
DeNOx (SCR)	1989	
Energy recovery type	CHP	
Electricity	6	MWe
Heat	60	MWth
Consumptions, per tonne MSW		
Freshwater	731	kg/t
Soda lye	2,8	kg/t
Lime	3,6	kg/t
Ammonia	3,1	kg/t
Gas	17,6	Nm3/t
chemicals	0,17	kg/t
Active carbon	unknown	kg/t
Residues	Mass ratio to incinerated MSW	
Slag	225,9	kg/t
Gypsum	1,7	kg/t
Ferrous scrap	24,5	kg/t
Filter ash	18,9	kg/t
Filter cake	1,1	kg/t
Cleaned waste water	440,0	kg/t
Total APC residues	**21,7**	kg/t
Total solid residues	**272,1**	kg/t
Part going to German Mines (by rail in big bags) (*)	1,1	kg/t
Part used in a "slag-filter ash concrete"	271,0	kg/t

(*) current cost 490 Euro/t

Wien - Flötzersteig

Annual nominal capacity (3 lines)	200 000	t/yr
Same operator (Fernwärme Wien), opened in	1963	
and same residue management		

Wels and Lenzing

Other operator. Wels rebuilt in	1995	
Annual nominal capacity Wels	60 000	t/yr
no precise data on residue management		
Lenzing : not given in Juniper97 study, under construction in Juniper95		

RECAP

Number of units over 30 t/h (Juniper 97)	3	
Overall capacity for units over 30 t/h	510	kt/yr
Estimated amounts going to German Mines	561	t/yr

Sources

from data sent by Mr.Reil Eberhard, 24/2/00 Eberhard.Reil@fernwaerme.co.at
Spittelau web site : www.spittelau@fernwaerme.co.at
Spittelau web adress : info@fernwaerme.co.at
Municipal Solid Waste incineration in Europe, Juniper Consultancy Service, 1995
Energy from Waste Plants. Databook of European Sites, Juniper Consultancy Service, 1997

Estimated amounts asked by ASA for export to Kochendorf in 1998 (March 1998) (Z.I.99/07/0116-8)	7000 t

(original table in MSWdat.xls/Austria)

Spittelau Thermal Waste Treatment Plant : Specific mass flow 1997

..\austria\Spittelau_Massenströme1997_engl.ppt *(répertoire austria)*
Spittelau_Massenströme1997_engl.ppt*(même répertoire)*

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Municipal Wastes and incineration in Spain

Annual Production	
Total	15000000 tons/an
incinerated	1140000 tons/an

(Juniper1997= 1072 kt

Waste final destination		
destination	**%mass**	**tons/an**
recycling	2,94%	441000
uncontrolled landfills	11,76%	1764000
controlled landfills	62,18%	9327000
compost	15,68%	2352000
incinerated	7,45%	1117500
Total	100,01%	15000000

Mean Content *(composition moyenne)*		
44%	*Matières organiques*	Organic Matter
21,20%	*Papier*	Papers
10,60%	*Plastiques*	Plastics
7%	*verre*	glass
3,40%	*métaux ferriques*	ferrous metals
0,70%	*métaux non ferriques*	non-ferrous metals
1%	*bois*	wood
12,10%	*Autres*	Others
100%	*Total*	Total

1998 Data on Municipal Waste incineration in Spain (7 MWI units)					
MSWI	Location (Region)	Availability	Annual Mass incinerated	bottom ash	APC
UIOM	*Région*	*Disponibilité*	*débit déchets*	*mâchefers*	*REFIOM*
		%	*tons/an*	*tons/an*	*tons/an*
Madrid		90,0%	268830	*27500*	*13500*
Mallorca : Palma 2	Palma de M.	91,3%	300000	81000	*(*) 15000*
Sant Adria de Besos	Barcelona	85,0%	240000	63500	7250
Melilla	North Africa	93,2%	35000	9000	900
Tarragona	Cataluna	85,0%	145000	36000	3300
Mataró	Cataluna	no data			
Girona	Cataluna	no data			
Total			988830	217000	39950
Percentage of mass incinerated			100%	21,9%	4,8 - 6,1%

(*) APC mean value of the range 9000-21000 given for Palma2

MSWI Projets

La Coruña	Galicia
Bilbao	Euskadi

Main flue gas treatment systems

Semi-dry process for 2 units, no data for others

Residues destination

Bottom ash --> roads, filling material

APC, fly ash --> landfills (after possible stabilisation, handling in big bags)

Possible landfill in salt mines ? discussed within the frame of Bilbao MSWI project

MSW Policy

- No development of incineration
- Better landfill control
- Priority to recycling ?

Main sources for these data :

Proceeding of "Conferencia International Sobre Residuos y Energia", Madrid, Escuela Technica Superior de Mecanica, October 27 and 28, 1999. Club español de lo residuos. (given by JCM, phone Feb.00)

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MSW in Spain : Comparison of recent data to Juniper 1997

1998 Data on Municipal Waste incineration in Spain (7 MWI units)

MSWI	Location (Region)	Availability	Annual Mass incinerated	bottom ash	APC	
UIOM	*Région*	*Disponibilité*	*débit déchets*	*mâchefers*	*REFIOM*	
		%	*tons/an*	*tons/an*	*tons/an*	
Madrid		90,0%	268 830	*27 500*	*13 500*	
Mallorca : Palma 2	Palma de M.	91,3%	300 000	81 000	*15 000*	(*)
Sant Adria de Besos	Barcelona	85,0%	240 000	63 500	7 250	
Melilla	North Africa	93,2%	35 000	9 000	900	
Tarragona	Cataluna	85,0%	145 000	36 000	3 300	
Mataró	Cataluna	no 1998 data				
Girona	Cataluna	no 1998 data				
Totals			988 830	217 000	39 950	
Percentage of mass incinerated			100%	21,9%	4,8 - 6,1%	

(*) APC mean value of the range 9000-21000 given for Palma2

Total including Mataró and Girona, assuming Jun1997 data for these plants

7 plants	**1 209 830**	t/year

Ratios calculated from 1998 data / **Juniper 1997 data**

MSWI	Bottom ash	APC ratio	Opened	Nominal Capacity	lines	GTS
	mâchefers	REFIOM		tons/yr		
	kg/tons	kg/tons		*tons/an*		
Madrid	102	50	1994	200 000	3	semi-dry
Palma 2	270	50	1995	315 000	2	semi-dry
Sant Adria de Besos	265	30	1975	380 000	3	ESP
Melilla	257	26	1995	37 000	1	
Tarragona	248	23	1991	78 000	2	ESP
Mataró			1994	170 000	2	?
Girona			1984	51 000	2	ESP
Vigo	closed ? (no recent indication)		1972	(60 000)		
Mondragon	closed in 1999 ? (*)		1980	(48 000)		
Jaen, Vielhy	closed ? (no recent indication)		1993,..			
	219	40		1 231 000		

(*) "planned to close" in Juniper 1995 study

Total including Mondragon, without Melilla

Total 1995	7 plants		**1 242 000**	t/year

ANNEXE B

Amounts of residues in neutralisation step

Neutralization of HCl by lime
Chemical mechanisms

- ***Reactions with HCl in dry and semi-dry systems :***

In dry and semi dry systems, neutralisation is a two-step reaction to form CaCl2:

$$HCl + Ca(OH)_2 \rightarrow CaOHCl + H_2O \qquad (1)$$

$$HCl + CaOHCl \rightarrow CaCl_2 + H_2O \qquad (2)$$

This means that in presence of lime excess only Hydroxichloride CaOHCl is formed. Second reaction is slower than the first one (kinetics factor 1 to 7). Furthermore, it has been observed that $CaCl_2$ and $Ca(OH)_2$ - when mixed together - react to form Hydroxichloride CaOHCl. [**Al 97], [Joz 95].** For these reasons, CaOHCl is more likely to be formed than $CaCl_2$.

Calcium oxichloride crystallises with one mole of water forming CaOHCl, H_2O.

The quantity of water associated with calcium chloride $CaCl_2$ can vary as a function of the process employed to dry the salt as well as the corresponding temperatures :

In the case of spray drying at a temperature below 130°, $CaCl_2$ crystallises with two moles of water forming $CaCl_2,2H_2O$

For spray drying operated above 130°C,$CaCl_2$, H_2O can also be present

For calcium chloride drying by external heat transfer $CaCl_2,6H_2O$ has to be considered

In the solid salt from spraying systems, 0.5 to 2% of free water is present in the solid residue.

For the calculations presented below, we assume that the gas treatment residue is handled properly. This means that is collected in proper packages (big bags or drums) and not stored in the open in order to prevent any extra water impregnation from rain or atmospheric humidity. $CaCl_2$ is known to be hygroscopic and used for ambient air drying. The same hygroscopic behaviour has not been reported for CaOHCl, but should exist at a lower level. In fact, hygroscopic behaviour of APC residues is not usually reported as important : that also tend to prove that the major component is CaOHCl and not $CaCl_2$.

The general reaction $Ca(OH)_2 + 2HCl \rightarrow CaCl_2,2H_2O$ is commonly referred to in the literature and is used as the reference. For a given stoechiometric ratio, the type of product ($CaCl_2$, CaOHCl) does not affect the of neutralization agent because the stoechiometry is related to the $CaCl_2$ reaction. It neither affect the quantities of solids recovered after the neutralisation, because the water content per chlorine is the same in $CaCl_2$, $2H_2O$ and CaOHCl, H_2O (see calculation of mass coefficients below)

- ***Reactions with HCl in wet processes***

In the presence of liquid, removal of HCl from the Raw Gas does not require neutralisation : HCl is soluble enough to be absorbed in the liquid forming an acid solution :

$$HCl_{gas} \rightarrow (HCl)_{solution} \rightarrow H^+ + Cl^-$$

In some German Incinerators, HCl is recovered as a solution to be valorised. This of course drastically limits the quantities of the residues attributable to PVC (only 5 plants are equipped with this process).

In other processes, HCl is mainly neutralised by lime ; its absorption occurs mainly in the first scrubber and its neutralisation ends up in the water treatment.

- ***Reactions with HCl in semiwet-wet processes***

The same process are exploited in the semi wet - wet process : HCl is neutralised in the wet scrubber as in the wet process, then the liquid is sprayed into the gas stream.

$CaCl_2$ present in the liquid is converted into dry $CaCl_2,2H_2O$. Possible treatment of the liquid can be carried out prior its evaporation.

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Neutralization of HCl by lime
Reactions and mass ratios

1) Stoechiometry neutralisation reactions

• assuming formation of $CaCl_2$

	Acid	+	Neut. Agent	→	Salt (choride)	*Anhydrous case*
	2 HCl	**+**	**Ca $(OH)_2$**	**→**	**$CaCl_2$, $2H_2O$**	***$CaCl_2$ (+$2H_2O$)***
Molar mass	73		74		147	*111 (+ 36)*
Per kg Cl	1.028		1.042		2.07	*1.563*

• assuming formation of CaOHCl,H_2O

	Acid	+	Neut. Agent	→	Salt (oxichloride)	*Anhydrous case*
	HCl	**+**	**Ca $(OH)_2$**	**→**	**CaOHCl,H_2O**	**CaOHCl *(+H_2O)***
Molar mass	36.5		74		110.50	*92.5 (+18)*
Per kg Cl	1.028		2.085		3.11	*2.61*

Stoechiometric ratio are conventionally related to $CaCl_2$, and thus corresponds in both cases to the same ratios of neutralisation agent to chlorine. Minimum stoechiometric ratio required for complete reaction producing oxichloride is then S.R.=2.

At stoechiometry (S.R.=1), 1 kg Chlorine produces 1.56 anhydrous $CaCl_2$, or 2.07 kg $CaCl_2$ salt, or 2.61 kg anhydrous oxichloride, or 3.11 kg CaOHCl, H_2O.

2) With various stoechiometric ratio R

	Acid	+	Neut. Agent	→	salt	Excess N.Agent	*Anhydrous case*
	2 HCl	**+**	**R * Ca $(OH)_2$**	**→**	**$CaCl_2$, $2H_2O$**	**+ (R-1) Ca $(OH)_2$**	***($CaCl_2$)***
Molar mass	73		R * 74		147	+ (R-1) * 74	*111*
Per kg Cl	1.028		R * 1.042		2.07	+ (R-1) * 1.042	*1.563*

Quantity of residue per kg Cl, for the 4 cases (4 different salts assumed to be produced) :

Stochiometric Ratio	CaCl2,2H2O	anhydrous CaCl2	CaOHCl,2H2O	anhydrous CaOHCl
R	2.07+(R-1)*1.042	1.56+(R-1)*1.042	3.11 + (R/2-1) * 2.085	2.606 + (R/2-1) * 2.085
1	2.07	*1.56*	Incomplete reaction	Incomplete reaction
1.3	2.38	*1.88*	"	"
1.5	2.59	*2.08*	"	"
1.7 (assumed for semi-dry processes)	**2.80**	*2.30*	"	"
1.8	2.90	*2.40*		
2 (assumed for dry processes)	**3.11**	*2.61*	**3.11**	*2.61*
2.2	3.32	*2.81*	3.32	*2.81*
3	4.15	*3.65*	4.15	*3.65*

Neutralization of SO_2 by lime
Reactions and mass ratios

Stoechiometry assuming formation of calcium sulphate $CaSO_4$

Reaction	SO_2 +	$Ca(OH)_2$ +	1/2 O_2	→	$CaSO_4$ +	H_2O
Molecular weight	64	74	16		136	18
Mass ratio kg/kg S	2	2.31	0.5		4.25	0.56

Stoechiometry assuming formation of hydrated sulphate $CaSO_4$, $2H_2O$

Reaction	SO_2 +	$Ca(OH)_2$ +	1/2 O_2 +	H_2O	→	$CaSO_4$, 2 H_2O
Molecular weight	64	74	16	18		172
Mass ratio kg/kg S	2	2.31	0.5	0.56		5.37

Conclusion :

At stoechiometry, 1 kg Sulphur produces 4.25 kg anhydrous residue or 5.37 kg hydrated residue.

Neutralization with sodium bicarbonate (dry processes)

Neutralisation with Sodium Bicarbonate :

NaHCO3 is only used in the dry process in the form of powder. $NaHCO_3$ is ground just before being injected to achieve a solid with high porosity and specific area.

Reactions with HCl **:** $HCl + NaHCO_3 \rightarrow NaCl + CO_2 + H_2O$

The excess of bicarbonate is transformed into carbonate :

$$2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$$

168 g of $NaHCO_3$ excess lead to 106 g of carbonate Na_2CO_3 and this therefore reduces the quantity of residues produced.

No crystallisation water has been measured neither for NaCl nor for $NaHCO_3$ and Na_2CO_3

Reactions with SO_X **:**

$$2NaHCO_3 + SO_2 \rightarrow Na_2SO_3 + H_2O + 2CO_2$$
$$2NaHCO_3 + SO_3 \rightarrow Na_2SO_4 + H_2O + 2CO_2$$

Reaction with SO_3 is faster that with SO_2. In general the reaction is faster than with lime. The intermediate formation of $NaHSO_3$ could exist but this compound has never been identified in the residues.

The excess of $NaHCO_3$ is also transformed in Na_2CO_3. Na_2SO_3 is oxidised into Na_2SO_4 in presence of oxygen from the gas and in the residue only Na_2SO_4 can be identified :

$$Na_2SO_3 + ½\ O_2 \rightarrow Na_2SO_4$$

Stoechiometry with HCl (S.R.=1)

Reaction	HCl +	$NaHCO_3$	→	NaCl +	CO_2 +	H_2O
Molecular weight	36.5	84		58.5	44	18
Mass ratio kg/kg Cl	1.03	2.37		1.65	1.24	0.51

1 kg Cl requires at least 2.37 kg $NaHCO_3$ and produces 1.65 kg NaCl.

Stoechiometry with SO_2(S.R.=1)

Reaction	SO_2 +	2 $NaHCO_3$ +	½ O_2	→	Na_2SO_4 +	2 CO_2	H_2O
Molecular weight	64	168	16		142	88	18
Mass ratio kg/kg S	2	5.25	0.5		4.44	2.75	0.56

1 kg S requires at least 5.25 kg $NaHCO_3$ and produces 4.44 kg Na_2SO_4.

Specific SR for HCl and SO_2 neutralisation with Sodium Bicarbonate :

For the determination of the specific stoichiometric ratios for HCl and SO_2 with NaHCO3, no satisfactory data could be identified in the literature. We thus used non-published results such as evaluations from operators of incineration plants as well as from the bicarbonate suppliers.

Due to the larger specific area of bicarbonate, the steric limitation to SO_2 neutralisation is obviously lower than for lime. It is confirmed by experimental overall stoichiometric ratios which are between 1.05 to 1.5 as measured in different incineration plants.

Nevertheless the concurrence of HCl and SO_2 neutralisation still exists and SO_2 is likely to require more excess of bicarbonate.

A realistic evaluation for HCl specific S.R. is close to 1.05 : this can be considered as a maximum as plants already operate successfully with an overall S.R. of 1.05.

For Neutralisation of SOx, we have assumed S.R. =1.2.

Reaction with HCl with S.R.=1.05

Reaction	HCl +	1.05 $NaHCO_3$	→	NaCl +	1.025 CO_2+	1.025 H_2O +	0.025 Na_2CO_3
Molecular weight	36.5	1.05 * 84		58.5	1.025 * 44	1.025 * 18	0.025 * 106
Mass ratio kg/kg Cl	1.0 3	2.48		1.65	1.27	0.52	0.07

1 kg Cl requires 2.48 kg $NaHCO_3$ and produces 1.65 kg NaCl and 0.07 kg Na_2CO_3.

Reaction with SO_2 with S.R.=1.2

Reaction	SO_2 +	2.4 $NaHCO_3$ +	½ O_2	→	Na_2SO_4 +	2.2 CO_2 +	1.2 H_2O +	0.2 Na_2CO_3
Molecular weight	64	2.4 * 84	16		142	2.2 *44	1.2 * 18	0.2 * 106
Mass ratio kg/kg S	2	6.3	0.5		4.44	3.03	0.67	0.66

1 kg S requires 6.30kg $NaHCO_3$ and produces 4.44 kg Na_2SO_4 and 0.66 kg Na_2CO_3.

ANNEXE C

Energy recovery from Municipal Waste, and share of PVC

(Not contractual rough estimation)

Energy recovery from Municipal Waste, and effet of PVC incineration

Juniper 1997 data			
Total energy recovered		43000	GWh/year
Thermal	73%	31390	GWh/year
Electricity	27%	11610	GWh/year
Installed capacity		7000	MW
Number of active sites	> 30 kt/year	275	
Waste capacity		47	Mt/year

Derived results				
Energy per kg MSW	*1kWh= 3600 kJ*	*A*	3294	kJ/kg
Thermal	73%		2404	kJ/kg
Electricity	27%		889	kJ/kg
average LHV for MSW		B	8830	kJ/kg
Recovery ratio		C=A/B	0,373	
Heat recovery ratio	73%	∗C	0,272	
Electricity recovery ratio	27%	∗C	0,101	

Theoretical recovery ratio		
Heat losses (unburned material + miscellaneous)	D	5%
Heat loss in flue gas (unrecovered heat)	E	12%
Theoretical recovery ratio	F=1-D-E	83%

Recovery efficiency of MSW incineration		
Overall recovery from MSW incineration	G= C	37%
Valorisation ratio (actual/theorcetical)	H=G/F	45%

Estimation of LHV of PVC compounds			
LHV for pure PVC	J=	20900	kJ/kg
Average % of pure PVC in PVC compounds	K	80,30%	
Estimated LHV for PVC	L=J*K	16782,7	kJ/kg

Estimated selling price of energy				
possible selling price of heat (mid-pressure steam)				
	in France		10,7	Euro/MWh
	in Italy		10,9	Euro/MWh
	in Belgium		12,5	Euro/MWh
	average	HP=	11,4	Euro/MWh
Selling price of electricity		EP=	30	Euro/MWhe

Actual income from MSW incineration					
Heat recovery	(above figure)			31390	GWh
Electricity recovery	(above figure)			11610	GWh
Heat income		11,4	Euro/MWh	358	M.Euro
Electricity income		30	Euro/MWh	348	M.Euro
Total income				706	M.Euro

Maximal possible Energy production from PVC incineration					
Lower Heat Value			L	16783	kJ/kg
Heat recovery	$\eta H=$	70%	$\eta H*F*L$	9751	kJ/kg
Electricity recovery	$\eta E=$	30%	$\eta E*F*L$	2428	kJ/kg
Heat income	11,4	Euro/MWh		30,9	Euro/t
Electricity income	30	Euro/MWh		20,2	Euro/t
Total income	41,4	Euro/MWh		51,1	Euro/t

Actual energy production from PVC incineration					
Lower Heat Value			L	16783	kJ/kg
Heat recovery	$\eta H=$	0,272	$\eta H * L$	4570	kJ/kg
Electricity recovery	$\eta E=$	0,101	$\eta E * L$	1690	kJ/kg
Heat income	11,4	Euro/MWh		14,5	Euro/t

Electricity income	30 Euro/MWh	14,1 Euro/t
Total income		28,6 Euro/t
Ratio to theoretical income		56%

Actual income from PVC incineration		
PVC incinerated	(0.8%MSW)	376 kt
Maximal theoretical income		19,2 M.Euro
Actual income		10,7 M.Euro

(table from pvcmsw.xls/recovery)

pvcmsw.xls

ANNEXE D

Commercial sheet
(project of publishable sheet)

(authorization submitted to ECVM)

- English version

..\fiches_présentation\Storage_residues_sheet.ppt

or Storage_residues_sheet.ppt

- French version

..\fiches_présentation\Fiche_Stockage_résidus.ppt

or Fiche_Stockage_résidus.ppt

ANNEXE E

Various documents on waste storage

- Articles [Sud00]
- Articles [Sud00b]

Available on paper only :

- Articles [Sud00c] on Lacq/Morcenx underground disposal
- Article Usine Nouvelle n°2675 on StocaMine
- Information from UEV (Heilbronn + Kochendorf)

Articles from Sud-Ouest du 15 mars 2000 [Sud00]

See file ..\France\article_Sud0uest\Sud00_article1.doc

..\France\article_Sud0uest\Sud00_article2.doc

Local links (if files are put in the same directory) :

See files Sud00_article1.doc

Sud00_article2.doc

Article from Sud-Ouest, Samedi 25 mars 2000 [Sud00b]

Fac-similé of image available in file ..\France\article_Sud0uest\Sud00_article3.doc

Or Sud00_article3.doc

DECHETS ULTIMES

Ils resteront en France

PIERRE VERDET

En adressant hier une note à tous les préfets, pour leur demander de « soulever une objection systématique à toute demande d'exportation de REFIOM vers un autre Etat membre en vue de son élimination »,. Dominique Voynet a rapidement corrigé une erreur apparente de son cabinet.

On se souvient que Philipe Vesseron, directeur de la prévention des pollutions et des risques majeurs dans son ministère, avait autorisé l'exportation vers l'Allemagne de ces dangereux déchets toxiques, issus des fumées de l'incinération des déchets ménagers, pour y servir de remblais dans d'anciennes mines de sel et de potasse (« Sud-Ouest» des 14 et 16 mars).

Cette décision avait provoqué la colère des professionnels du déchet, mais aussi des associations écologistes comme FNE et même d'élus verts comme Noël Mamère. Celui-ci déclarait hier soir:

« C'est une réaction sage et nécessaire de la ministre, il fallait qu'elle dise le droit. Elle l'a fait et nous considérons désormais cette affaire comme un incident qui ne doit pas se renouveler »

Les élus verts du Conseil régional d'Aquitaine se félicitaient également de la décision de la ministre. «Cette circulaire réaffirme la primauté du droit communautaire au sens de la directive du 15 juillet 1975, qui considère cette opération de remblaiement dé mines comme une opération d'élimination et non de valorisation comme la législation allemande le permet de façon scandaleuse », affirmait leur président, Jean Lissar.

Ces déchets devront donc continuer à être dirigés vers les centres d'enfouissement de classe 1 créés sur le sol français, même si le si le prix est beaucoup plus élevé que celui proposé par les sociétés minières allemandes, comme l'avaient immédiatement remarqué de nombreuses collectivités locales.

..\France\article_Sud0uest\article3_text.DOC (copie séparée de cet article)