DRAFT

REPORT ON MONITORING AND REGISTRATION OF DIVERSION OF BIODEGRADABLE WASTE

REPORT TO THE MINISTRY OF THE ENVIRONMENT SLOVAK REPUBLIC

TWINNING LIGHT PROJECT SLO_TLP 0128 "OPTIMISED MANAGEMENT OF BIODEGRADABLE WASTE"

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1 PRELIMINARY REMARKS

1.1 Monitoring & registration of waste streams: Principal aspects

It probably needs no further explanation that *any advanced dealing with the by-products of civilisation* - in more simple and less pathetic words: any reasonable waste management system - requires some information on

- the *quantities* of the subject as a whole
- its *qualities* as composition, chemical-physical parameters relevant for describing the value and environmental impact of final products
- the *timewise development* of amounts (i.e. *waste forecast*) - in order to
    - estimate the *demand of capacities* (for collection, treatment and disposal)
    - to estimate the *cost* related to it
    - to eventually develop *alternatives*, and
    - to set achievable *targets*.

The information requirements increase with the level of the respective waste management system: In case a disposal structure consists in nothing more than a landfill (no matter which technical standard), the administration body responsible for issues related to waste does not require more information than *"How much waste* (as volume) *gets produced* (per day / year) *?"* - with the answer to this question the lifetime of the existing landfill can be estimated, and planning efforts for a new site can be undertaken.

In such "basic" systems the installation of a weighbridge on the landfill entrance fulfilled any registration requirements, and the detailed information *weight of single waste loads* was used for *distributing costs* of operating the disposal site (it should be noted that the technical conditions at *waste water treatment* do not allow such simple and effective cost allocation to the single producer).

Systems have become by itself more complex - be it caused by

- *shortage of landfill capacities*
  which forced decision making bodies to reduce waste streams to be disposed of by means of separate collection and utilization, and/or to reduce the volume of the (remaining) waste stream by technical means (pre-treatment)

- *overriding legal requirements*
  which have got the same or at least a similar cause (limited availability of final disposal capacity, increasing cost of advanced landfill systems)

and thus the information requirements on the subject "waste" increased in general, in order to answer questions as eg.

Question	Particular information requirement
➢ *will the quality of a treated partial stream - eg. biowaste after composting - meet market requirements ?*	Content of nuisance, persistent contaminants…
➢ *to what extent does the waste producer participate in a separate collection system ?*	Content of recyclables in the residual waste stream
➢ *does the Slovak Republic meet the target "30 % reduction of biodegradable matter in municipal waste in 2005" ?*	Content of biodegradable matter in the residual waste stream, estimate on the timewise development…

This last point is of particular importance, as far as strategies for management of biodegradable waste, and fulfilment of related targets for diversion from landfills, are concerned. *It is in particular EU legislation which* calls for a proper monitoring of municipal waste. Fig. 1 shows the core issue "maximum biodegradable matter in municipal waste" set out by EU Directive No 1999/31 („Landfill Directive").

In this respect the self-obliged Slovakian target shown in the graph (defined in the National Waste Management Programme) can be assessed as challenging, although this is affected by incorporation, in related calculations, of septage, which represents a comparatively high amount in Slovakia given the rural nature of many settlements.

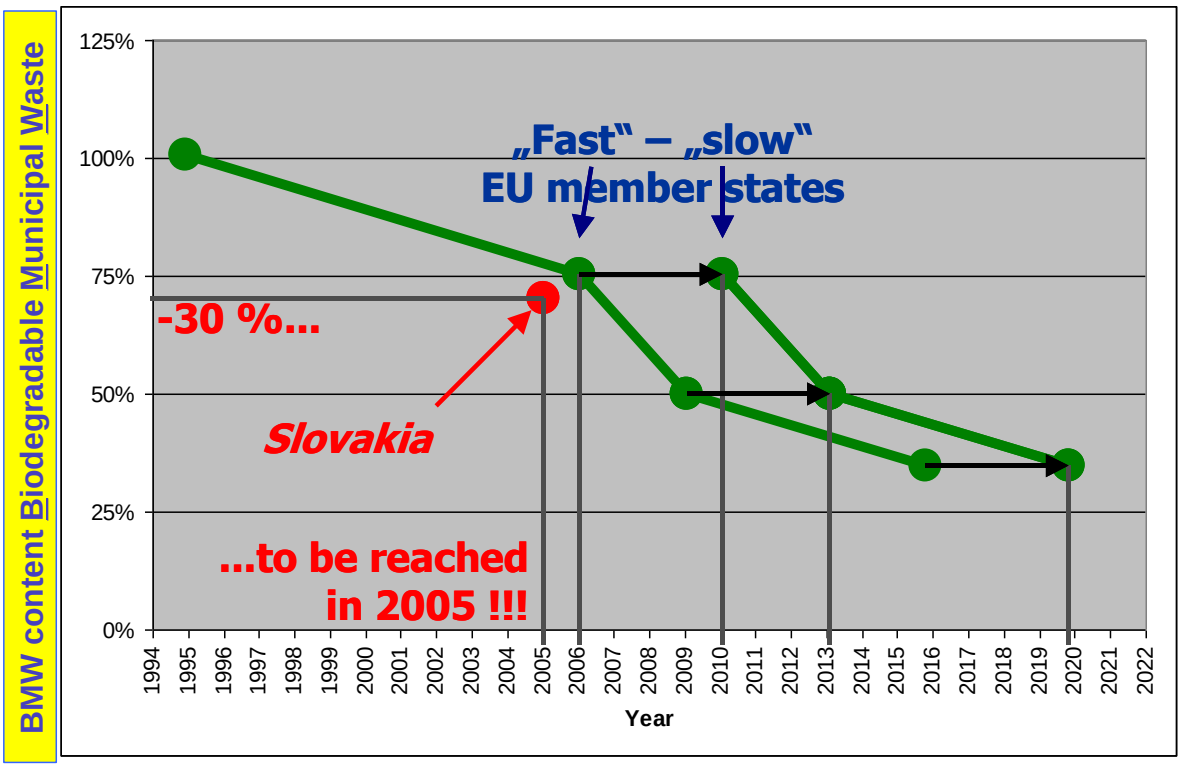

Fig. 1: EU Directive N° 1999/31 as the main driving force for long-term waste monitoring & forecasting; comparison to Slovak targets as mandated by the National Waste Management Plan

It should be clearly stated here that every single EU member state is free to choose *with which strategies and related instruments* the targets are intended to be reached, be it

- by means of *diversion* (separate collection of paper and biowaste), and/or
- *treatment* (stabilization by biological and/or thermal methods, as shown in Fig. 2),

however *proper monitoring* is a must of course.

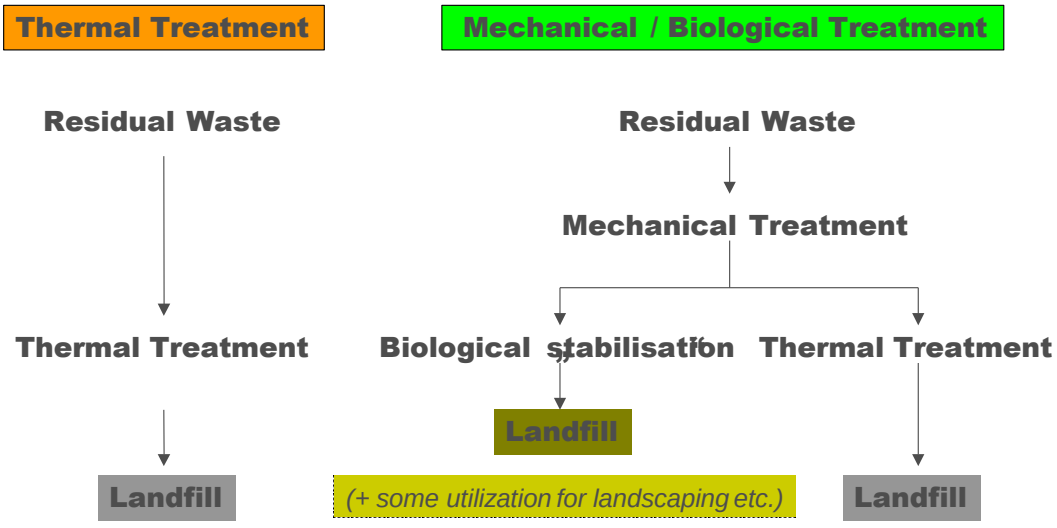

Fig. 2: Basic technical alternatives for reduction of biodegradable matter

1.2 General methods of monitoring municipal waste streams

Monitoring municipal waste streams as a whole is usually a task of administration units with a certain *control and steering function* - the single municipality might engage with it, but in any case such monitoring has to be performed by a suitable administration unit on regional, at least, or on national level. The character of such monitoring is that of typical "desk work": Needed instruments are nothing more than a telephone line and a PC with some standard spreadsheet software (eg. EXCEL).

The foundation of any municipal waste monitoring system is a sound database - particularly when *forecast* (prognosis) features are required (" What will be the amount of municipal solid waste in the Slovak Republic in 2010 ?").

It is assumed that such a database - in substance the *current amounts of municipal solid waste broken down by municipality* - exists, most probably also data of past years, and data on "secondary" waste streams (materials already collected at source separately, sewage sludge, and the like). According to the example given below such "waste history" of a larger waste catchment area enables an authority with ´steering functions´ to estimate trends, simply by *projecting recent historical developments into the (near) future.*

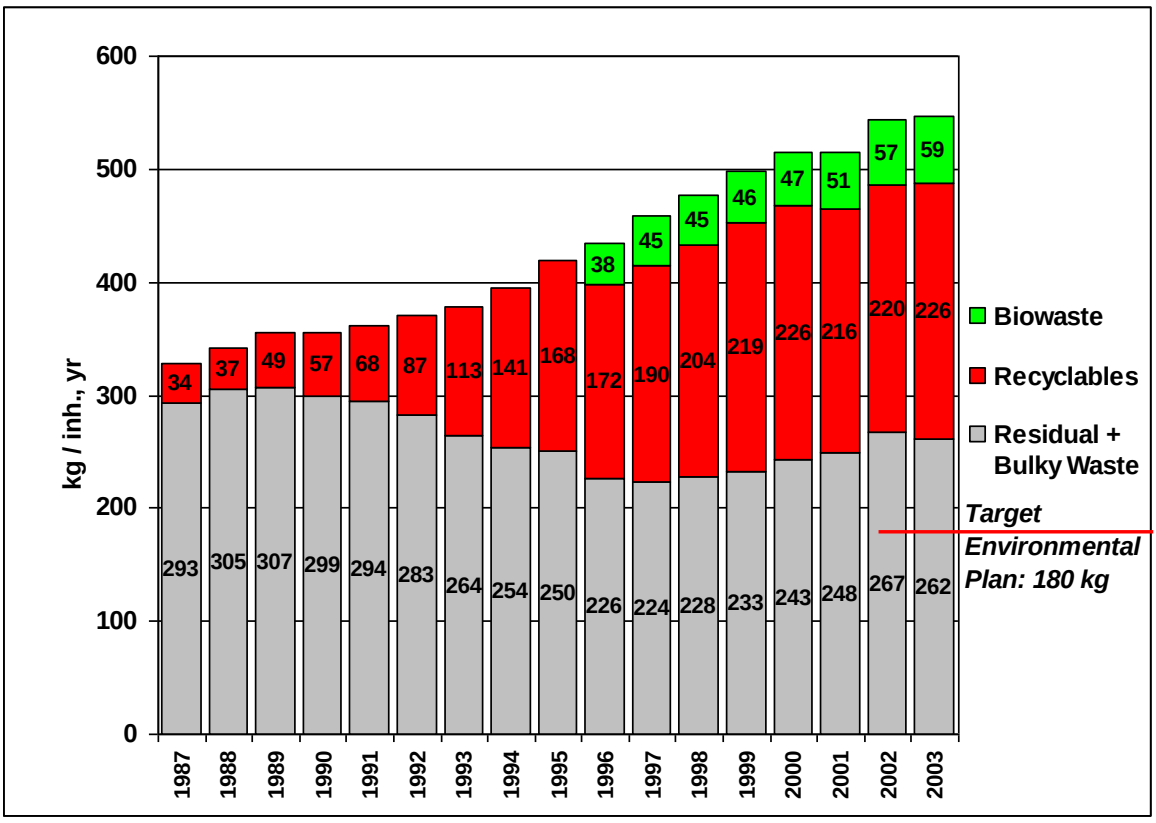

Fig. 3: "Waste record" of a medium sized city (130.000 inhabitants, Innsbruck/Austria). The present quite typical profile shows that an overall waste growth of 4 % p.a. (= doubling in 18 years !) could be "controlled" by means of separate collection on the disposal side (grey columns).

For a more refined projection the database (= current amounts) has to be mathematically combined with *factors influencing waste development*. In such calculation (usually done in an ordinary spreadsheet) timewise development of municipal waste is considered in relationship to one or more of the following:

Parameter	*Usually applied on…*
➢ *Population growth* (respectively population *development*, as in certain areas also a decrease might be observed)	*Regional data level* i.e. amounts of municipalities out of the same area get multiplied with the same factor, eg. if the population growth 2004 - 2010 for *Western Slovakia* area is estimated by the National Dept. for Statistics at 1,5 % p.a. ⇨ MSW data base (amount in 2004) for *Bratislava* x 1,015 = amount in 2005, amount in 2005 x 1,015 = amount in 2006 … other factors (from below) get multiplied accordingly
➢ *Economic development* (expressed usually as development of GDP): Waste arisings are connected to a certain extent with economic development [1].	*Regional or national data level* It is recommended to apply waste increase due to economic development *only for the ´consumer´ waste components (*glass, paper & cardboard, metals, plastics) - note that this parameter and the following one (Intensity of source separated collection) calls for an integration of *composition data* [2] into the model
➢ *Intensity of source separated collection* (by fraction, in %).	*Municipality data level*
➢ *% of population connected to collection schemes* Possibly in some rural areas not all dwellings are connected to regular	*Municipality data level*

[1] usually not one by one, but a 50 % rate (i.e. 2 % GDP growth resulting in 1 % waste increase) seems to be a reasonable guess *in case no comprehensive and reliable datasets are available*

[2] In the first stage this may be a *simple assumption out of experience*, later on to be refined by real data gathered in *sorting analyses*, see 2

waste collection systems

By variation of these parameters every development in terms of *socio-economics* to be expected and *waste management activities* to be proposed can be modelled. *Scenarios* can be evaluated (Table 1 gives an example on possible parameter variation), and forecasts for single municipalities as well as a *whole country* can be given - *thus the fulfilment of targets can be modelled and evaluated, including the target on biodegradable waste set by EU Landfill Directive*

Scenario	Population growth	Economic development (as GDP)	Development of source separated collection
0	0,0 % p.a.	+ 1,0 % p.a.	No further development
1	0,14 % p.a. [3]	+ 3,9 % p.a. [3]	No further development
2	0,14 % p.a.	+ 3,9 % p.a.	"Modest", i.e. a steady increase of separate collection (target for recyclables 40 %, organics 30 %, to be reached in 2010
3	0,14 % p.a.	+ 3,9 % p.a.	"Fast", i.e. a steady increase of separate collection (same targets as in Scenario 2), to be reached in 2006

Table 1: Example for defining parameters for various *waste development scenarios*

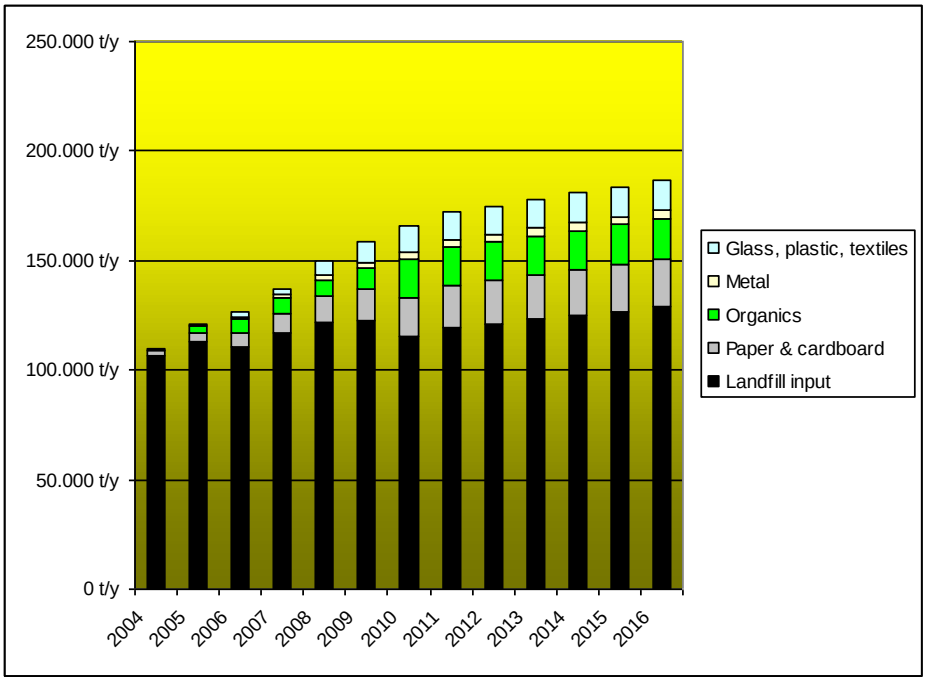

Fig. 4: "Waste forecast" for a Southeast European country (data not directly related to Table 1).

[3] Real current data (2003) for Slovakia (source: CIA´s World Factbook)

2 A STRATEGY TO MONITOR DIVERSION

The fulfilment of targets of the Landfill Directive needs to be consistently monitored, in order to assess effectiveness of intended strategies.

As already remarked, we may “bite” on the amount of biodegradable waste by means of different possible strategies, basically related to

- Source reduction (e.g. prevention of paper packaging; promotion of home composting)
- Recycling (implementation of source separation for biowaste, to be sent for composting
- Treatment of residual waste (by means of thermal or biological treatment, in order to cut biodegradability before landfilling)

The system for monitoring of the strategy (and related registration of results) needs to assess how much of the starting amount of biowaste has been diverted through various concurring methods.

Basically, the amount of biowaste captured through source separation/composting may be detected through monitoring of treated quantities at permitted sites. Arguably, much more difficult, instead, is to assess how much biowaste has ben self-composted in backyards. Moreover, the result itself of certain types of treatment, as mechanical-biological treatment, requires a definition of whether the end material is still to be considered as “biodegradable” (and to which extent) or not.

The complexity of possible approaches, makes it more recommendable to establish a system that focuses on the *amount of biodegradable waste in residual waste*, rather than trying to make a calculation of diversion through combinations of various contributions.

The calculation we therefore propose may be summed through an equation that may be summed up as follows:

$$\mathbf{MBW_L = [MSW_R \times (sumBWF)] - (MSW_T)} \qquad \mathbf{(1)}$$

In which:

$\mathbf{MBW_L}$ = landfilled Municipal Biodegradable Waste (whose calculation is our goal)

$\mathbf{MSW_R}$ = residual Municipal Solid Waste (after prevention/reduction/source separation/recycling) sent for disposal

sumBWF = sum of Biodegradable Waste Fractions (paper, board, garden waste, food waste, wood, natural textiles, nappies) as a percentage of rMSW

MSW_T = amount of treated Municipal Solid Waste *that meets the standards for acceptability as a material "no more biodegradable".*

Equation (1) is conceptually easy, and basically requires the following:

- the amount of MSW produced in a certain District/Region or nationwide (depending on the scope of the analysis)
- the percentage of BWF *detected through sorting analysis*
- the assessment of biodegradability of treated residual waste *detected through consistent test methods.*

Arguably, thermally treated materials (ashes) may be considered "no more biodegradable". As to materials treated through mechanical-biological treatment, a reasonable approach is to adopt a test method to assess fermentability ; in this respect, worldwide, methods based on respirometry (assessment of oxygen uptake by microbes to degrade still present) is proving to be a practicable, reliable and comparatively affordable approach. According to this approach, below a certain threshold, respiration – and related residual biodegradability - is considered as "negligible" and treated materials do not count towards calculation of the load of biodegradable waste still being landfilled.

In the light of the foregoing concepts, the following sections focus, on one hand, on methods to perform sorting analysis, and on the other, on test methods to assess biodegradability.

2.1 Sorting analysis

Sorting analyses are applied for both untreated and treated (domestic) waste, both before and after source separation, and are able to give an important set of information on waste composition, its variation with time and implemented strategies for recycling, etc.

Anyway, the main use we recommend them for, according to the outlined strategy for monitoring, is the assessment of percentages of biodegradable waste in residual waste.

To gather information on the physical composition of certain domestic waste streams, there is no other - eg. analytical, automatized - method than *manually sort out the components which are interesting* for the respective question.

2.1.1 Some introductory comments on sorting analyses

- *There is no applicable official European standard on waste sorting analyses yet* many single member states have there national "recipes", and the present documentation is meant as nothing more than a bundle of hands-on recommendations based on experience gathered during the last 20 years in a number of analytical campaigns - in Europe (mainly Germany, Austria, and Italy where since the late 70´s sound knowledge on the composition of domestic waste streams is considered as valuable), but also overseas (in the respect of developing national or regional waste management master plans, or planning treatment facilities).

- *A ´national standard´ on waste sorting analyses is highly recommendable* in order to make results comparable within the country. In any case a national authority should coordinate relevant programs.

- *Sorting analyses involve a lot of manpower, being consequently relatively costly* compared eg. with a standard test out of wastewater management. Therefore it seems to be worth considering *to integrate sorting campaigns in PR work related to waste management* (school excursions at the place where analyses are being performed, etc.).

2.1.2 About statistics & representative sampling

It is refrained herein from a full compendium of *statistical rules* to be applied when developing a sampling plan for a sorting analysis - as these rules are not ´waste-specific´, and depend on the particular situation / influencing factors to be described (eg. prevailing system of waste receptacles, detailed socio-economic sub-structures to be described, and the like).

In order to compensate the influence of statistical outliers the *minimum size of a single sample* is of utmost importance - and a basic statistical ´rule of a thumb´ rule says that

- the sample to be analysed should be *100 (min.) ... 1.000 (highly sufficient) times more than the largest / heaviest single component* to be found in the material

As larger waste parts (domestic waste) are in the range of 700 g (a heavy glass bottle) to 1.500 g (a weekend newspaper), the "right size" of a sample in this perspective is

- in the range of some hundred, *say 500 kg.*
  (A sample of such a size can be processed by 4 - 5 staff and a usual number of sorting fractions - which is 15 to 30, see page 16 - within one day.)

Out of this the important question emerges *"How many waste producers / citizens can be described with a 500 kg sample ?"* That depends

1. on the *specific waste generation*on the *collection frequency*.

Example:

- Collection frequency: *weekly*
- Specific waste generation: *250 kg/inh., yr*.

So 1 citizen ´contributes´ ~ 5 kg to the sample, thus 100 citizens can be described directly. Applying the „General statistical rule" from above (100 times more = min., ... 1.000 times more = highly sufficient): A socio-economic structure of say 10.000 people can be described.

Out of experience a typical set-up of *dwelling structures* to be described in a larger region of a Central European country like Slovakia would be as follows:

- *Residential Type A* (single houses, average garden size > 200 m^2)
- *Residential Type B* (up to 3 storeys)
- Residential Type C (Highrise buildings)
- *Commingled Residential / Commercial*
- Mainly *agricultural*
- *Central Business District*
- …

Further aspects to be considered are the prevailing *heating system* (areas with district heating vs. stoves with potential "self thermal pre-treatment") and the *annual season*: It becomes more and more common to have either one annual campaign (in early summer), or two: Heating period / Off-heating period.

As a rule a medium sized region (up to 300.000 inhabitants) can be properly described by a program lasting not more than a fortnight, and typical "full-scale" programs for a Province (1 Mio. inhabitants +) are designed for 4 to 8 weeks.

2.1.3 "Direct sampling", or "sampling out of the collection truck" ?

Another very important aspect when taking domestic waste samples is the question *Should the sample be taken…*

A) *directly "at source",*

i.e. out of the waste bin in parallel to collection (loaded on a separate vehicle) or

B) *..out of the amounts delivered to disposal,*
i.e. out of the collection device ?

Option A is clearly recommended. Main disadvantages of option B are

- A large waste amount - eg. the load of a compaction truck, say 6 tonnes - has to be reduced by "quartation" to the sample size that finally gets analysed (⇨ Fig. 5).

  - This represents a *considerable risk in terms of work safety* as a big number of bags in a large waste heap has to be opened manually (cutting injuries by glass, used syringes or other sharp items)

  - By mixing during "quartation" - manually or assisted by a shovel loader - the moisture content of the organic (wet kitchen waste) fraction passes to other fractions as eg. paper, thus resulting in ´wrong´ weight percentages

- Information on the sampling area gets partially lost - when sampling "at source" (Option A) relevant information on the waste producing level can be taken (eg. ´30 bins from that and that addresses have been taken into the sample, 24 of it showed home composting…´) and furthermore such sample is fully reproducible (in a campaign 5 years later the same addresses can be taken into the sample…)

Fig. 5: Sample taking, Option B:
Reducing a large waste load by “quartation” to a reasonable sample size to be analysed

2.1.4 About further processing of the sample

A typical technical set-up of the entire analysis process is visualized on the following scheme/figure.

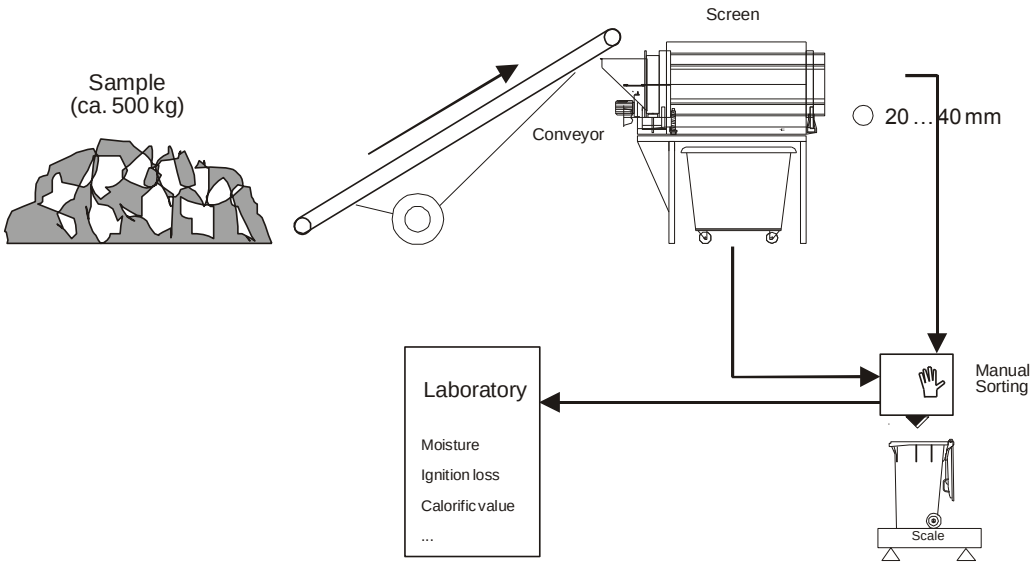

Fig. 6: Typical technical set-up of the core of the waste analysis process: Conveyor - screen - sorting of the screen overflow in up to 30 fractions

- *Screening the sample* (in a continuously fed screen with mesh sizes in the range of 20 to 40 mm) is highly recommended, asa steady material flow guaranteed *higher* and *reproducible* performance of the pickers

  - Sample processing gets easier, and of higher consistency (eg. lab analysis of underflow…)

„Extra“ picture

Fig. 7: Pretreatment of sample: Trommel screen with changeable mesh sizes

- *Further labwork* can be designed individually to the intended questions of the relevant program (Fig. 8). *Moisture contents* should be measured in any case directly on site.

Fig. 8: Combined screen & sorting analysis of the output of a MBT plant:
Sorting table, outlet trommel screen (to the right), dryer (in the background)

- Number and type of *sorting fractions* depend on the questions of the relevant program. When the efficiency of strategies aiming at diversion of “biowaste” is to be assessed, it is enough to take samples of the *remaining residual waste*, and sort

  - paper products
  - organics generated in the kitchen, suitable for compostine / anaerobic digestion
  - garden waste
  - wood
  - textiles of natural origin
  - nappies.

A “full sorting analysis of residuals waste” may be intended, instead, to describe the efficiency of *all collection schemes for recyclables implemented in a certain area, and/or the suitability/importance of new separate collection schemes to tackle prevailing fractions in residual waste.* Such an analysis may comprise up to 15 - 30 sorting fractions [4]. In Annex 1 a full list of fractions that may be sorted is shown.

2.1.5 About presentation of results

It is recommended to present results of analyses involving more than say 10 sorting fractions not only in a plain tabular form, but also as a graph. Pie charts - see table below - are very common.

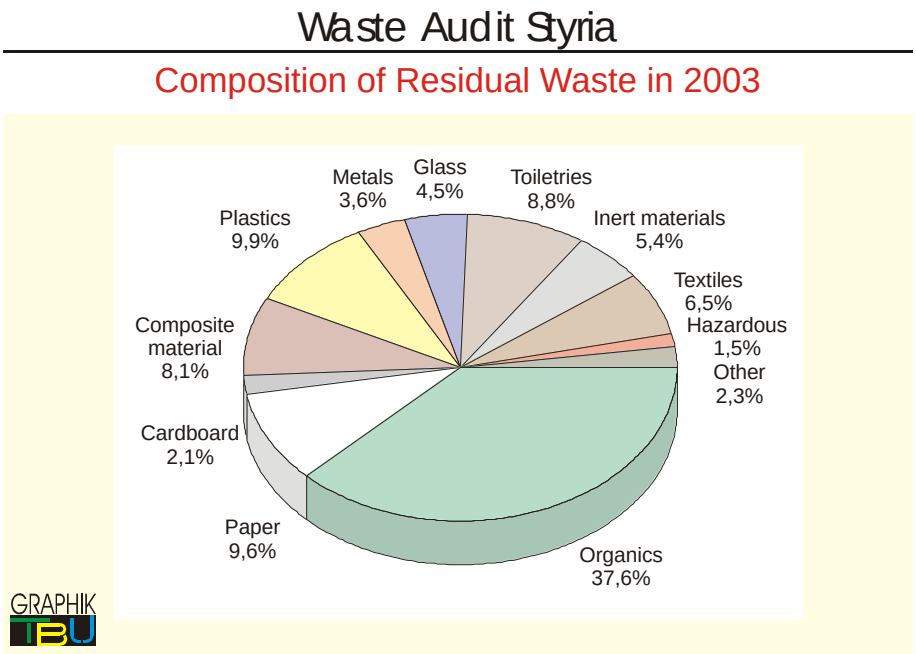

Fig. 9: Comprehensive results of an extensive waste analysis (total number of samples: 80, total number of analysed fractions: 34, total weight of material analysed: ≈ 20 t)
Note that in the present pie chart the fraction “toiletries” includes *disposable diapers*.

As a matter of fact pie charts are a perfect tool to view *compositions*, but the very important overall information *specific waste generation* (= how *large* is the pie ?) cannot be shown directly or does not get the attention it deserves [5]. Therefore it may be sometimes recommendable to work with *bar charts,* particularly when it comes to

[4] note that the same material has to be differentiated in *packaging* / *non packaging* when describing the efficiency of certain recycling schemes run by the packaging industry, in order to asses e.g. compliance with obligations of the Packaging Directive

[5] Example: Residual waste of 2 municipalities is analysed.
Municipality A with a specific waste generation of 300 kg/inh., yr shows 10 % paper.
Municipality B with a specific waste generation of 120 kg/inh., yr shows 15 % paper, but:
It is municipality B where “less paper gets thrown into the waste bin” (18 vs. 30 kg per inh., yr.)

comparisons (Fig. 10). As a further step *separately collected amounts* should be taken into consideration (Fig. 11).

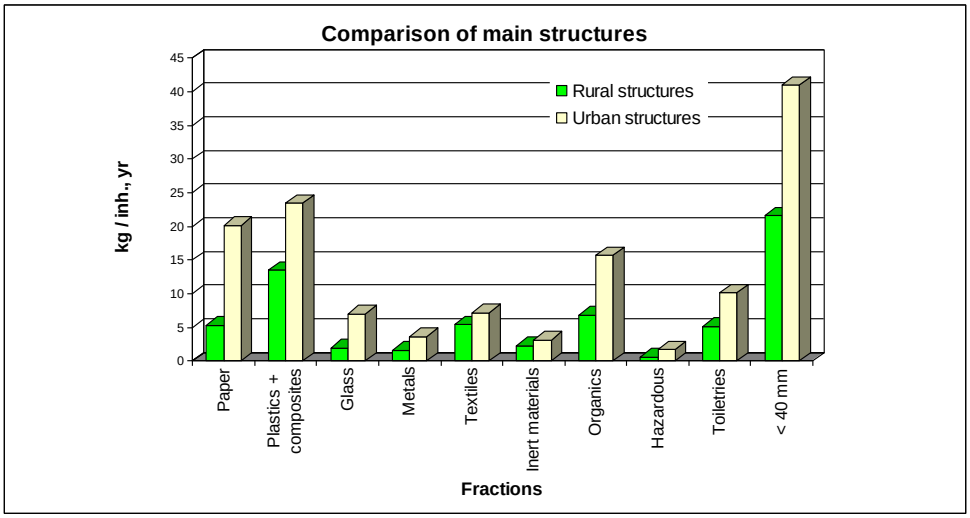

Fig. 10: Composition of residual waste - comparison of two structures: *Rural* (specific waste generation ~ 80 kg/inh., yr) and *urban* (~ 150 kg/inh., yr).

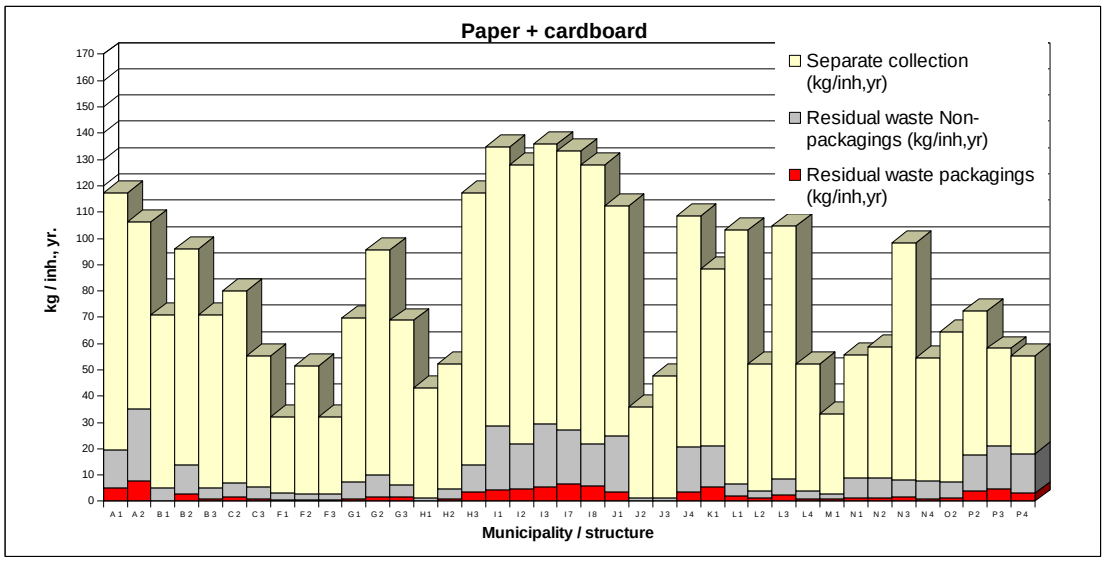

Fig. 11: Comparison of various structures in respect to one recyclable fraction (paper and cardboard): The upper column shows amounts already collected separately, the two lower amounts to be disposed of in the garbage bin.

2.2 Respirometry: a tool to assess fermentability/biodegradability of treated waste

2.2.1 Waste management and bio-products

Diversion of biodegradable waste from landfills may be achieved by means of reduction (reuse, backyard composting) separate collection (e.g. of paper, biowaste) and treatments of residual waste (as depicted in Figure 2).

Independently from the waste management strategy, end products/materials with a certain content of organic matter will be produced (Figure 12).

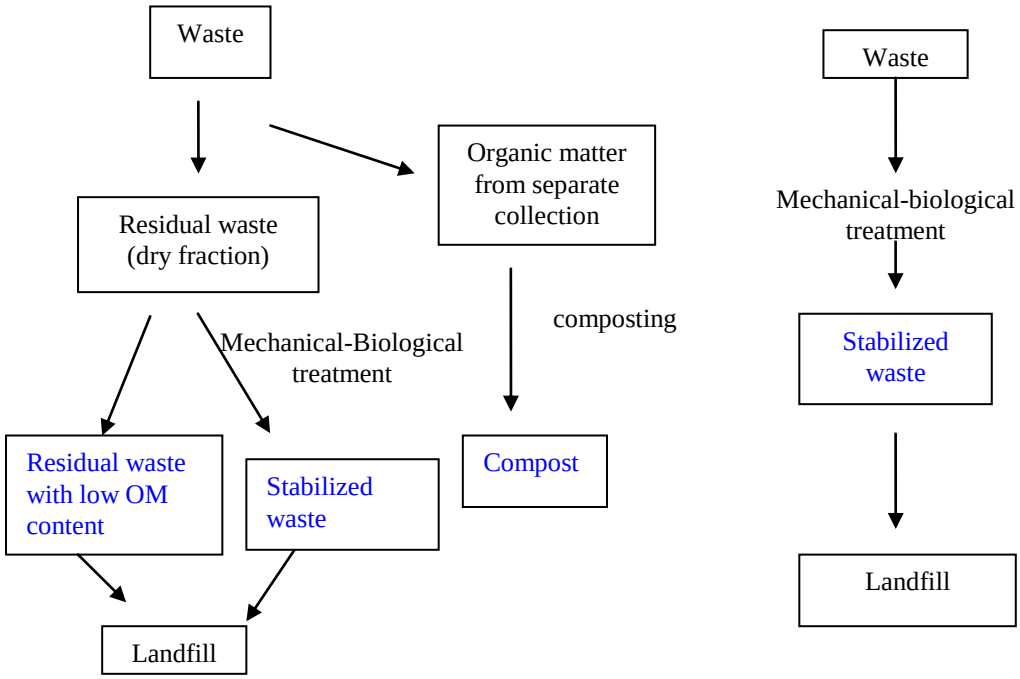

Fig. 12: Reduction of biodegradable waste by means of separate collection / biological treatments and related end materials (in blue)

From figure 12 (which does not include thermal treatment, in which case we'd have ashes with a very low organic content, to be landfilled) we may single out and consider the following typical end materials:

- residual waste (dry fraction) with low organic matter content = to be landfilled
- residual waste (dry fraction) with high organic matter content = to be treated before landfilling
- stabilized waste = to be landfilled

- compost = for soil application

Compost should achieve a high quality with reference to environmental and agronomic aspects; its "maturity is an important aspect for that. Residual waste and/or stabilized waste should, in first instance, achieve a certain "stability" in order to avoid typical impacts of a landfill, namely biogas production, odours, leachate etc. .

2.2.2 Biological stability

Biological processes such as composting (sometimes coupled with anaerobic digestion), biostabilization, and biodrying are used in solid waste management to convert organic waste materials into agriculturally useful products (Chen and Inbar, 1993), to prepare residual waste for safe disposal in landfills (Wiemer and Kern, 1996; Adani et al., 2000), and to prepare refuse derived fuel (RDF; Calcaterra et al., 2000). Irrespective of the process, all these methods have to achieve certain levels of biological stability by means of an aerobic (or sometimes anaerobic) degradation of organic matter. The degree of biological stability affects many important aspects, such as the potential for odor generation, residual biogas production, phytotoxicity, plant disease suppression ability, etc..

"Biological stability" determines the extent to which readily biodegradable organic matter has decomposed (Lasaridi and Stentiford, 1996). It identifies the actual point reached in the decomposition process and represents a gradation on a recognized scale of values, which thus enable comparison of the process of decomposition (Lasaridi and Stentiford, 1996). Biological stability of treated materials, not only during the aerobic biological processing but also to be found in the final products, is important for the process to be controlled effectively, for the product to be used beneficially (in case of compost from separately collected biowaste) or landfilled safely (in case of tread residual waste); it also gives valuabale information about efficacy of the process and to optimise its management (Lasaridi and Stentiford, 1998). As a matter of fact, stability is related to the following (Iannotti et al., 1993; Müller et al., 1998) (Fig. 13 and Table 2):

- the potential for odour generation,
- possibility for further degradation of the biomass,
- residual biogas production,
- potential for regrowth of pathogens,
- phytotoxcity after application of the product,
- plant disease suppression ability,

Process parameters such as airflow rate and retention time widely influence the achievement of a certain stability, and may be optimised through an assessment of stability acheved under a certain process scheme.

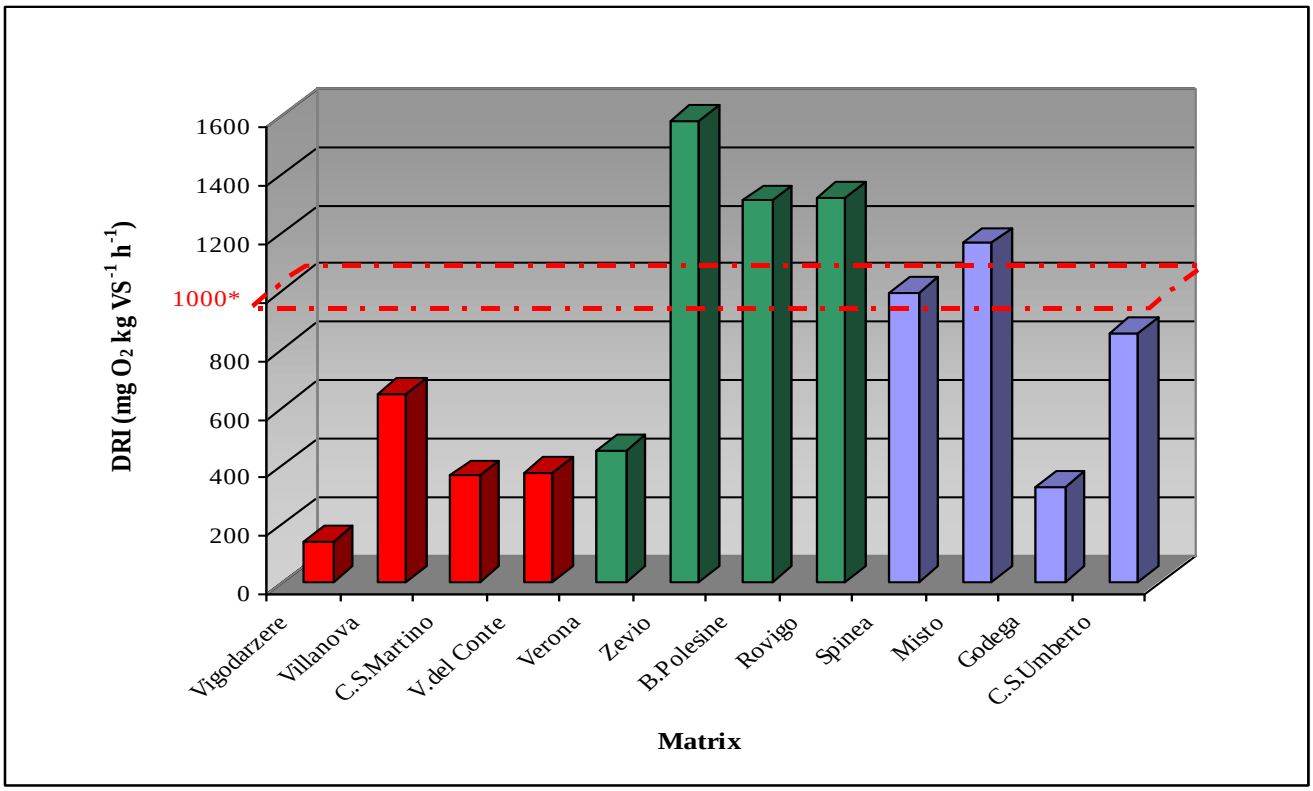

Fig. 13. Biological stability (by DRI) measured for residual waste coming from door to door collection (red), road container collection (green) and double road container (blue) (From Adani et al., 2003); better captures with a dor to dor collection cut the percentage of organics in residual waste, thereby givng a higher degree of stability (lower DRI).

Table 2. Biological stability (DRI) values and corresponding Odour Units for treated waste at different biological stability degree (from Adani et al., 2004)

DRI ($mg\ O_2\ kgSV^{-1}\ h^{-1}$)	O.U. ($o.u./m^3$)
314	300
343	300
508	700
712	320
856	800
862	800
909	900
969	1100
1118	1700
1337	3400
2005	2300
2467	10000
2885	6000
3318	20000
3746	17000
5142	24000
5172	24000
6600	21000

2.2.3 Test methods to assess stability

Many analytical methods have been proposed for the determination of biological stability (Chanyasak and Kubota, 1981; Iannotti et al., 1992; Adani et al., 1995; Avnimelech et al., 1996; United States Composting Council, 1997a).

For example, residual biogas production and/or calorific value have been proposed in the past and in same case considered in Legislation (e.g. Austria and Germany). Both methods are useful to qualify products. Nevertheless residual biogas production requires long time analysis (20-90 days) therefore very high costs are incurred. Moreover in the case of fresh material results ay be controversial. Therefore these analyses should be proposed as ancillary for others (discussed later).

Calorific value does not match biological stability to a sufficient extent and sometimes an erroneous use of it is made. In some National regulations enforcing the Landfill Directive, the calorific value is considered as a threshold for acceptability at landfills. In this case, anyway, the aim of the Regulation is typically to limit the organic matter landfilled in order to recover all energy contained in the waste. Therefore *this parameter is not intended as a measure of the biological stability*.

The determination of the respiratory activity of the biomass has received more attention from researchers, focusing on both CO2 production (Naganawa et al., 1990; Willson and Dalmat, 1986) and O2 uptake (Iannotti et al., 1992; Paletski and Young, 1995; Lasaridi and Stentiford, 1998). For respirometric purposes oxygen uptake is preferred (Lasaridi and Stentiford, 1996) and has been proposed for adoption as the standard method by many international standardisation bodies (American Public Health Association, 1985; American Society for Testing and Materials, 1992; United States Composting Council, 1997b).

Respiration tests by means of oxygen uptake can be divided into “static” and “dynamic” methods (Scaglia et al., 2000); oxygen uptake is measured in the absence (static) or presence (dynamic) of continuous forced aeration of the biomass.

Static methods, such as the widely used Sapromat (Binner and Zach, 1999), SOLVITA (Changa et al., 2003), or the method adopted by the United States Composting Council (1997b), are negatively affected by the disadvantage that they do not allow the oxygen to be dispersed throughout the biomass, thus limiting diffusion and mass transfer (Paletski and Young, 1995). Minimization of diffusion is important because limited oxygen transfer through the biomass layers and into the bacterial cell wall is typically considered to be the rate-limiting step in fixed-film biological reactions that exist in organic matrices (Paletski and Young, 1995). Therefore, when static methods are used, *underestimation of oxygen*

uptake is possible, especially when "fresh" organic matter is present. Moreover, in order to reduce the inconvenience, a limited amount of material may be tested in order to allow for aerobic conditions throughout it. *This affects negatively possibilities to have a reliable assessment for heterogeneous materials such as treated residual waste, since a small sample may never be satisfactorily representative of the material.*

These problems can be solved through continuous forced aeration of biomass (Adani et al., 2001) and/or through continuous biomass stirring combined with intermittent aeration, in a liquid condition (SOUR method) (Lasaridi and Stentiford, 1998). Nevertheless, the SOUR method tends to fall short of real conditions for three reasons: the use of solid biomass in a liquid medium, the use of very low particle size (i.e., <1 mm), and the dependence of SOUR on the water-soluble fraction (Adani et al., 2003a).

In conclusion, although all respirometric methods allow a comparatively good testing of biological stability, **dynamic methods should be preferred, above all once treated waste, or "young" (i.e. comparatively unstable) materials are to be tested.**

The 2nd Draft of Biological treatment of EU (EU, 2002) indicated the dynamic method as useful for biological stability determination.

AT_4 (or Sapromat) is indicated as useful method, too, probably not to incur any conflict with existing legislation in e.g. Germany. Nevertheless this latter, presents some limits such as the following:

- high cost (40.000 € c.a.);
- it operates only on small grain size materials obtained through sifting procedure; therefore the mass tested is not representative of all the materials, above all when treated mixed waste is to be tested;
- for this very reason, AT_4 beneficial use is limited to refined biostabilised materials;
- it is a static method, whch determines an underestimation of the respirometric activity, above all when fresh materials are tested;

Support to the dynamic approach comes from the American Standard Testing Material (ASTM, 1996), who suggest the use of a dynamic method for biological stability determination of compost and related materials. Many Italian Regions have already adopted the Dynamic Method (either to assess acceptability of composted products and

treated waste to be landfilled, or to determine residual fermentability and potential odour production of materials).

The Dynamic Respiration Index (DRI) is therefore strongly recommended as a more reliable method for determination of biological stability

In Annex 2 a detailed desription of the test method is provided.

2.2.3.1 Assessment of stability in Slovakia

With reference to the Slovak background conditions, no lab is currently able to perform respirometric analysis. Nevertheless during our visit, we found a great interest for the subject from both public and private bodies (e.g. the Environmental Ministry Slovak Environmental Agency, the Ekotoxikologike' Centrum of Bratisla and the Slovak Technical University la Bratislava).
A laboratory now is working, for example, in the Czech Republic. Anyway, one equipped laboratory could be enough to satisfy the Slovak needs right away, considering current level of implementation of waste management strategies and dimension of the Country. The investment is comparatively low (approximately 15.000 €).

Nevertheless, *pending establishment of such laboratory, a more simple full scale method, could be proposed, i.e. the self heating test*. Details of this method are reported by The U.S. Composting Council (1997). In brief, this method considers the re-heating of the biomass put in a Dewar container. The difference between biomass T and room T, gives the “stability class”.

A prospect of biological stability limits, and cross-comparison of varius test methods, is given in Table 3.

Table 3. comparison of alues for DRI, ASTM and self heating test. (1996)

Compost classification by ASTM	DRI (ASTM) mg O_2 kg VS^{-1} $96h^{-1}$	$DRI_{DiProVe}$ mg O_2 kg VS^{-1} $96h^{-1}$	**$DRI_{DiProVe}$** mg O_2 kg VS^{-1} h^{-1}	Self-heating Test
Compost 1	258000			II
Compost 2	109000			III
Compost 3	35000	57000	**1000**	IV
Compost 4	23000	29000	**500**	IV
Compost 5	20000			IV
Compost 6	8000			IV

ANNEX 1: Survey on typical sorting fractions: possible list (comprehensive)

Sampling area:		**Sheet N°:**	**Data taken by:**
Date:	**Volume of sample:**	**Weight of sample:**	
Fraction:			
Newspapers			
Cardboard (packaging material)			
Other cardboards			
Paper packagings			
Other paper, clean			
Other paper, wet			
Plastic foliage, packaging			
Plastic foliage, other			
´Hard´ plastic packages			
PET-bottles			
Other ´hard´ plastics			
Styrofoam			
Compound packagings for beverages			
Other compound packagings			
Other compound materials			
WEEE			
Glass packagings (green/amber/white)			
Other glass			
Metal packagings (Fe/NFe)			
Other metals			
Textile packagings			
Other textiles			
Wood packages			
Other wood			
Inert packagings (ceramic bottles...)			
Other inert materials			
Organic materials (garden)			
Organic materials (kitchen) compostable			
Organic materials (kitchen) not compostable			
Disposable diapers			
Hygiene materials			
Hazardous materials			
Residuals overflow			
< 40 mm			

ANNEX 2: Biological Stability Determination in Compost and Waste by Dynamic Respiration Index (DiProVe Method University of Milan)

1. Preliminary Considerations

The Dynamic Respiration Index (DRI) is determined by evaluating the oxygen consumption, per unit of time, required to biodegrade fermentable fractions contained in the biomass. In line with the operative conditions adopted for the respirometric test the index is defined as Real Dynamic Respiration Index (RDRI) when the test is carried out on a laboratory sample, whereas the definition is Potential Dynamic Respiration Index (PDRI) when the sample is standardised for what concerns the main processing parameters (allowing operation in controlled conditions with the advantage of comparability of results deriving different tested samples). The respirometric data can be expressed in terms of the unit of weight of Total Solids (TS) of the Volatile Solids (VS).

2. Compost (or waste) sampling

The UNI or The US Composting Council methods for SRF or compost sampling (UNI, 1992; The U.S. Composting Council, 1997**a**) were used to obtain a representative sample for the determination of the Respiration Index, the sample objective being 5-50 liters of material to subject to the respirometric test.

Determination of the Real Dynamic Respiration Index (RDRI)

A sample obtained as indicated is assessed to determine the RDRI (cfr. 6).

Determination of the Potential Dynamic Respiration Index (PDRI)

In the event of wanting to determine the PDRI, understood as the measure of microbiological activity under standard conditions, the following parameters are corrected within the following reported limits:

moisture = 750 g kg^{-1} of the water holding capacity;

pH = 6.5 – 8.5;

bulk density < 0.70 Mg m^{-3}.

3. Sample characterisation

3.1. Moisture determination (The U.S. Composting Council **b**, 1997)

3.2. pH determination (The U.S. Composting Council **c**, 1997)

3.3. Bulk density determination (The U.S. Composting Council **d**, 1997)

4. Sample standardisation

4.1 Moisture sample standardisation

4.1.1 Determination of water holding capacity (WHC)

The test to determine the maximum water holding capacity will be done as follows:

- Determination of the moisture in the sample (cfr. 3.1).
- Place a cotton bag in a sufficiently wide and deep container (in such a way that there is free space between the bag itself and the sides and bottom of the vessel).
- Weigh out about 1000 g of the sample as such (P_i) and place it in the bag inside the container.
- Pour in water until the sample is completely immersed.
- Close the cotton bag.
- Keep the bag with the sample under the water, using a weight to hold it down (but not too heavy so as not to compress the sample in the bag nor to press the bag onto the bottom of the container).
- Maintain this immersion for 12 hours, then extract the bag and leave it drain for 6 hours.
- Remove all the material from the bag carefully, and weigh it (P_f).

The water absorbed during the test is the difference in quantity between the initial and final sample weights. It, together with that already present in the sample as such, represents the maximum quantity of water absorbable by the sample and defines the condition of maximum water holding capacity.

4.1.2 WHC calculation

$$M_{av}=P_i * M_{rv} /1000$$

$$TS_{av} = P_i - M_{av}$$

$$WHC_{av}= P_f - TS_{av}$$

$$WHC_{75av}=0.75 * WHC_{av}$$

$$J = WHC_{75av} - M_{av}$$

Where:

P_i= initial weight of the sample (g)

P_f= final weight at the water holding capacity (g)

M_{av}= moisture absolute value (g)

M_{rv}= moisture relative value (g kg^{-1} w.w.)

TS_{av}= total solid absolute value (g)

WHC_{av}= water holding capacity absolute value (g)

WHC_{75av}= 750 g kg^{-1} of WHC_{av} (g)

J = water to add to P_i to reach 750 g kg^{-1} WHC (g)

After the determination of J, the sample can be moisturised so that its moisture content is standardised to a value of 750 g kg^{-1} WHC for the next determination of the Dynamic Respiration Index (DRI).

$$X= J * P_{DRI} * P_i^{-1}$$

where:
P_{DRI} = sample weight to estimate DRI (g)
X = water to add to P_{DRI} to reach 75 g kg^{-1} WHC (g)

4.2 pH sample standardisation (if the value is not in the indicated range)

The pH of the material undergoing analysis is corrected during the re-moisturising of the dry mass using diluted aqueous acidic (sulphuric acid) or alkaline (calcium bicarbonate) solutions.

4.3 Standardisation of apparent density (if the value is not in the indicated range)

A biologically inert "bulking agent" is used.

5. Materials

The respiration test is done using a ‘continuous flow aerobic respirometer’.

The respirometer (Figure 1) has:

- An adiabatic reactor body with a capacity, expressed in litres, equal to the average size, expressed in millimetres, of the sample being analysed (e.g., for an average sample of 10 mm the reactor volume would be 10 L);
- Aerating system with a flow rate regulator and displacement meter;
- System to measure in/out oxygen concentrations;
- Thermometric probe to measure the external and internal temperature in biomass fermentation;
- Continuous recording system for: oxygen concentration, temperature and air flow.

6. Procedure

The Dynamic Respiration Index (DRI) is determined by quantifying the hourly oxygen consumption of the tested material, using a continuous air flow adiabatic respirometer as indicated earlier. The prepared sample is put into the respirometer and subjected to continuous air-flow aeration that guarantees an oxygen concentration in the exiting air of the respirometer higher than 140 mL L^{-1}. Throughout the testing the sample is kept under observation in the fermentor for 1 to 4 days, depending on the duration of the lag phase, automatically measuring the index at 2 hourly intervals.

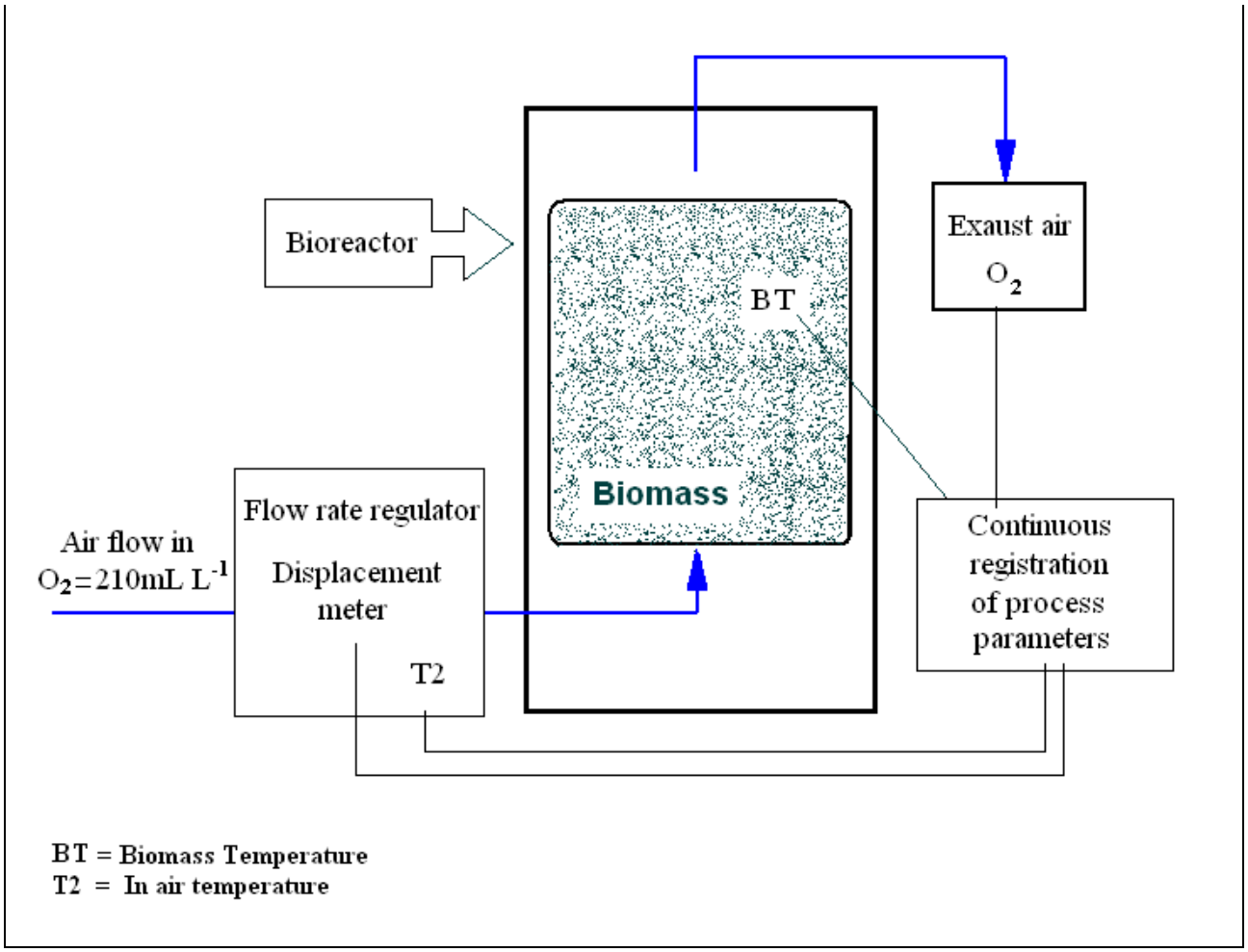

Figure 1. Scheme of the aerobic adiabatic dynamic respirometer

7. DRI calculation

The measure of the quantity of oxygen consumed by the aerobic biological activity is deduced from the difference in the oxygen concentration of the inlet and outlet air of the respirometer, and is calculated as the average of the instantaneous respirometric indices (DRI_i) (Eq. 1) relative to the 24 hours during which the respiration of the biomass is highest (Eq. 2).

$$DRI_i = Q * h * (O_{2i} - O_{2f}) * V_g^{-1} * 31.98 * VS^{-1} * h^{-1} \qquad \textbf{1.1.1.1.1}$$

where:

DRI_I = Dynamic instantaneous Respiration Index (measured every 2 hours);

Q = air flow (L h^{-1});

(O_{2i} -O_{2f}) = difference in oxygen concentration at the entrance and exit of the respirometer (mL L^{-1})

V_g = volume occupied by one mole of gas. Assuming standard values T_1= 273.15 K and P_1= 1 atm equal to V_{g1} = 22.4 L mol^{-1}, the corrected value of V_g (V_{g2}) to temperature T_2 is calculated by the expression: $V_{g2} = (V_{g1} * T_2 / T_1)$ where T is Kelvin temperature.

31.98 = molecular weight of oxygen (g mol^{-1});

VS = volatile solids (kg). The data of aerobic biological activity can also be expressed on total solids (TS).

h = duration of measurement in hours (2h).

$$DRI = \frac{\sum_{t'=0}^{24} DRI_i}{12} \qquad \textbf{Eq. 2}$$

where t' is the period of time (24 h) during which the maximum DRI values are measured (Figure 2).

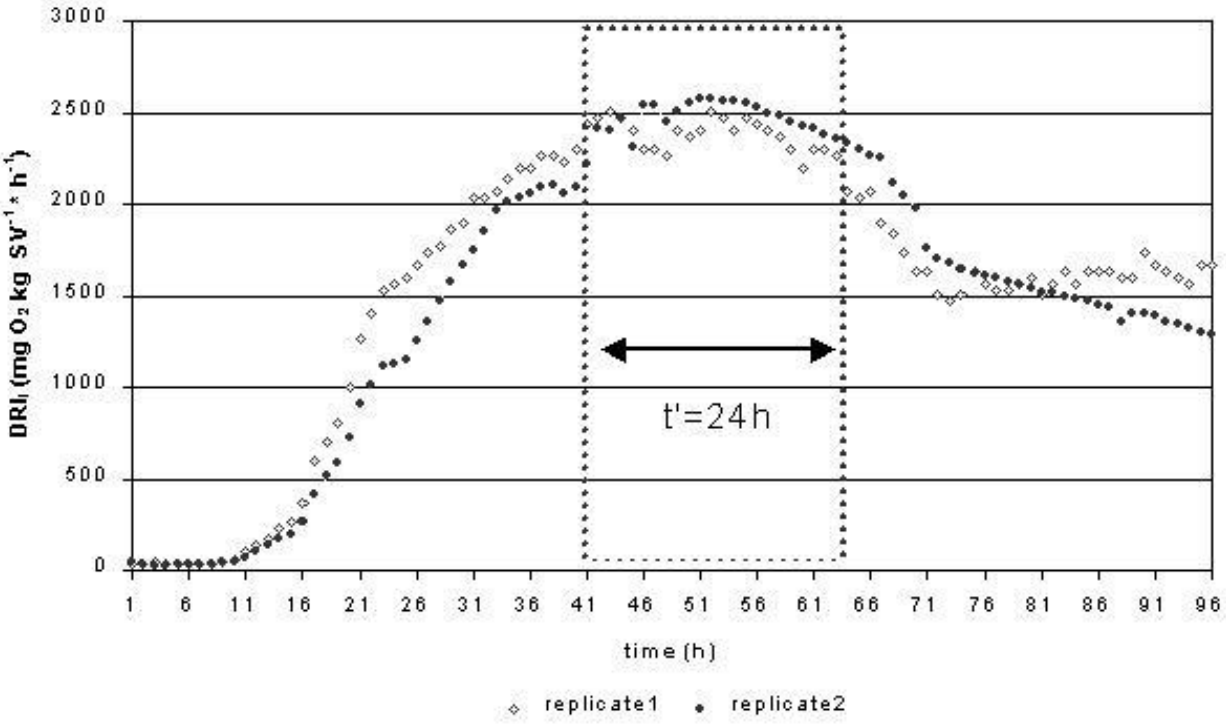

Figure 2. Course of DRI

8. Remarks

The conditions of the described method are such as to simulate, to as great a degree as possible, the reality in which the tested substrates are found during the cycle of biological treatment.

The continuous aeration to which the material is subjected for the entire duration of the test is, undoubtedly, the strong point of the procedure, in that it impedes O_2 concentration and phenomena limiting O_2 diffusion and dispersion from becoming limiting factors. The principle of measuring consumption by the dynamic respirometric index, based on measuring the difference in oxygen concentration of the reactor inlet and outlet air flow, allows freedom in the size of the reactor itself, obtaining optimal measurement reproducibility also with reactors of different sizes (from 10 to 50 L); furthermore problems related to calculation free air space (FAS) are avoided.

For determined categories of highly heterogeneous waste (ø = 5 cm), the use of a reactor capacity not less than 50 litres allows generous sample aliquots (20-50 litres of material), with the advantage of better representation and hence goodness in measurement.

9. Stability limits proposed

9.1 Biological Stability limits proposed by DiProVe method

Biomass typology	**PDRI**
compost (or waste) at medium stability	$\leq$ 1000 mg O_2 kg VS^{-1} h^{-1}
compost (or waste) stable	$\leq$ 500 mg O_2 kg VS^{-1} h^{-1}

9.2 Correspondence between limits proposed by DiProVe and ASTM (1996)

Compost classification by ASTM	DRI (ASTM) mg O_2 kg VS^{-1} $96h^{-1}$	$DRI_{DiProVe}$ mg O_2 kg VS^{-1} $96h^{-1}$	**$DRI_{DiProVe}$** mg O_2 kg VS^{-1} h^{-1}	Self-heating test
Compost 1	258000			II
Compost 2	109000			III
		57000	**1000**	
Compost 3	35000			IV
Compost 4	23000	29000	**500**	IV
Compost 5	20000			IV
Compost 6	8000			IV

Biological stability

10. Process Validation

The DRI validation process is presently in the hands of the Ricicla Group -DiProVe- Università degli Studi di Milano (Italy) and the Public Health Institute of Rome (Italy).
The intention is to determine the precision of the method, its repeatability (s_r) and reproducibility (s_R), on four different samples of waste matter, following the regulation ISO 5725-2.
Experimentation on two samples with regard to the determination of DRI, VS, moisture, water holding capacity, pH and bulk density has been completed. The results have been collected together and elaborated statistically using the software Colidata 4.1.2 (Confalonieri e Scaglia, 2002).

10.1 RESULTS

	Moisture (g kg^{-1} w.w.)	Mean value	Standard deviation	Repeatability	Reproducibility
Sample 1	Lab X	184.5	2.5	12.0	13.6
	Lab Y	186.2	1.0		
	Lab Z	188.0	3.6		
	Lab W	195.0	26.9**		
Sample 2	Lab X	289.5	5.4	5.8	6.2
	Lab Z	287.6	7.3		
	Lab Y	293.5	2.6		
	Lab J	Data missing			

**Outlier according to the Test of Cochran

	Volatile Solid (g.kg^{-1}d.m.)	Mean value	Standard deviation	Repeatability	Reproducibility
Sample 1	Lab X	389.8	3.9	16.3	7.7
	Lab Y	367.3	9.4		
	Lab Z	401.7	6.5		
	Lab W	380.8	8.3		
Sample 2	Lab X	483.2	25.5	22.6	32.3
	Lab Z	475.0	19.4		
	Lab Y	463.6	15.8		
	Lab J	412.4	34.1		

	pH	Mean value	Standard deviation	Repeatability	Reproducibility
Sample 1	Lab X	8.00	0.14	0.18	0.09
	Lab Y	8.07	0.12		
	Lab Z	7.93	0.06		
	Lab W	8.07	0.40		
Sample 2	Lab X	7.32	0.01	0.100	0.095
	Lab Z	7.30	0.10		
	Lab Y	7.20	0.14		
	Lab J	7.40	0.40		

	Bulk density ($kg\ L^{-1}$)	Mean value	Standard deviation	Repeatability	Reproducibility
Sample 1	Lab X	0.66	0.01	0.05	0.01
	Lab Y	0.69	0.02		
	Lab Z	0.59	0.01		
	Lab W	0.70	0.00		
Sample 2	Lab X	0.69	0.03	0.023	0.054
	Lab Z	0.57	0.02		
	Lab Y	0.62	0.01		
	Lab J	0.61	0.03		

	water hold capacity ($g\ kg^{-1}$ w.w.)	Mean value	Standard deviation	Repeatability	Reproducibility
Sample 1	Lab X	507.0 a	14.1	12.4	10.7
	Lab Y	484.3 a	12.0		
	Lab Z	495.0 a	3.0		
	Lab W	498.7 a	12.1		
Sample 2	Lab X	556.2	1.7	22.1	14.3
	Lab Z	603.0	30.4**		
	Lab Y	571.6	8.3		
	Lab J	578.2	13.5		

**Outlier according to the Test of Cochran

	DRI ($mgO_2/\ kg^{-1}$ VS h^{-1})	Mean value	Standard deviation	Ripeatability	Reproducibility
Sample 1	Lab X	524	37	49	60
	Lab Y	496	85		
	Lab Z	505	30		
	Lab W	1840••	137		
Sample 2	Lab X	3522	64	125	149
	Lab Z	3317	156		
	Lab Y	3475	106		
	Lab J	1821••	1097**		

**Outlier according to the Test of Cochran
•• Outlier according to the Test of Grubbs

10.1.1 Coefficients of percentage variation of repeatability (cv_r) and reproducibility (cv_R) for the analysed parameters

		Coefficient of variation of Repeatability	Coefficient of variation of Reproducibility
Sample 1	Moisture	7.30	6.44
	Volatile Solids	2.00	4.23
	pH	1.08	2.24
	Bulk density	1.50	7.57
	Water hold capacity	2.16	2.50
	DRI	11.80	9.64
Sample 2	Moisture	1.99	2.14
	Volatile Solids	4.93	7.04
	pH	1.37	1.30
	Bulk density	3.22	9.70
	Water hold capacity	2.48	3.82
	DRI	3.63	4.33

10. APPENDIX

Repeatability standard deviation (s_r)

$$s_r = \sqrt{s_r^2} \quad (1)$$

where:

$$s_r^2 = \frac{\sum_{i=1}^{p} (n_i - 1) \cdot s_i^2}{\sum_{i=1}^{p} (n_i - 1)} \quad (2)$$

where:

p number of laboratories participating in the inter-laboratory testing.

n_i number of test results obtained in each *i* laboratory at one level.

s^2_i variance calculated for each *i* laboratory.

Reproducibility standard deviation (s_R)

$$s_R = \sqrt{s_R^2} \quad (3)$$

where:

$$s_R^2 = s_L^2 + s_r^2 \quad (4)$$

s^2_L variance between laboratories (5) .

s^2_r (2) repeatability variance.

The variance between laboratories is:

$$s_L^2 = \frac{s_d^2 - s_r^2}{n} \quad (5)$$

where:

$$s_d^2 = \frac{1}{1-p}\left[\sum_{i=1}^{p} n_i \left(\overline{y_i}\right)^2 - \left(\overline{\overline{y}}\right)^2 \sum_{i=1}^{p} n_i\right] \quad (6)$$

where:

$\overline{y}$ arithmetic mean of n_i test results (y) made from each laboratory i.

$\overline{\overline{y}}$ grand mean of test results (7).

$$\overline{\overline{y}} = \frac{\sum_{i=1}^{p} n_i \overline{y}_i}{\sum_{i=1}^{p} (n_i - 1)} \quad (7)$$

Coefficient of variation of Repeatability (cv_r)

$$cv_r = 100 * \frac{s_r}{\overline{\overline{y}}}$$

$\overline{y}$ arithmetic mean of n_i test results (y) made from each laboratory i.

s_r (1) repeatability standard deviation.

Coefficient of variation of Reproducibility (cv_R)

$$cv_R = 100 * \frac{s_R}{\overline{\overline{y}}}$$

$\overline{y}$ arithmetic mean of n_i test results (y) made from each laboratory i.

s_R (3) reproducibility standard deviation.

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