Eco-efficiency Analysis

Residual Waste Disposal

- Mechanical biological treatment (MBT),
Waste-to-Energy (WtE) and Landfilling -

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Summary (1)

- This Eco-efficiency study compares different disposal methods for residual waste. Landfilling of non-treated residual waste, which is going to stop in Europe in 2005 is compared to Waste-to-Energy (WTE) and Mechanical-Biological Treatment (MBT).
- While current cost differences of the different disposal methods have shown no significant impact on the result of this analysis, there are major differences in environmental performance.

Summary (2)

- Within the three disposal methods Waste-to-energy is the most eco-efficient. It is in particular favorable regarding energy and resource recovery (minimal final disposal).
- In the overall result the Mechanical-biological treatment reaches only a middle rank in between Waste-to-Energy and Landfilling.

Summary (3)

- Increased Eco-efficiency of the MBT can be achieved through improving the emission cleaning equipment as well treating the light material fraction (packaging of composite materials, plastics and metals) in WTE facilities.

Residual Waste Disposal

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Demand Related Utilization and System Variations:

1. Defining demand related use

2. Selection of process alternatives

Disposal of 1t residual waste (H_u= 9,8 MJ/kg)

- Nil-variation landfill
- Thermal process: modern Waste-to-Energy (WtE) facilities
- Mechanical-biological treatment (MBT): enclosed intensified decomposing

The Systems cover the entire disposal chain…

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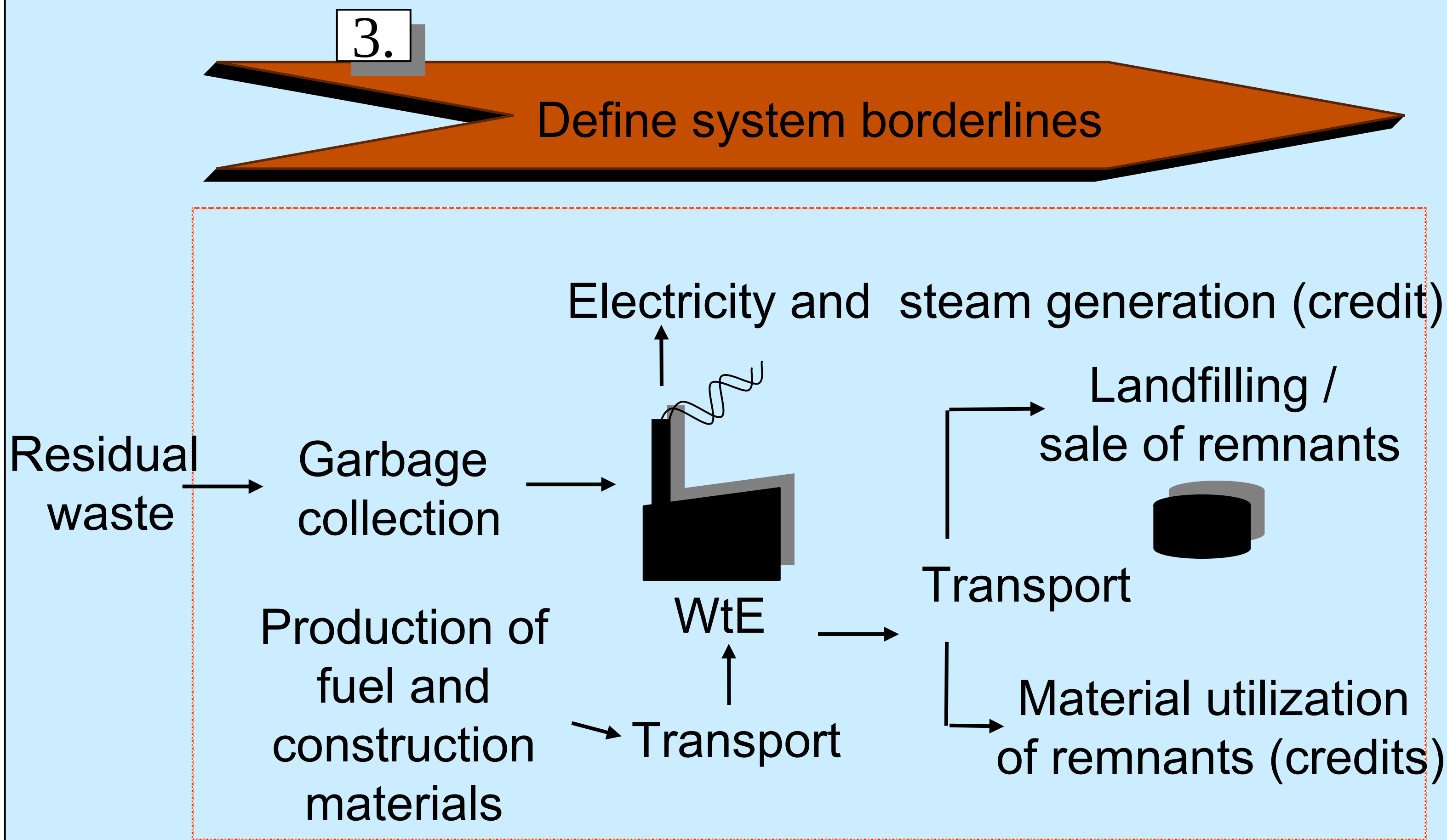
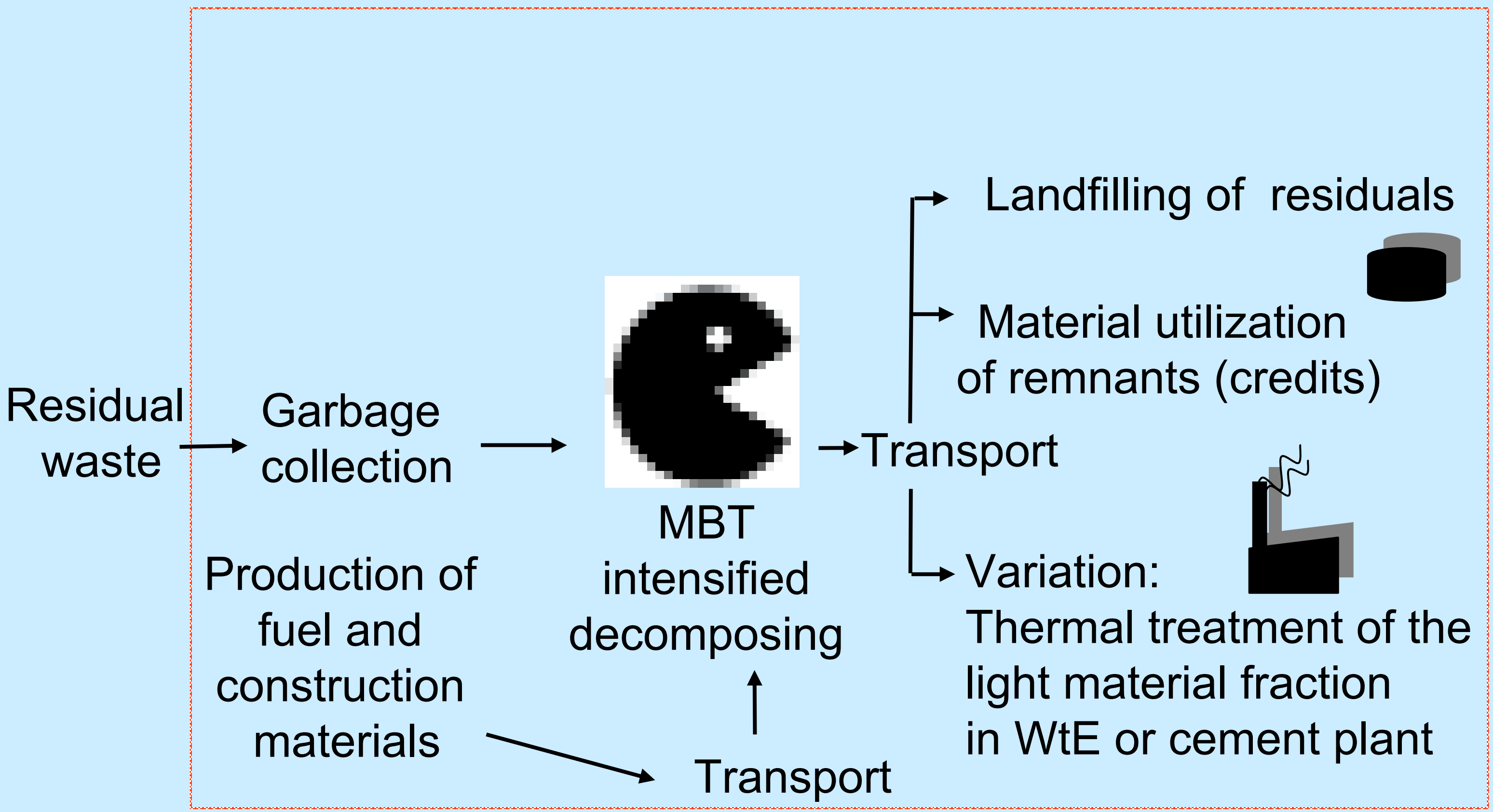


The WtE System

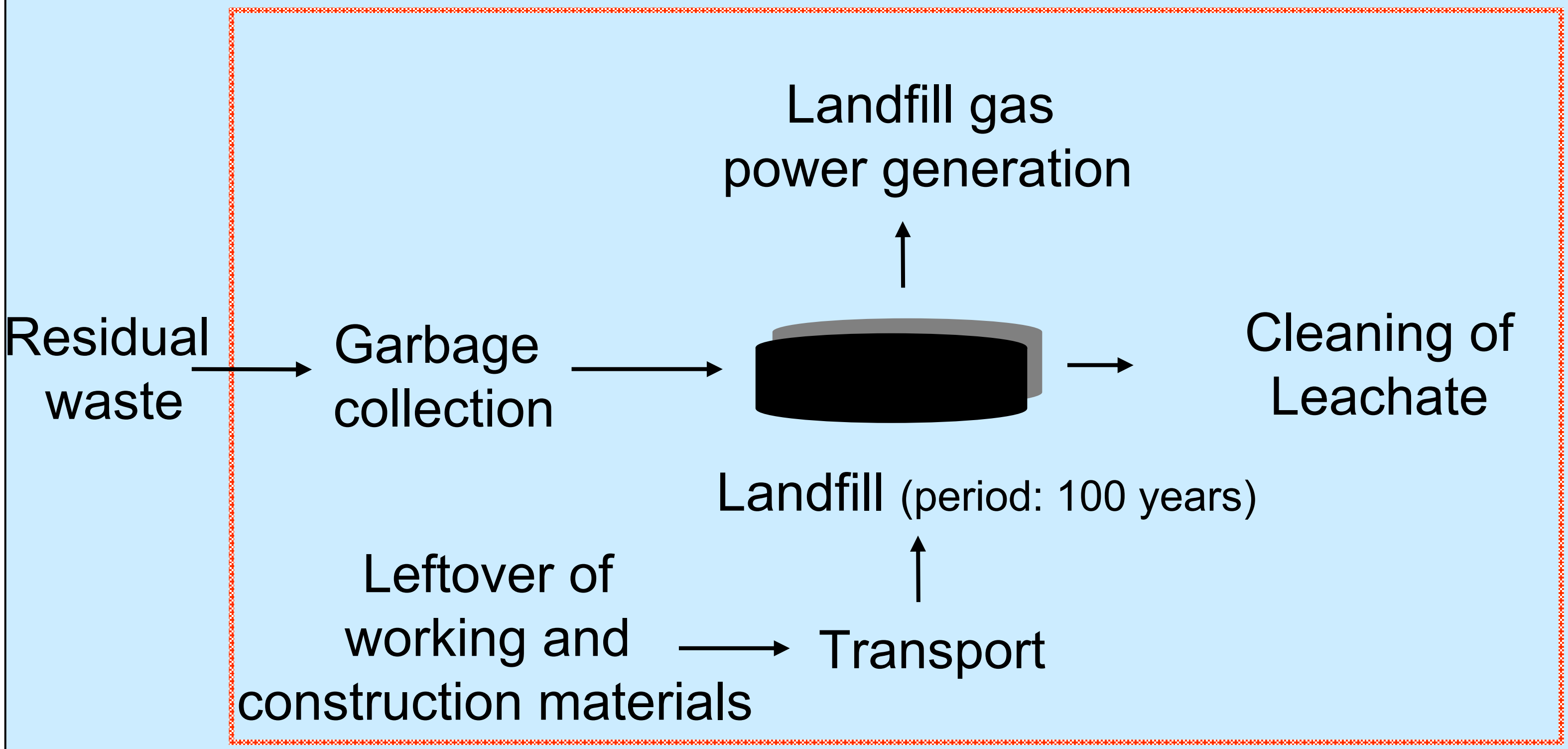
…starting with the collection of the garbage… BASF



The MBT System

…until the moment when all remnants -

are utilized or deposited and no more substantial damage or costs are expected.



The landfill system

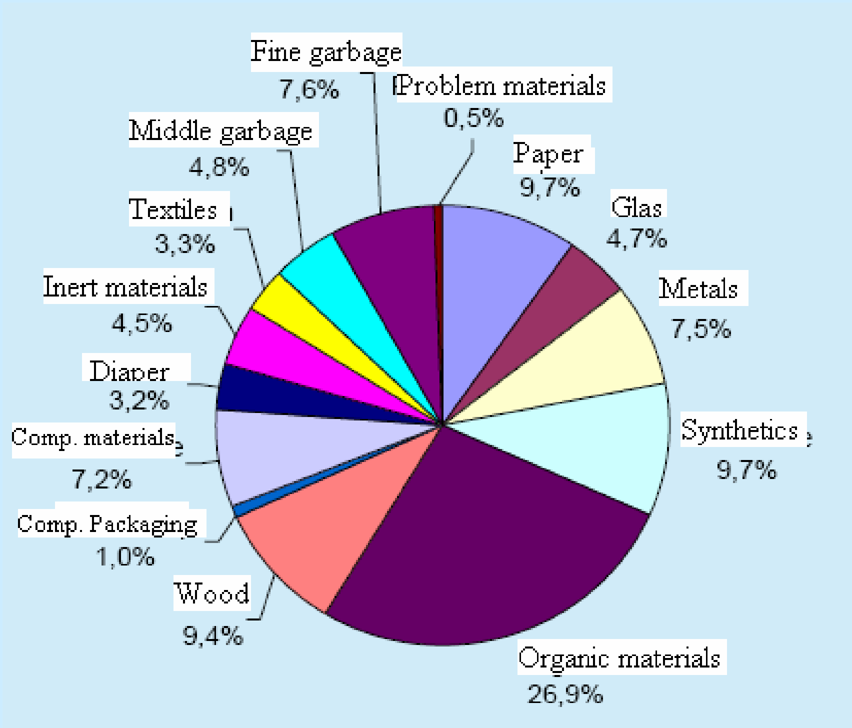
Characteristics of residual waste

Trash fractions

Composition by trash type:

- 60% municipal solid waste
- 30% commercial waste similar to municipal solid waste

Calorific value (H_u): 9,8 MJ/kg



Source: In house calculation using Eco- Institute model, 1998

Assumption WtE* (base case)

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• Facility type	stoker-fired furnace with cogeneration system			
• Yearly performance	320.000 metric tons			
• Dimensions (standardized) value	2 x 21,5 Mg/h throughput with 9,7 MJ/kg refuse calorific			
• Energy generation * *	District heating	Electricity		
max. district heating coupling:	75 MW	0 MW		
max. electricity uncoupling:	0 MW	23,8 MW		
yearly average (base case):	45 MW	4,0 MW		
• Area	6 ha			
• Operating life	20 years			
• Utilization of remnants	Slag		→	Use in road construction
	Boiler dust, Salt mixtures		→	Mine offset
	Flue gas dust (hazardous waste)		→	Mine offset
	Metal, Gypsum, HCl		→	Sale as product

* Calculation of WtE is based on data from the WtE facility Rugenberger Damm (MVR)

Source: MVR, 1999: 21ff.

* * Excluding own power usage: 4,2 MW electricity, 30 t/h steam (22,5 MW)

Most important inputs/outputs WtE

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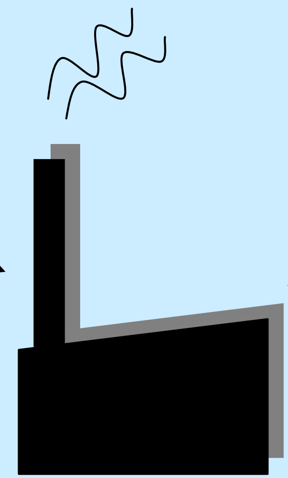
Residual waste	1 t

Working materials (per t refuse)	
Water	469 l
Additional fuel oil (EL) * *	2 kg
Ammonia water (25%)	5 kg
Fired lime	2,1 kg
Lignite cokes	1,4 kg
$CaCl_3$	0,11 kg
$AlCl_3$	0,69 kg
$Na_2S_2O_3$	0,06 kg

Construction materials (per t refuse, 20 a operating life)	
Gravel	7,4 kg
Concrete	21,7 kg
Asphalt	0,6 kg
Steel	3,75 kg
Copper	0,03 kg



WtE

•Amount adjusted to waste input, thus not identical with MVR

* * Bibliographical reference

WtE facilities are usually run without water discharge.

Energy * (per t refuse, minus on-site power)	
Electricity	95 kWh
Steam	1.420 kg

Air emissions	
Exhaust volume	3920 Nm3/t
SO_2	3,50 mg/Nm³
NO_x	80,60 mg/Nm³
C-total	0,50 mg/Nm³
Halogenated hydrocarbons* *	0,09 mg/Nm³
HCl	0,35 mg/Nm³
Cd+Tl	0,0006 mg/Nm³
Hg	0,0004 mg/Nm³
Sb+As+Pb+Cr+Co+ Cu+Mn+Ni+V+Sn	0,0169 mg/Nm³
Dioxin/Furan	0,0001 ng(I-TEQ)/Nm³

Remnants (per t refuse)	
Slag *	220 kg
Ferrous scrap*	46 kg
Non-ferrous metals	2 kg
Boiler dust	7 kg
Flue gas dust	12 kg
Hydrochloric acid (30%)	9 kg
Gypsum	4 kg
Salt mixtures	3 kg

Assumptions MBT (base case)

BASF

• Facility type	intensified decomposing		
• Yearly performance	30.000 metric tons		
• Mechanical level	see above procedure scheme		
• Biological level	encapsulated table window method, decomposition for 16 weeks, waste water free operation		
• Waste air purification	Air scrubber and bio filter		
• Area	2,6 ha		
• Operating life	20 (years)		
• Retention of remnants	Scrap metal	→	Sale as product
	Impurity material	→	Municipal waste landfill
	Light materials	→	Municipal waste landfill (Scenarios: WtE/Concrete facility)
	End product	→	Municipal waste landfill

Source: Wallmann, 1999 a.o.

FLow-Chart MBT

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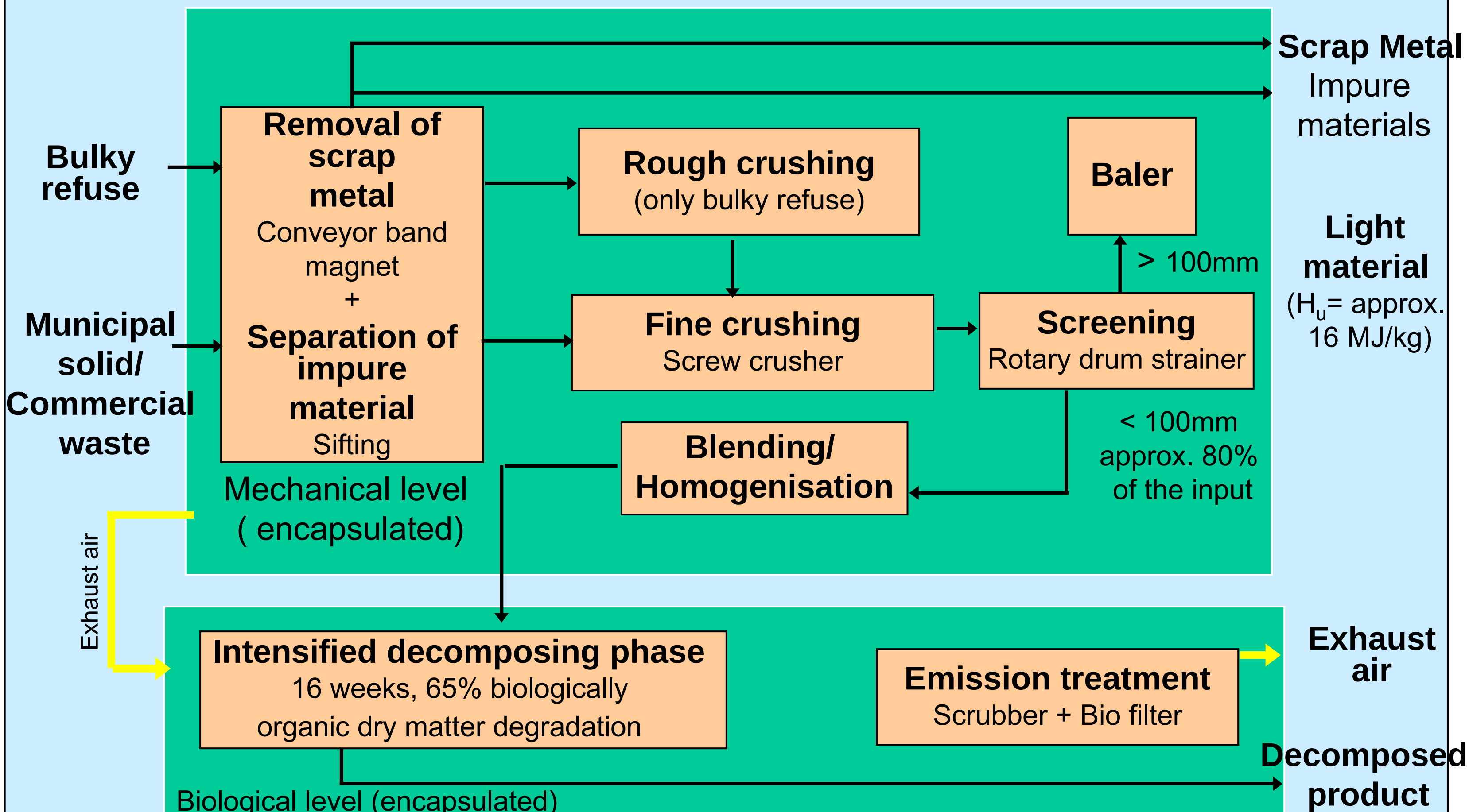


Source: Wallmann, 1999

Most important inputs/outputs MBT

BASF

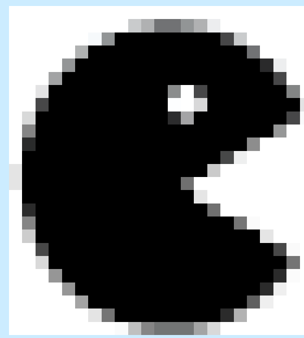
Residual waste	1 t

Fuel (per t refuse)

Water	473 l
Diesel	0,40 kg
Electricity	46 kWh

Construction materials (per t refuse)

Gravel	15,1 kg
Concrete	14,5 kg
Asphalt	4 kg
Steel	2,14 kg
Aluminum	0,02 kg
Rubber	0,02 kg
Polystyrene	0,07 kg
Polypropylene	0,07 kg
Polyethylene	0,02 kg



MBT intensified decomposing

Zero waste waterdischarge

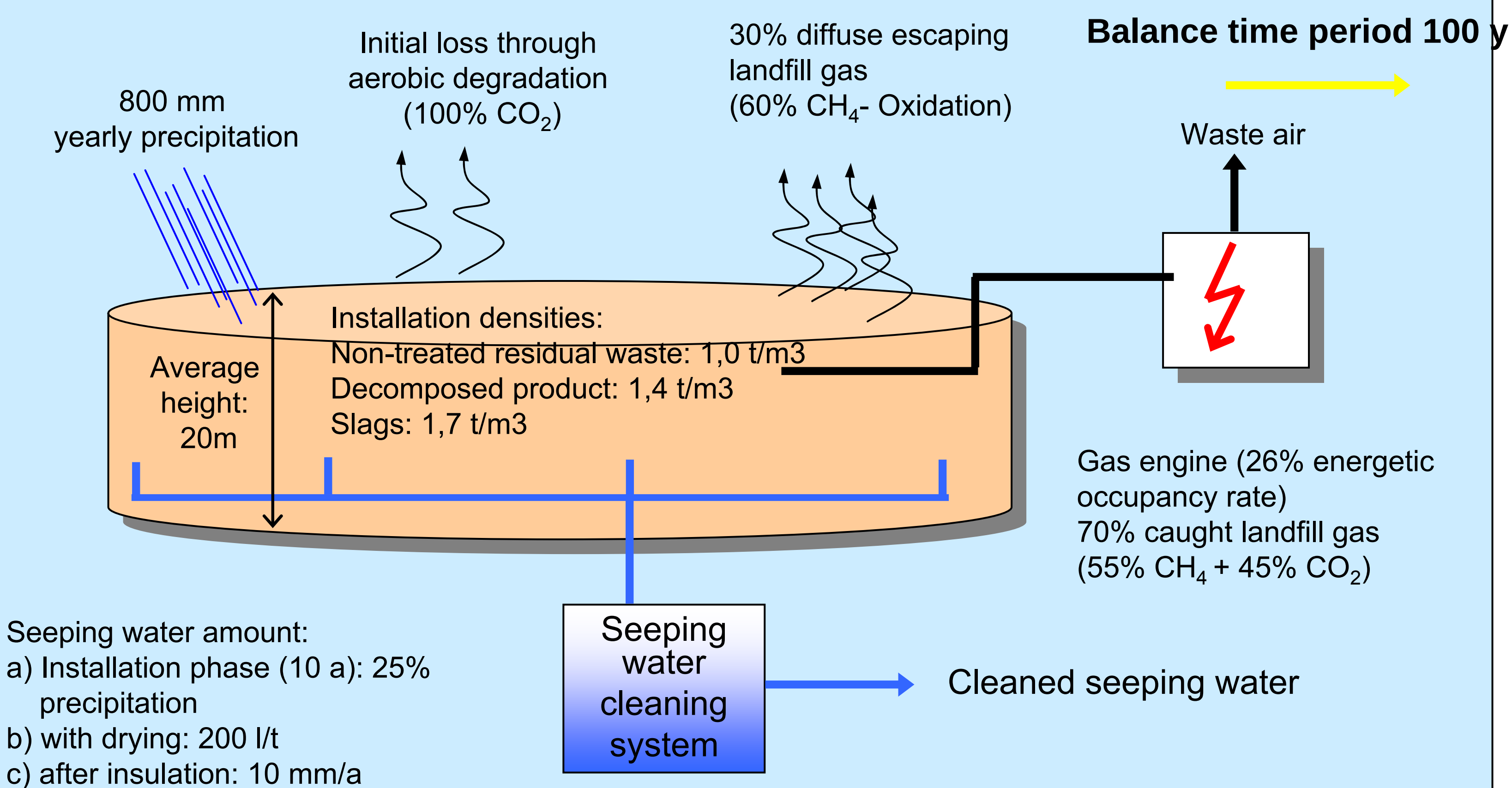
Air emissions

Exhaust volume	~ 21.125 Nm^3
SO_2	0,11 mg/Nm^3
CH_4	0,76 mg/Nm^3
NM-VOCs	4,80 mg/Nm^3
Halogenated hydrocarbons* *	0,07 mg/Nm^3
NH_3	1,18 mg/Nm^3
N_2O	0,51mg/Nm^3
HCl	0,09 mg/Nm^3
Cd+Ti	0,0096 mg/Nm^3
Hg	0,0002 mg/Nm^3
Sb+As+Pb+Cr+Co+ Cu+Mn+Ni+V	0,0023 mg/Nm^3

Remnants (per t refuse)

Decomposed products	530 kg
Ferrous scrap*	46 kg
Light materials	130 kg
Impurity material	46 kg

Assumptions landfill



Source: Schwing, 1999 and others

Most important inputs/outputs landfill

BASF

Residual waste	1 t

Working materials (per t refuse)

Diesel	1 l/t garbage
Electricity	45 Wh/m3 seeking water

Construction materials (per t refuse)

Clay	217 Kg
Sand	108 kg
Gravel	95 Kg
Concrete	3,1 kg
Steel	0,1 kg
Brickwork	13,6 kg
HDPE	0,5 kg
PVC	0,0004 kg
Bituminous Carrying layer	3,1 kg

Landfill

Energy * (per t refuse)

Electricity	137 kWh

Air emissions (per t refuse)

Landfill gas potential	137 Nm3
Initial loss	43 Nm^3
CH_4	8.085.000 mg
SO_x	132.000 mg
No_x	287.000 mg
NM-VOCs	86.100 mg
Halogenated hydrocarbons* *	3.920 mg
HCl	86.100 mg

Emissions from leachate (per t residual waste)

Leachate amount	345l
COD	277.250 mg
BOD5	30.175 mg
N total	93.950 mg
NH4+-N	93.030 mg
P total	1.500 mg
AOX	12 kg
Heavy metals	243 mg
SO_4^{2-}	56.095 mg
Cr	740.560 mg

Assumption costs

Specific treatment costs *	WtE:	250 DM/t (including downstream steps)
	MBT:	69 DM/t (without downstream steps)
		145 DM/t (incl. downstream steps)

Landfilling costs	untreated refuse:	120 DM/t
	pretreated refuse and slag:	60 DM/t
	hazardous refuse (underground):	375 DM/t
Trash collection	140 DM/t	
Transport costs (Truck 40t, 50% fill rate)	0.20 DM/tkm Transport costs plus 23 DM/t Loading costs	

*Glossary:
The specific costs for treatment of the WtE facility equal the real costs of the WtE facility Rugenberger Damm (Hamburg) and cover all costs of associated final transport and treatment steps.
To guarantee a better comparison to the WtE facility the cost balance of the MBT was taken from a bigger plant (>200.000 t/a). The costs do not include the costs from the transport and treatment steps required afterwards. The fixed costs of the WtE as well as the MBT are about 80% of the specific treatment costs. The dependence of the treatment costs on the usage rate of the plant is the same for both disposal methods.
Source: UBA, 1999 and others

Counted credits

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Product	Use	Credit
Electricity	Injection in grid	Substitute of electric current in the German power mix
Steam	District heating	Substitute of steam and natural gas
Scrap metal	Marketing	Substitute of pig iron
WtE-Slag	Use in street construction	Substitute of gravel
Non-ferrous metals	Marketing	Substitute of raw aluminum
Hydrochloric acid	Marketing	Substitute of hydrochloric acid
Gypsum	Marketing	Substitute of natural gypsum
Boiler ash, Mixed Salts	Mine Stabilization	No credit, counted as municipal waste *
Fly-ash	Mine Stabilization	No credit, counted as hazardous waste *
MBT-light fractions	Fuel cement factory	Substitution of coal

* Due to the required costs in mine stabilization no credits for boiler dust, salt mixtures and flue gas dust are calculated. The remnants are counted as refuse.

Data quality

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Subject	Origin	Year	Quality	Validity
WtE	Company data MVR Hamburg	2000	very high	Modern WtE
MBT	Wallmann, 1999 (thesis) and other literature studies	1999	high, partly estimated values	The same kind of intensified decomposing process
Landfill	Schwing, 1999 (thesis) and other literature studies	1999	high, partly estimated values	Landfills of the same kind
Residual waste	Eco-Institute, 1998 and other literature studies	1998	high	Residual waste in general
Construction and Working materials	Boustead program	1999	medium	Germany/ Middle Europe
Refuse collection and transport	BUWAL 250/II and other literature studies	1996	high to medium, partly estimated values	Germany/ Middle Europe
Electricity	BUWAL 250/II and other literature studies	1996	high, mean value from company data	Germany
Costs	UBA, 1999 and other literature studies	1998	high to medium	Germany

Data quality:
very high: firsthand, e.g. company data (measured)
high: studies and qualified literature
medium: qualified estimated values, e.g. company data (estimated values), estimations of experts

Results

The Eco-efficiency portfolio combines costs with environmental impact.

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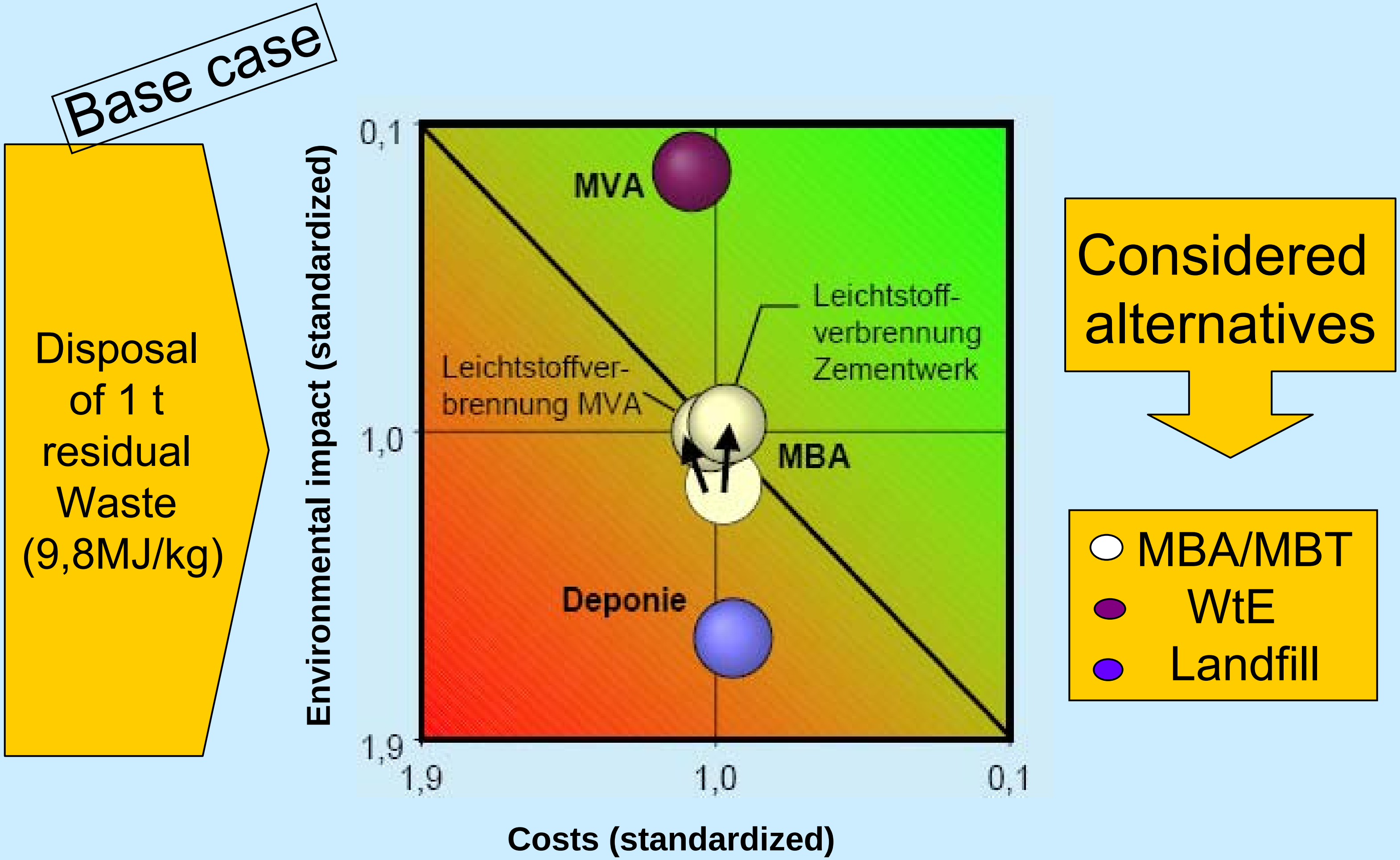


Leichtstoffverbrennung MVA= Incineration of light materials in the WTE
Leichtstoffverbrennung Zementwerk = Incineration of the light materials in cement facility

Commentary for the Eco-efficiency portfolio 1

- The pretreatment of residual waste demonstrates a significant ecological improvement in comparison to conventional landfilling
- The cost difference between the three chosen disposal variants are not important compared to the ecological differences

Commentary for the Eco-efficiency portfolio 2 BASF

- Waste-to-Energy is the most expensive, but by far the most eco-efficient way for residual waste disposal

- The Eco-efficiency of Mechanical Biological Treatment reaches a middle rank compared to Waste-to-Energy and Landfilling

The main cost and origin of environmental pollution are identified.

COST FACTOR

- Waste collection
- Facility operation (fixed cost)
- Additional transport and Landfilling of remnants of MBT process

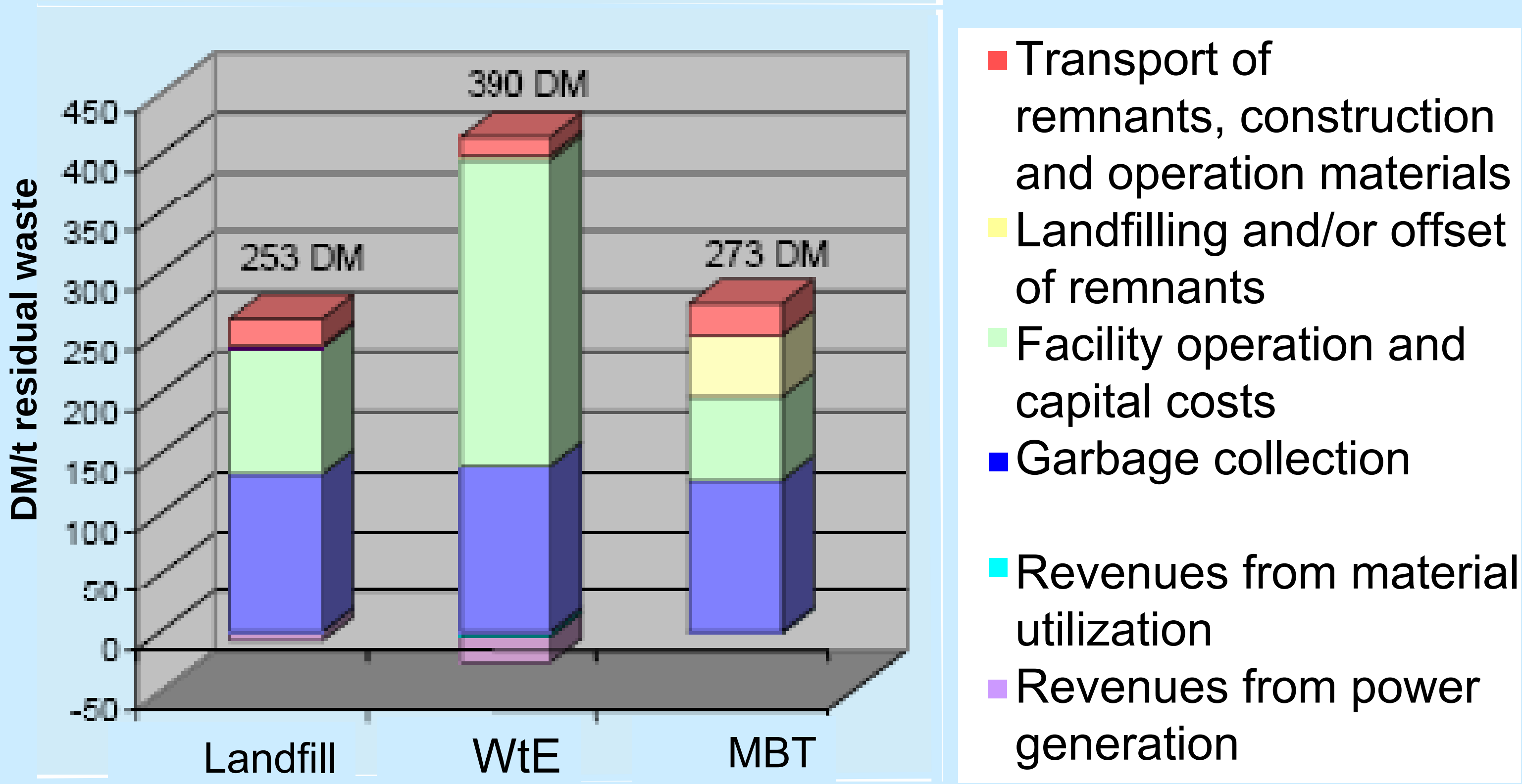
POLLUTION ORIGIN

- Amount of non-usable remnants that have to be landfilled
- Un-used energy contained in residual waste
- Direct air polluting emissions

Discussion/Analysis of the individual results

Total Cost

Garbage collection and facility operations represent the highest costs of the disposal chain. The obtained profits from the sale of the energy (2 cents per kW) and materials recovered/produced have only a limited impact.



Direct landfilling of residual waste is less expensive than pretreatment.

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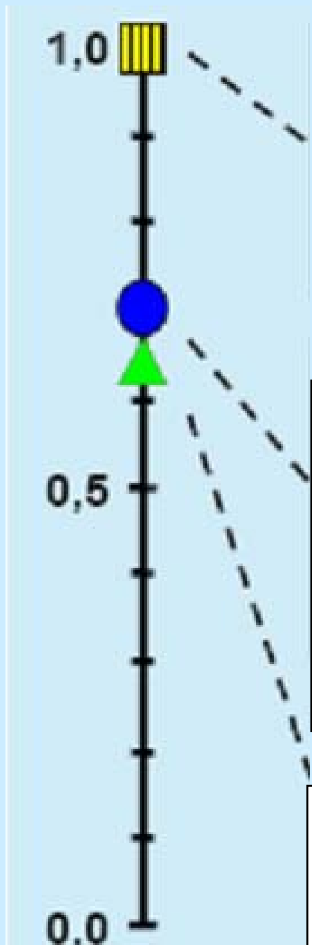


WtE

- WtE has the highest disposal costs due to the extensive technical operation (high investment costs).
- Revenues from the sale of energy and materials are limited.

MBT

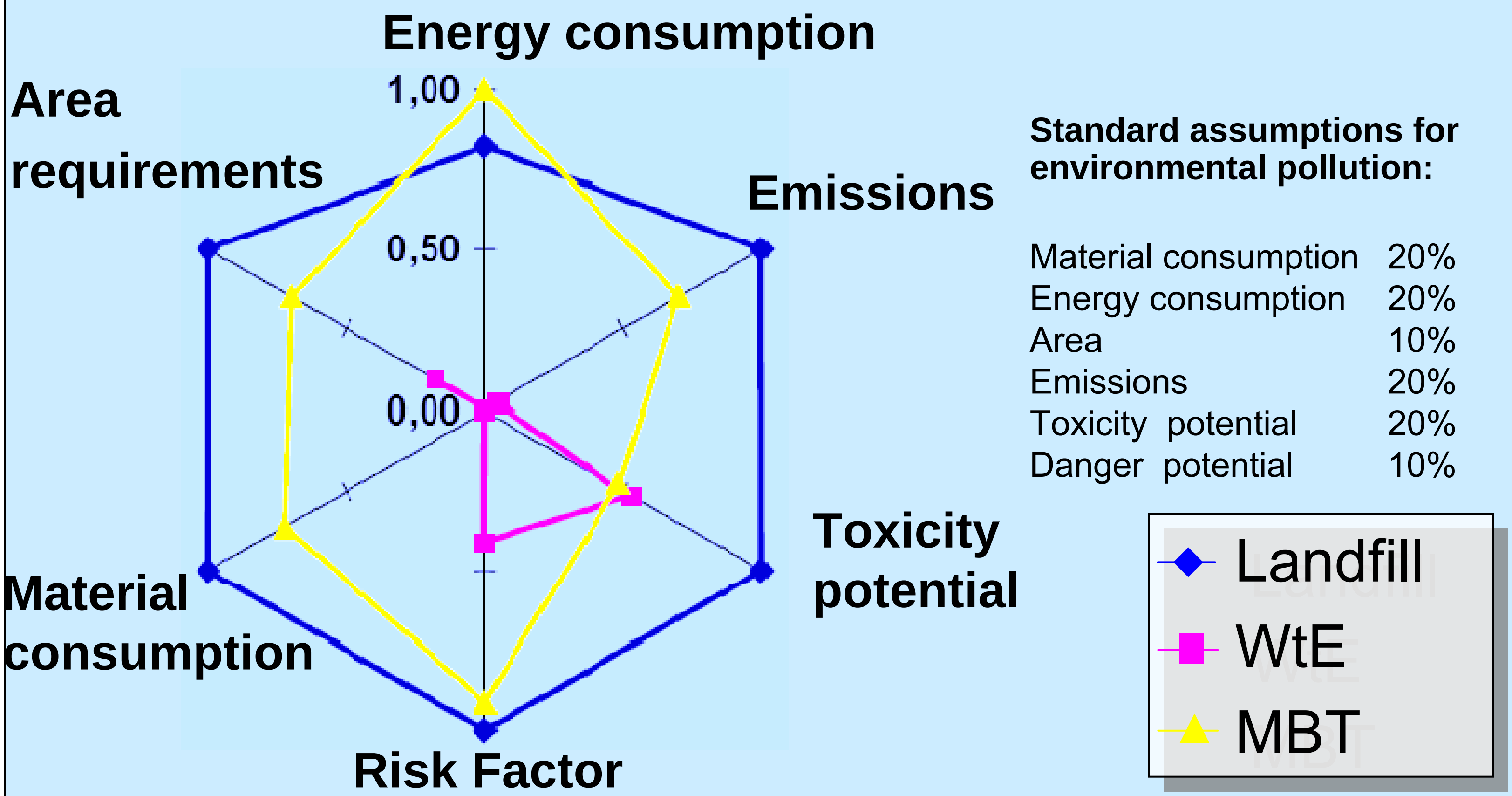
- The direct treatment costs of MBT are comparatively low (relatively low investment costs).
- The huge amount of remnants (end-product, disruptive or light materials) cause relatively high costs for the consecutive transport and landfilling.

Landfill

- The direct landfilling of non-treated residual waste occasion in general the lowest disposal costs.

Ecological fingerprint

Worst alternative = 1; all others are rated in correalation



Standard assumptions for environmental pollution:

Material consumption	20%
Energy consumption	20%
Area	10%
Emissions	20%
Toxicity potential	20%
Danger potential	10%

Commentary to the ecological fingerprint

BASF

- Recovered energy from WtE in form of electricity and district heating as well as the recovered end-products replace other environmental damaging production processes. As a result **WtE saves a lot of resources, energy and emissions** compared to the alternative options.
- The results show that **MBT is the better solution to landfilling**. The energy balance however of the landfill is favorable to MBT if the methane is recovered as energy.
- Over a longer period of time (100 years) the area used for landfilling has a much bigger impact on the land than the treatment facilities. The WtE facility of Hamburg scores well, since almost no remnants occur.
- The toxicity potential includes the Human- and Eco-toxicity of the air and water emissions from waste pre-treatment, landfilling and the use of slag in road construction.
- When calculating the risk factor, accidental risks, hygienic risks, noise emissions and drifts (aesthetic damage to the landscape caused by paper and plastic litter) have been taken into account.

Primary energy consumption

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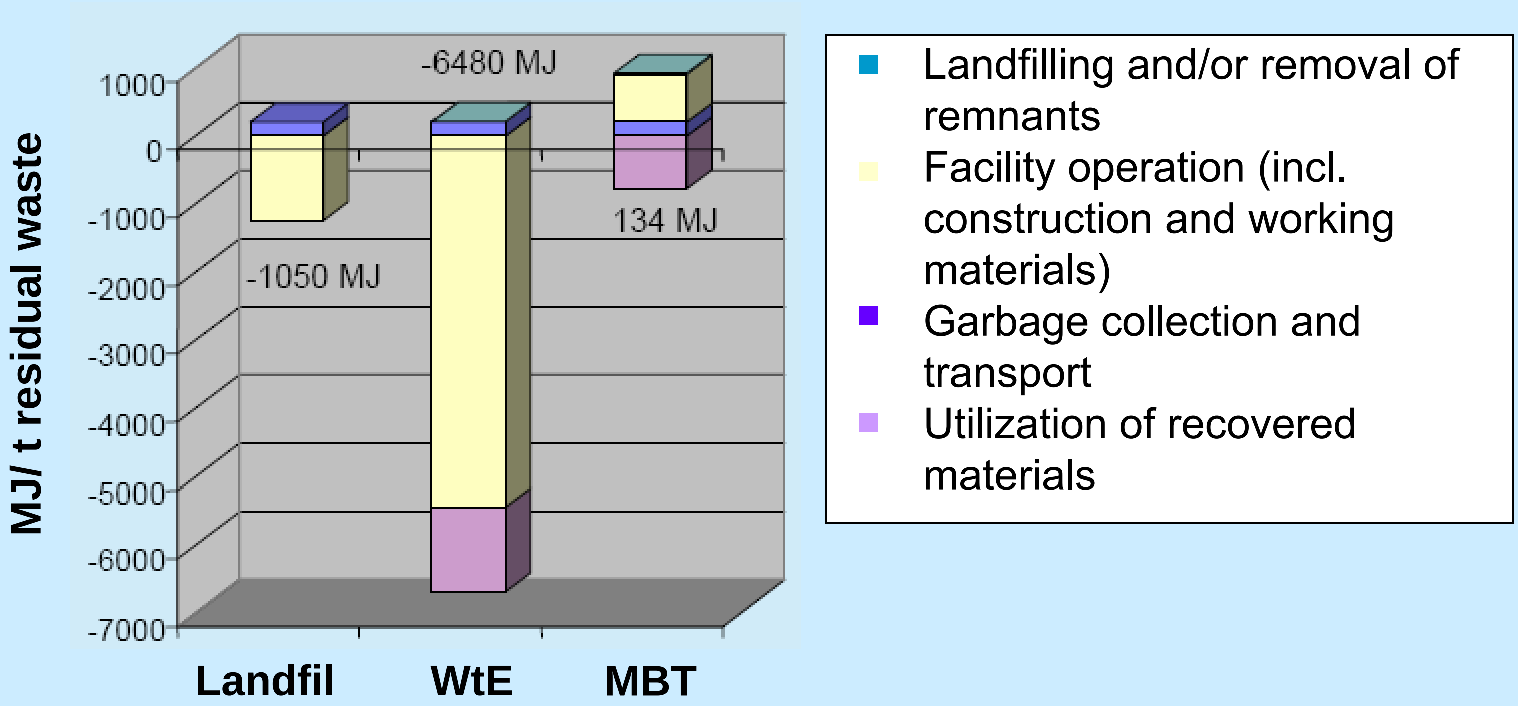
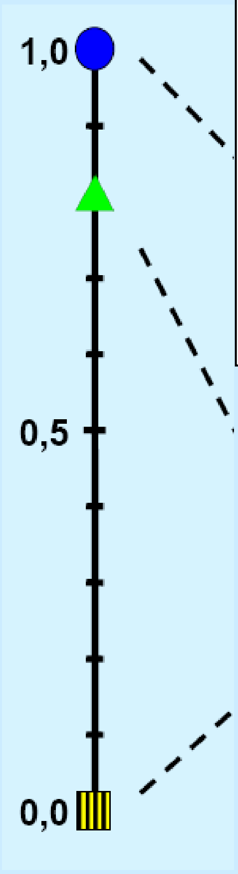
The use of the energy content of garbage is determining the energy balance. In contrast the energy needed for garbage collection and transport carry almost no weight.



WtE saves primary energy



MBT

- MBT has the most unfavorable energy balance, because there is no utilization of the energy contained in the residual waste compared to the other disposal alternatives.
- The recovery and utilization of scrap metal compensates for the vast amount of energy necessary for the production of raw iron.

Landfill

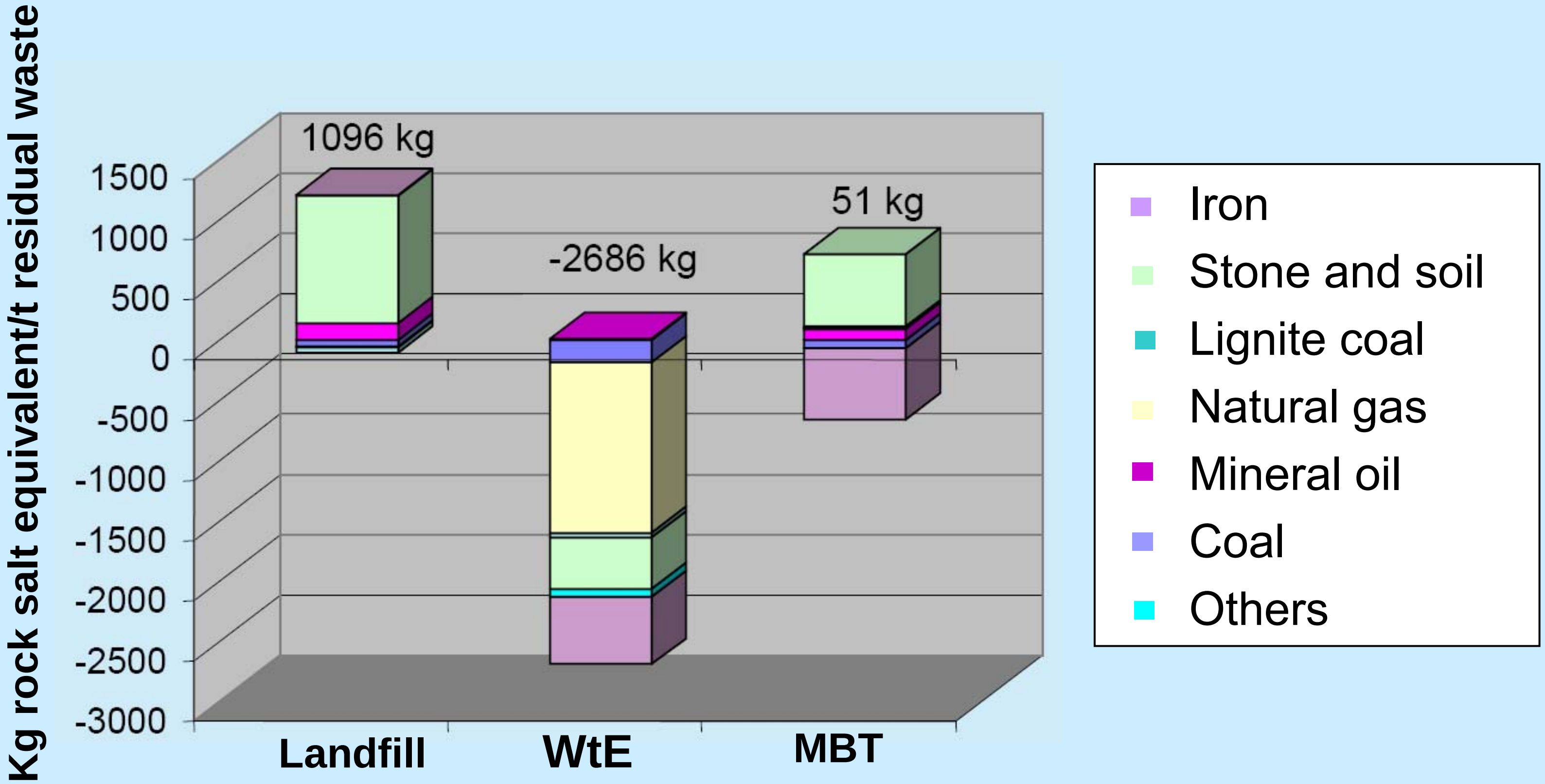
- Energetically, landfilling performed slightly better than MBT because of the utilization of the landfill gas (methane).

WtE

- The net saved primary energy which is caused by the efficient energy use and the material recovery and utilization reaches with app. 6500 MJ/t residual waste about two third of the waste's calorific value.

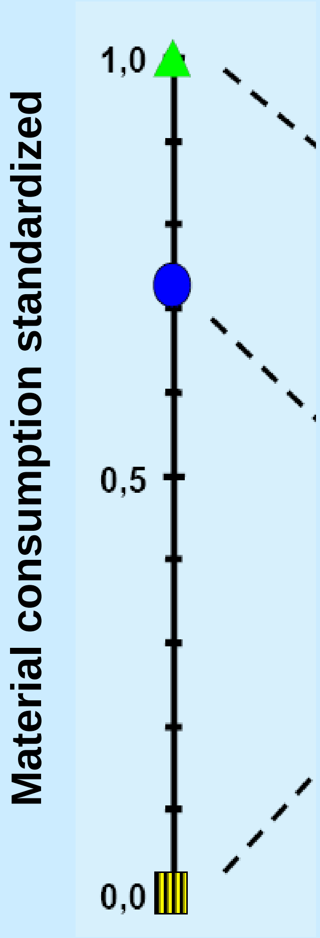
Material use*

The choice of the disposal route affects the conservation/protection of mineral resources and iron. Non renewable fossil fuels can also be substituted by the utilization of the waste's calorific value of the WtE.



*The individual raw materials are rated according to their reserve capacity.

Landfilling causes the biggest resource consumption.



Landfill

- The construction of the landfill consumes the highest amount of natural non-renewable resources, especially for the landfill liners and covers (sealants)

MBT

- The MBT has a huge consumption of stones and soil because of the big amounts of the remnants which have to be landfilled.
- The material balance is steadied by the recovery and utilization of iron scrap.

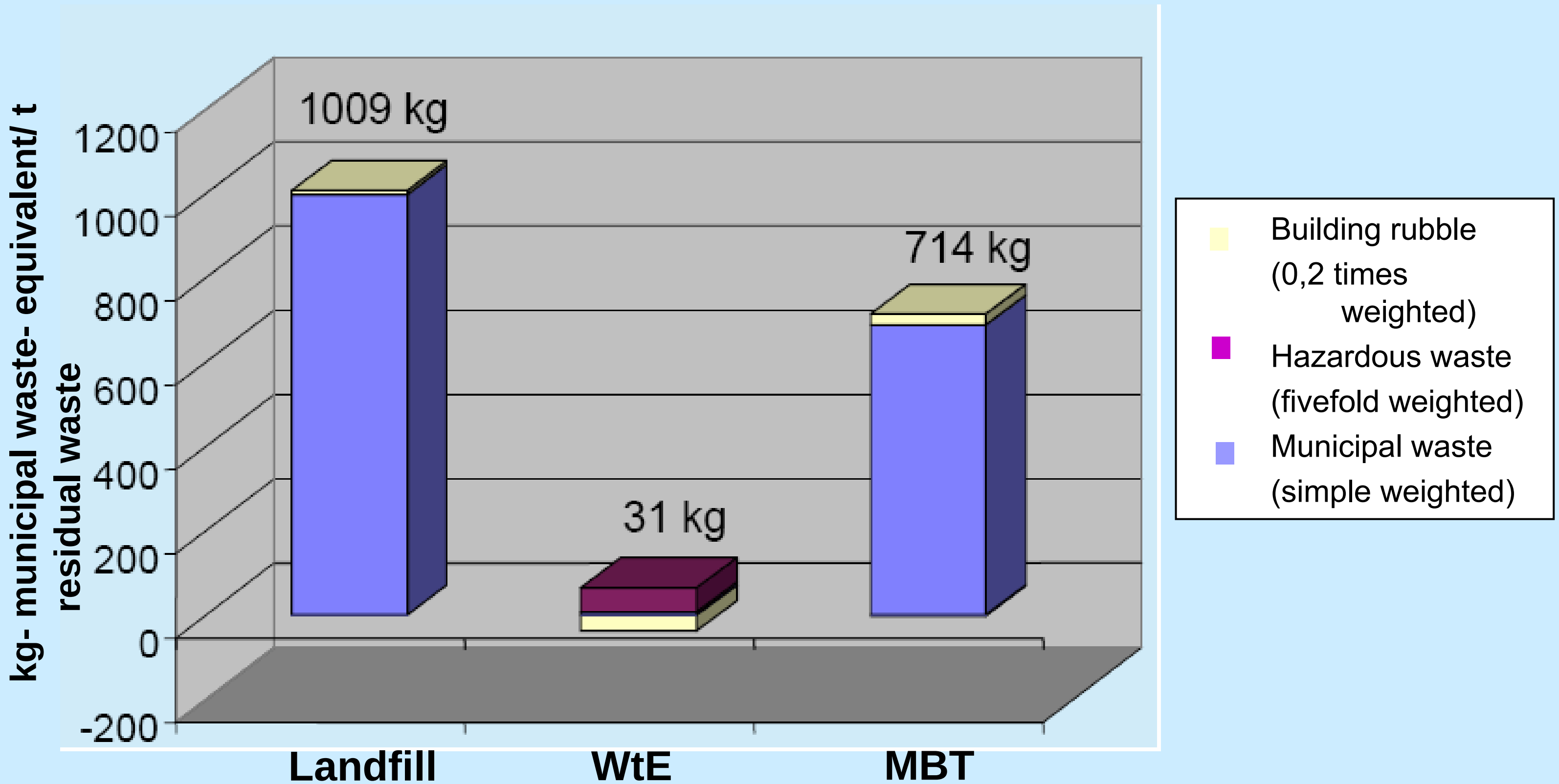
WtE

- The generated steam from the facility substitutes the produced steam from natural gas.
- The iron and mineral resources are gone easy on through the material use.

Landfill waste*

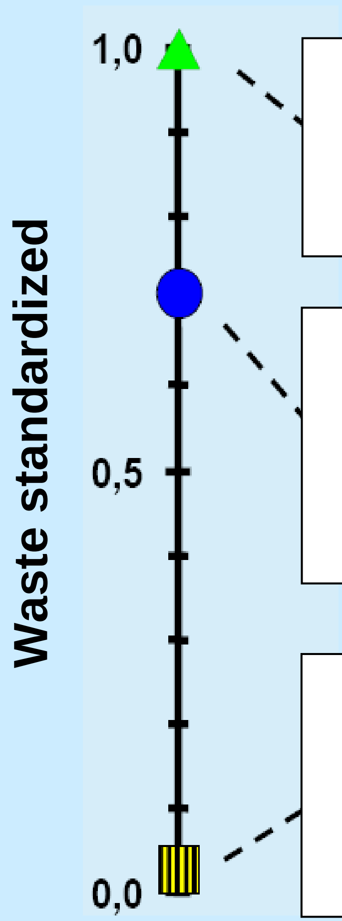
BASF

From the original ton of residual waste different amounts of garbage have to be landfilled.



*weighted (see legend)

Only WtE is able to reduce the residual waste that has to be landfilled significantly.



Landfill

- All residual waste is being dumped.
- The allocation of construction materials causes additional mineral garbage

MBT

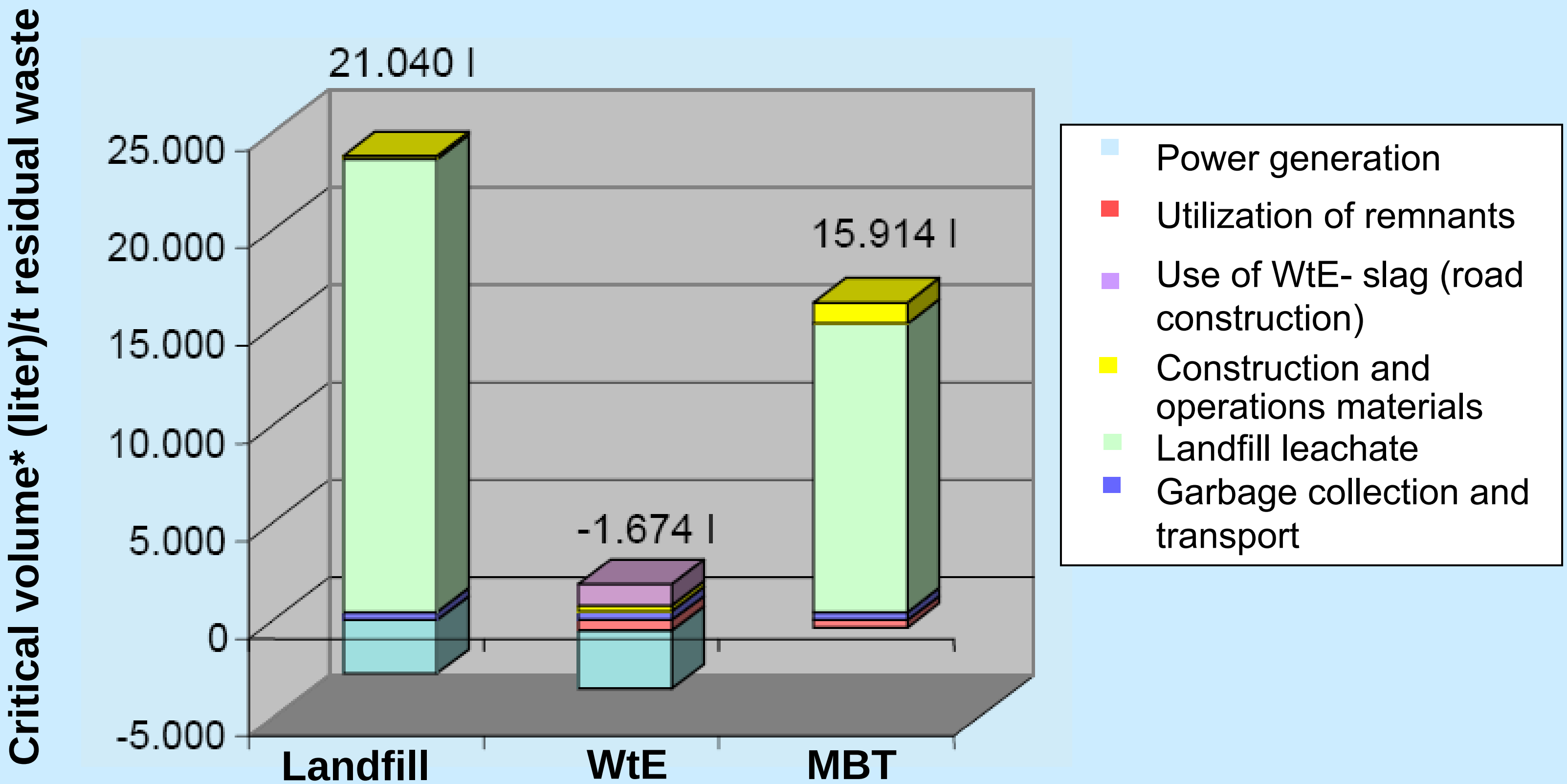
- In spite of intensive pretreatments about two third (690 kg) of the residual waste remains for Landfilling.
- Furthermore building rubble is produced when needed electricity and construction materials are allocated.

WtE

- The residual waste can be reduced to a minimum by combustion and utilization of slag.
- But WtE is the only process that produces 12 kg hazardous waste (fly and boiler ash).

Emissions resulting from sewage/leachate BASF

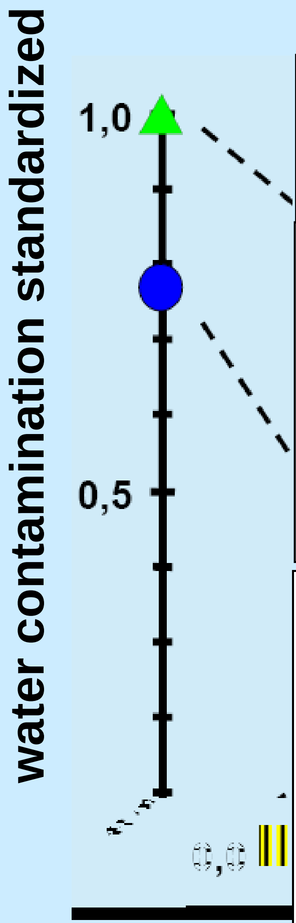
The leachate from landfills causes the main water/groundwater pollution. However, credits from the generation of electricity have advantages for the sewage/leachate balance.



*The critical volume indicates the theoretical amount of water, which would be polluted until the individual pollutants reach their legal limits (method: see appendix).

Landfilling is at a major disadvantage in regards to water contamination

BASF



Landfill

- The landfilling of the untreated residual waste causes the worst water contamination.

MBT

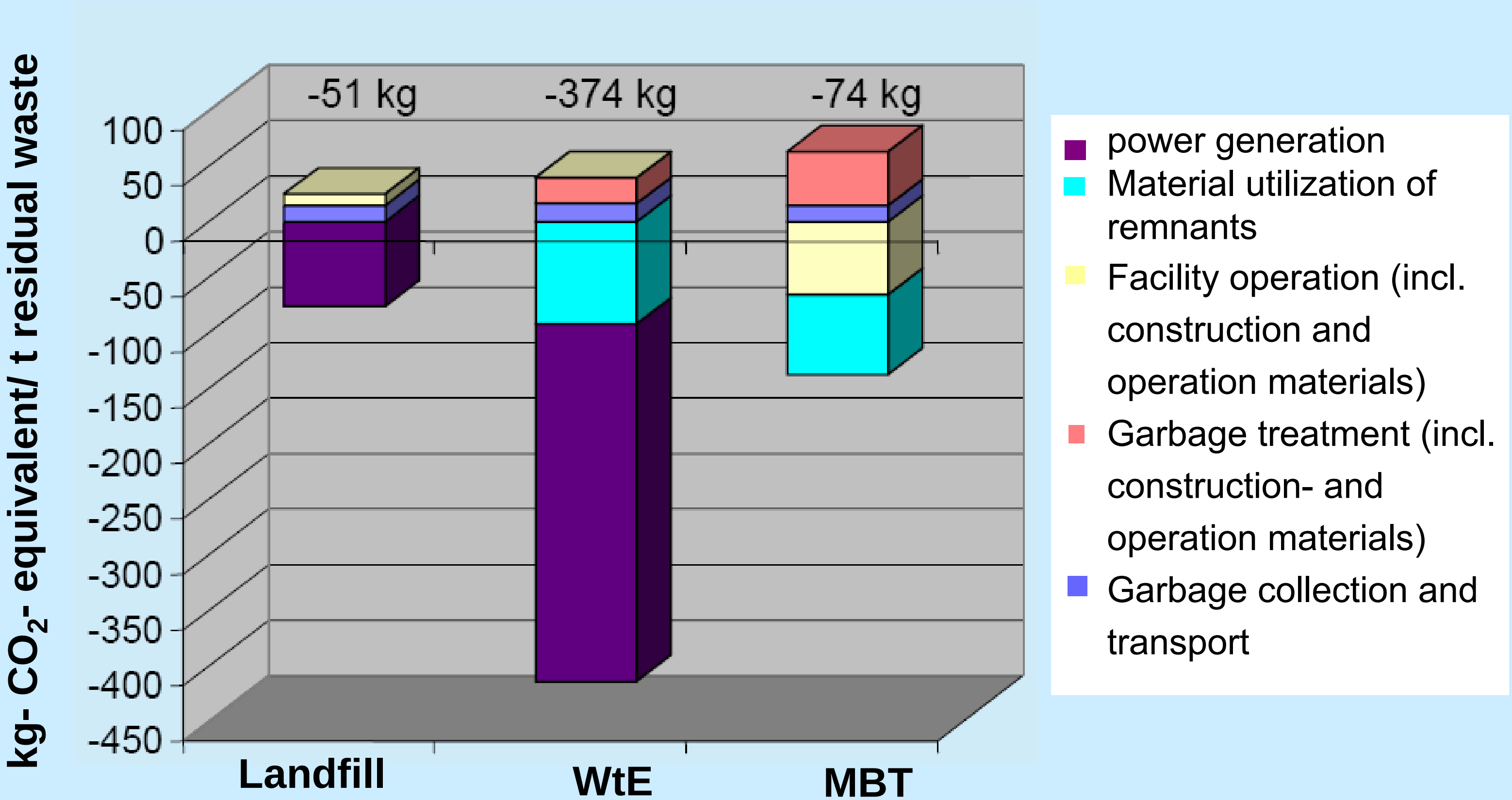
- Just like WtE, MBT causes no direct water contamination, since the generated waste wateris used for internal systems.
- The leachate emission from the sedimentation of the decomposed product as well as of the impure and light materials are still significant.

WtE

- WTE receives power generation credits from avoided water contamination.
- The weak-point is the bottom ash . However, proper/correct placement in road construction and the high pH-balance result in minimal water exposure and prohibit the leakage of heavy metals.

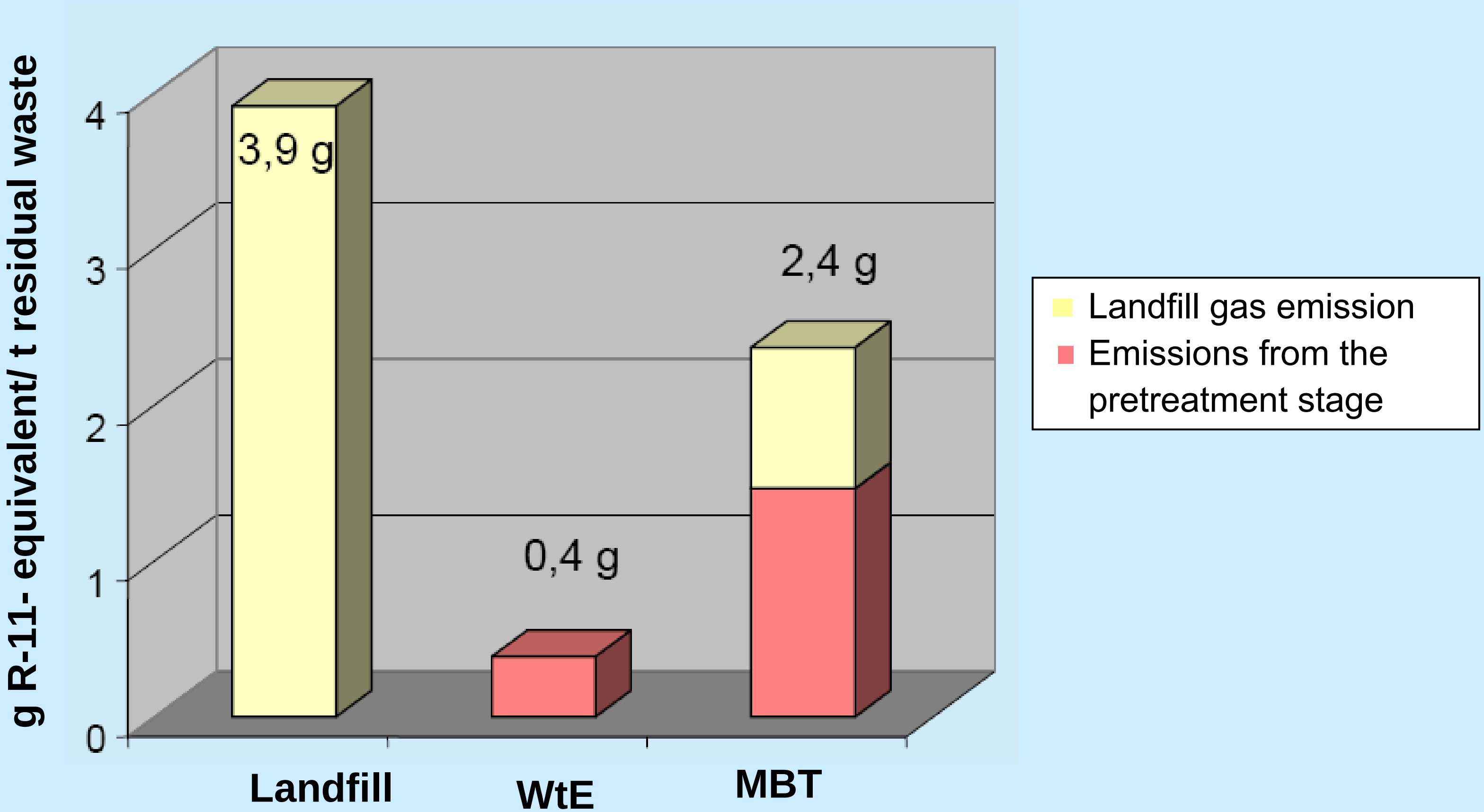
Greenhouse effect

The higher the production and utilization of energy and end products the higher the environmental relevance.



Ozone Destruction Potential

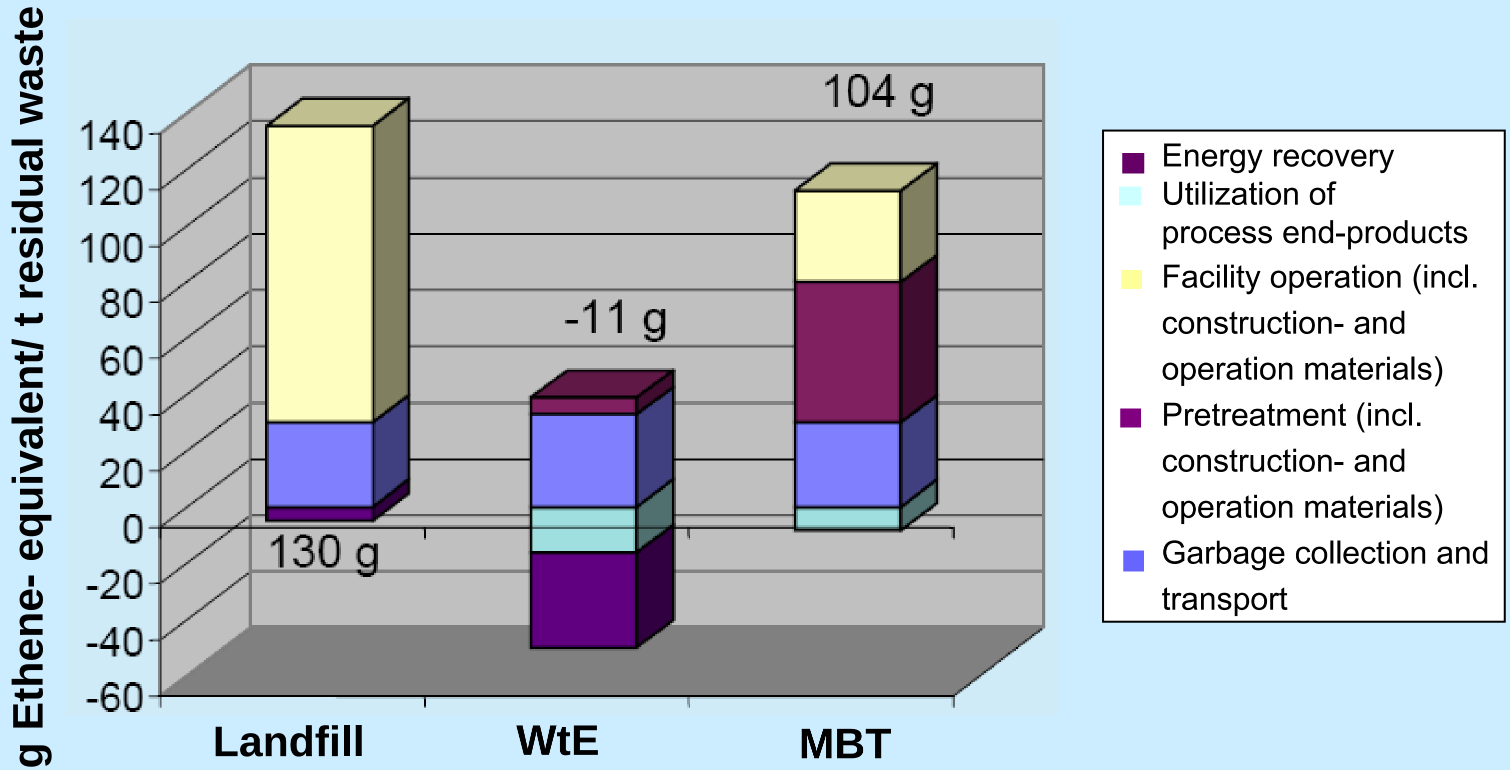
More halogenated hydrocarbons are emitted through the biological decomposing processes in landfills and MBT than through waste incineration. Compared to landfilling large amounts of emissions are released during the pretreatment stage.



Photochemical ozone creation potential

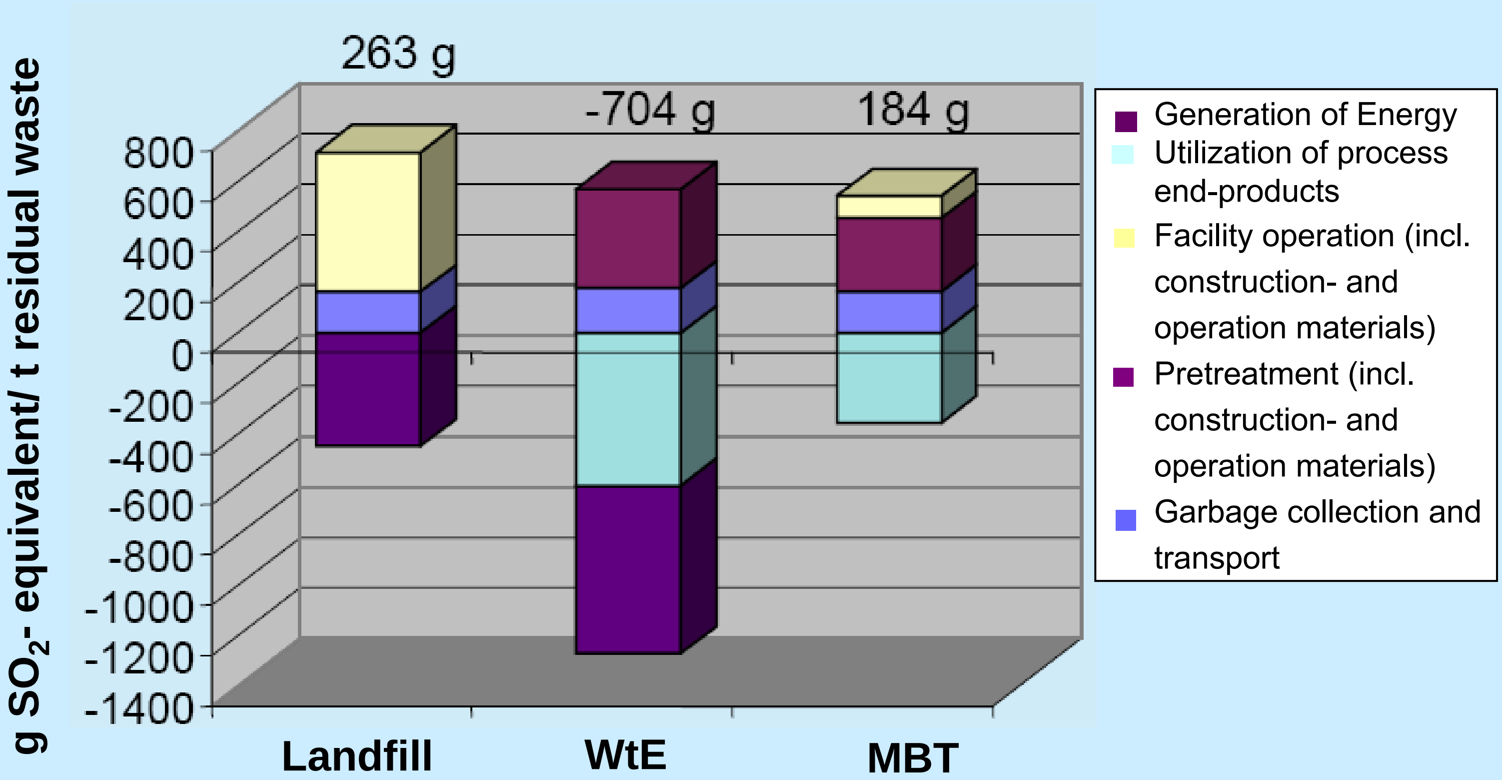
BASF

Methane and other volatile organic compounds are released through the biological decomposition of waste in MBT and landfilling and contribute to summer smog. In addition, truck-traffic contributes significantly to the destruction of the ozone layer.



Acidification potential

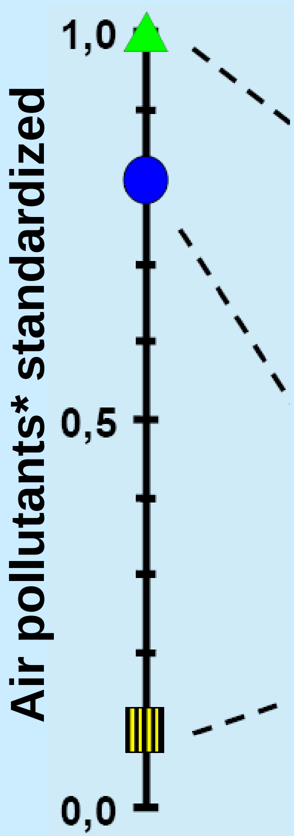
Key for the acidification potential are the credits for the production of energy and usable end-products.



The evaluation of the emissions/air pollution

BASF

shows that WtE is the best performer.



Landfill

- The Landfilling of the untreated residual waste causes the worst pollution concerning all four tested effect categories for air pollutants*.

MBT

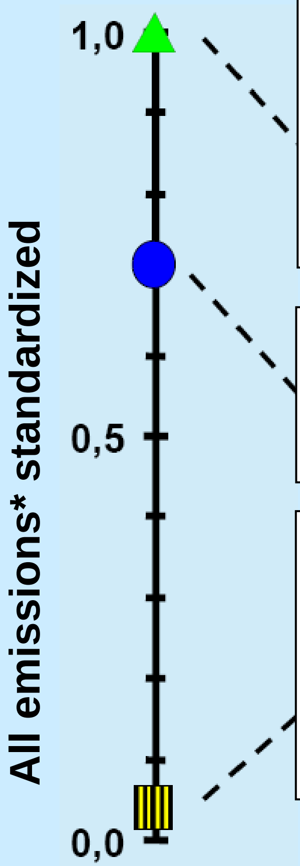
- The landfill gas potential is highly reduced by the mechanical-biological pre-treatment of waste.
- The utilization of only standard emission treatment through bio-filter and air-purifier result in a higher emission potential of the MBT facility.

WtE

- Due to the strict limits of the 17th Clean Air Act the emissions are significantly lower.
- The production of energy and usable end-products result in additional reductions of emissions.

*Greenhouse potential, Ozone destruction potential, photochemical ozone creation potential, Acidification potential

The garbage shows the biggest effect in the evaluation of all emissions.



Landfill

- In regards to the three categories emissions, water pollution and waste landfilling is always the worst alternative. Thus landfilling shows also as the worst alternative in the overall evaluation of emissions.

MBT

- The limited reduction of the waste is reflected in the overall evaluation of emissions – still high.

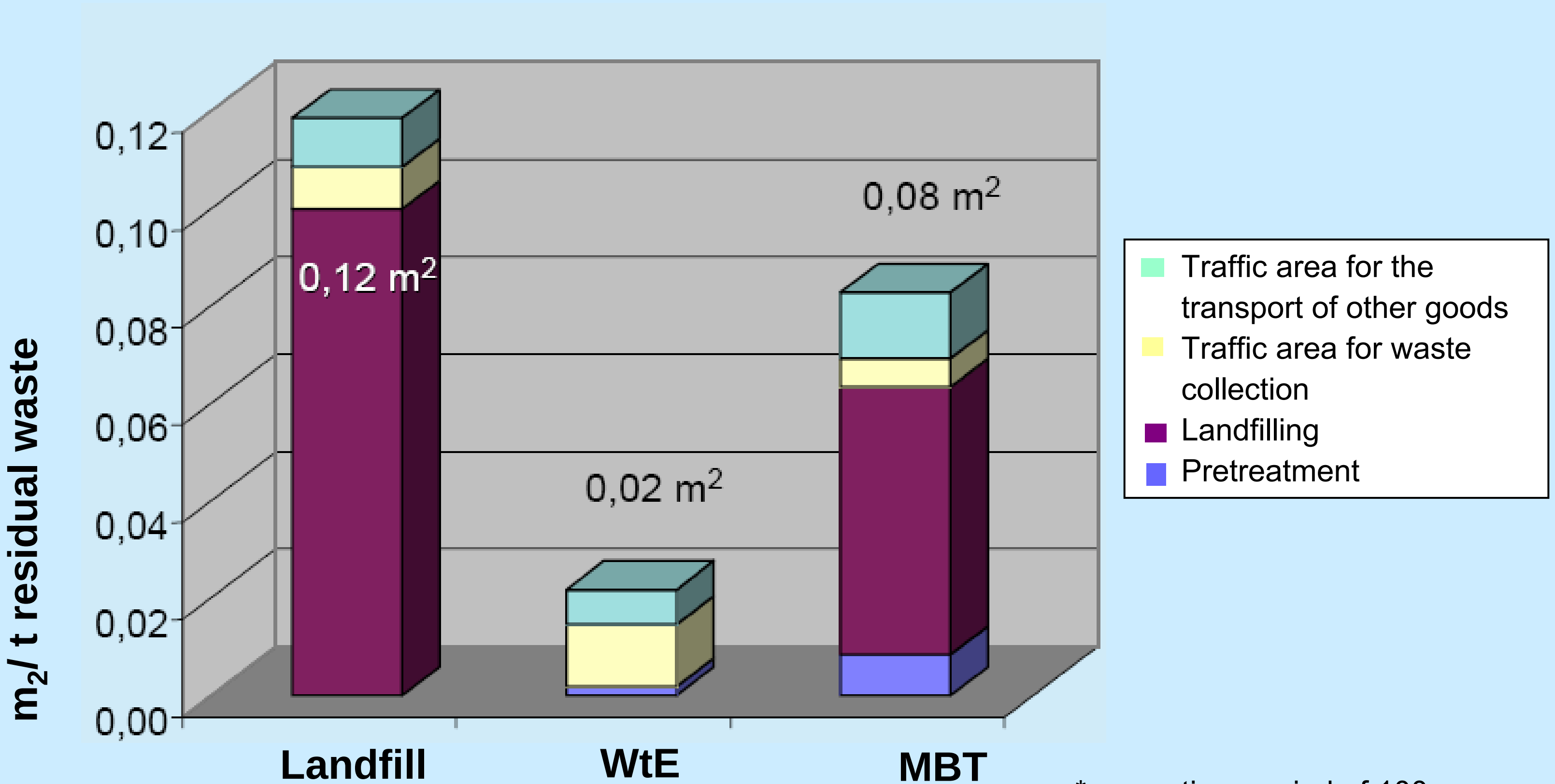
WtE

- Waste incineration significantly reduces the volume of the waste.
- Emissions and water contamination are offset by the credits for energy and usable end products.

*Pollution (8%), waste water(2%) and Garbage (90%)

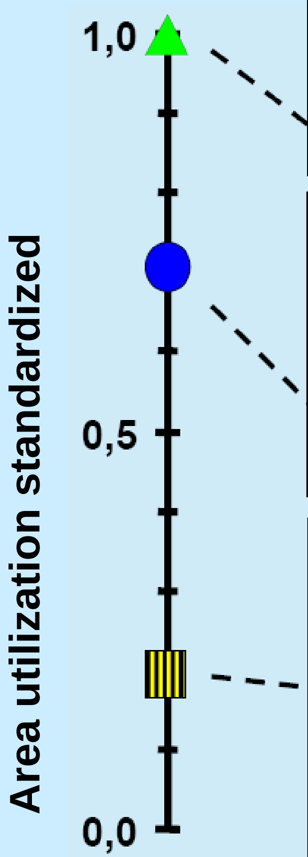
Area requirements*

In general, most relevant for the area requirements is the waste which has to be dumped. This area can not be used for a very long period of time.
Important is also the area required for the necessary transport of materials.
On the other hand the area for pretreatment is minimal.



*over a time period of 100 years

MBT requires about four times the space of incineration.



Landfill

- For every ton of untreated residual waste a landfill area of 0,1 m^2 is needed and a traffic area of 0,02 m^2.
- The total area requirements are the highest with 0,12m^2/t residual waste .

MBT

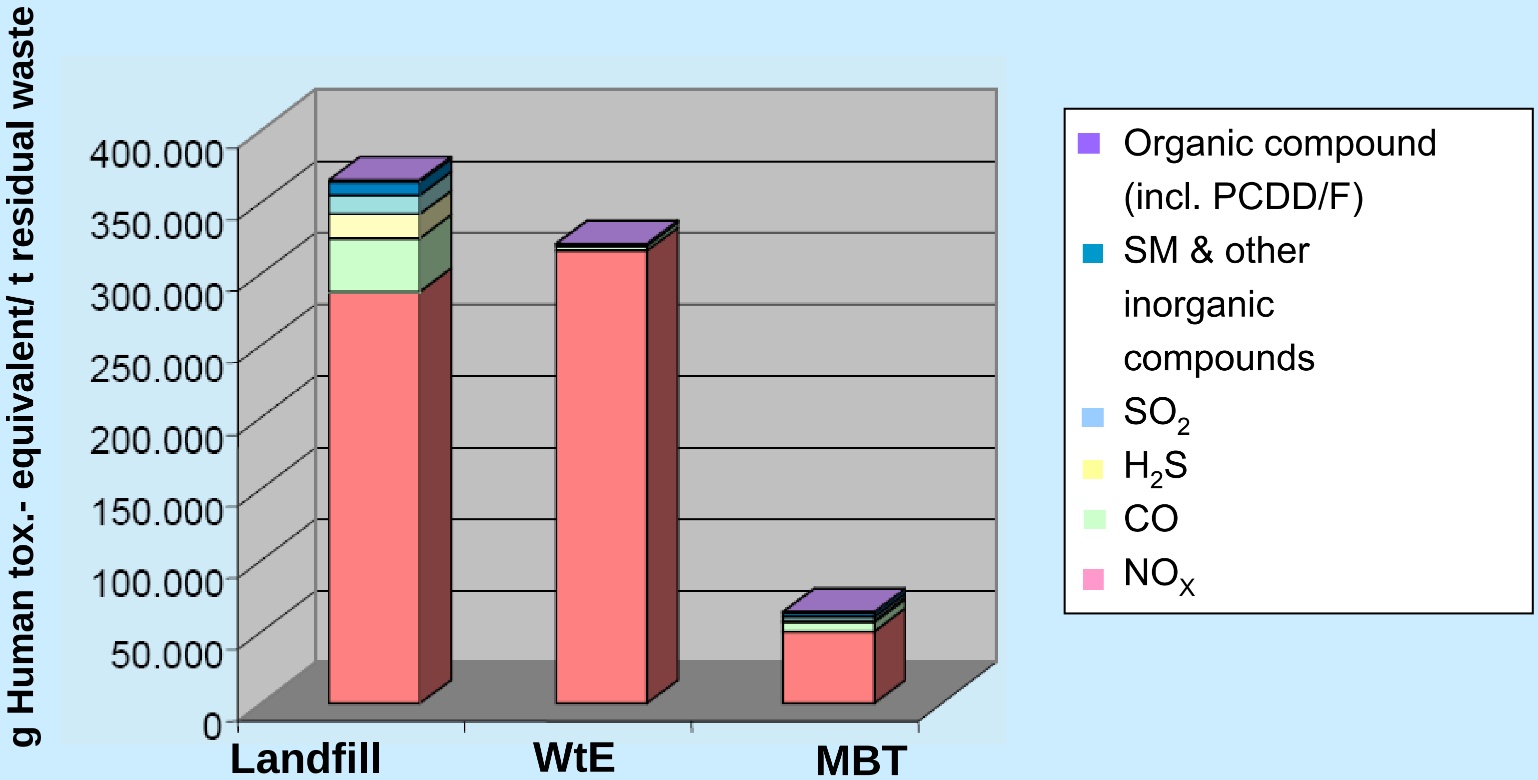
- The large amounts of process remnants (total of 690kg) require a significant amount of space. Despite compressed disposal the decomposed product itself requires about 0,04 m2 landfill space.
- The area requirements for the MBT facility itself is higher than that of the WtE facility.

WtE

- The area requirements of WtE are influenced by the road transports which amount to 0,02m2/t residual waste.
- There is no need for surface area landfilling as the few to be landfilled remnants are utilized in salt mines.
- Due to the high waste throughput area requirements per ton are relatively small.

Human toxicity potential - Pollution

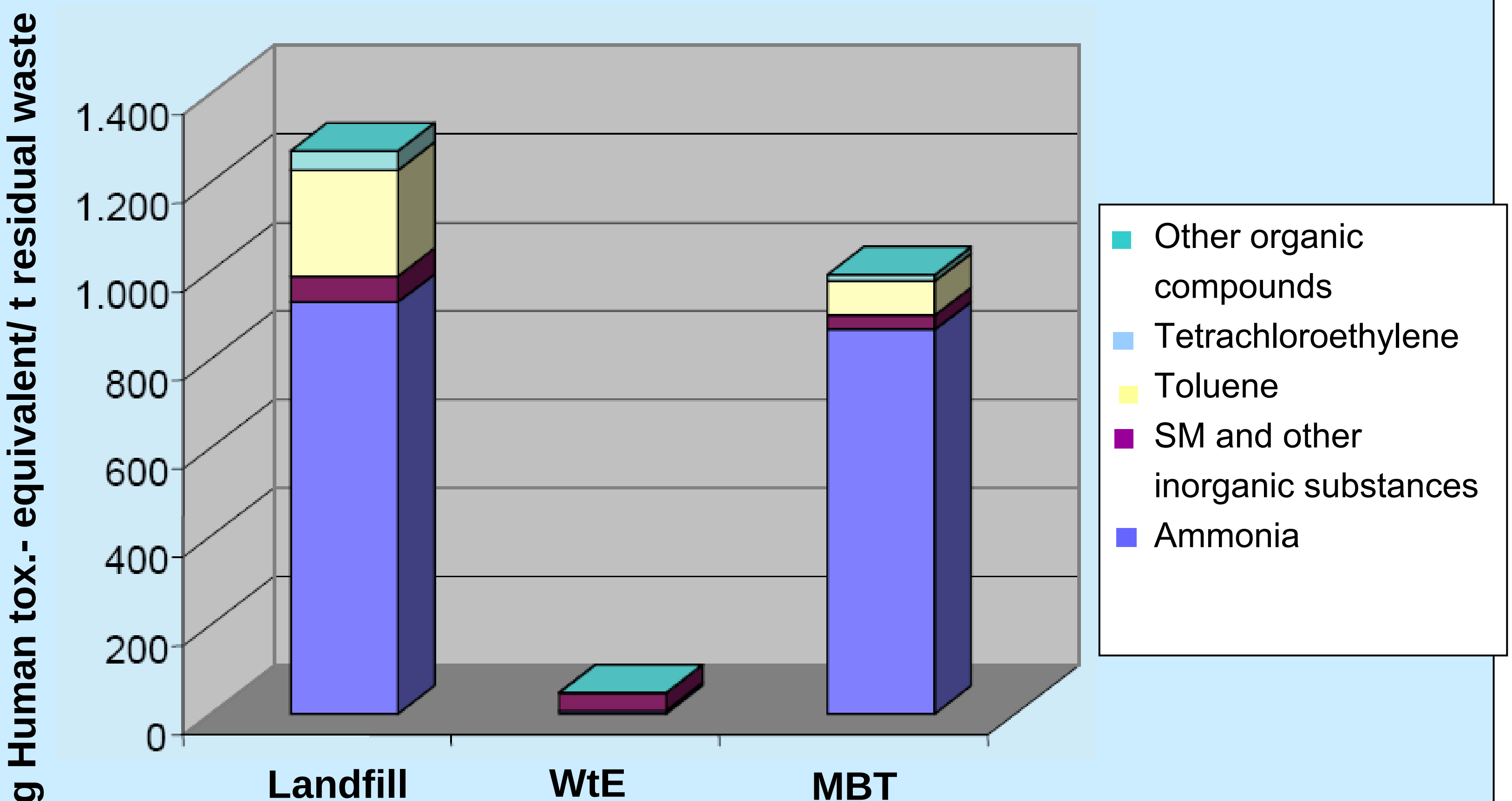
The determination of the toxicity potential is created by the Human- and Eco toxicology potential of air and water emissions.* Nitric oxides play the key role in determining the human toxicity potential compared to dioxins who are only minimal.



Only emissions from pretreatment, landfilling of the residual waste and decomposed product as well as the utilization of bottom ash in the construction of roads are considered in the determination of the toxicity potential. Pollutants are calculated based on EU hazardous waste guidelines (Human-tox.: Xi = x 1; Xn,C = x 10; T = x 100; T+ = x 1000; Eco-tox.: N = x 1).

Human toxicity potential – Water emissions BASF

WtE and MBT are waste water free operations. The water emissions originate in case of WtE from slag, in case of the MBT from landfilling the remnants. Slag emits mostly heavy metals, while the main pollutants of landfill leachate are organic substances and ammonia,



Eco toxicology potential - Pollution

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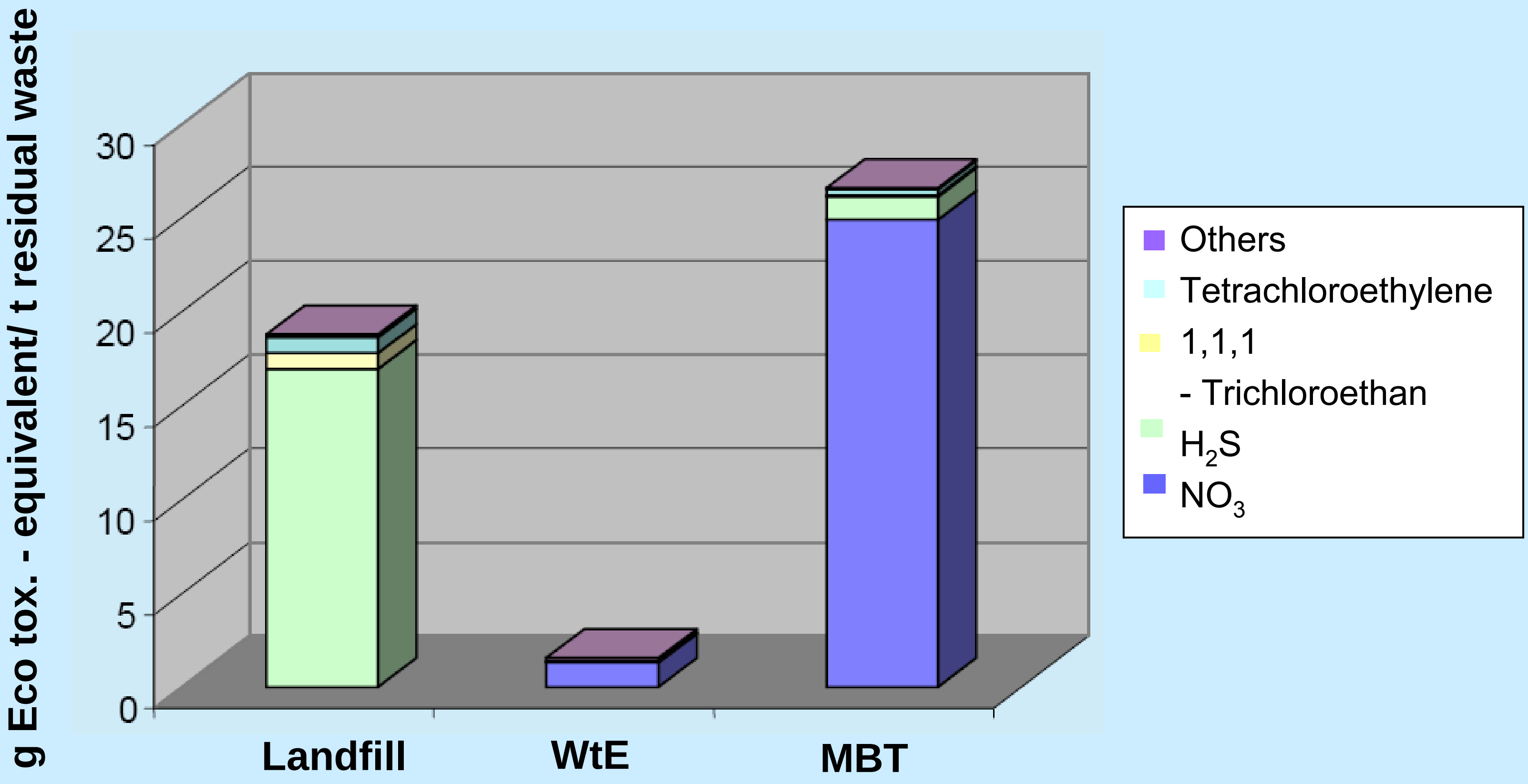
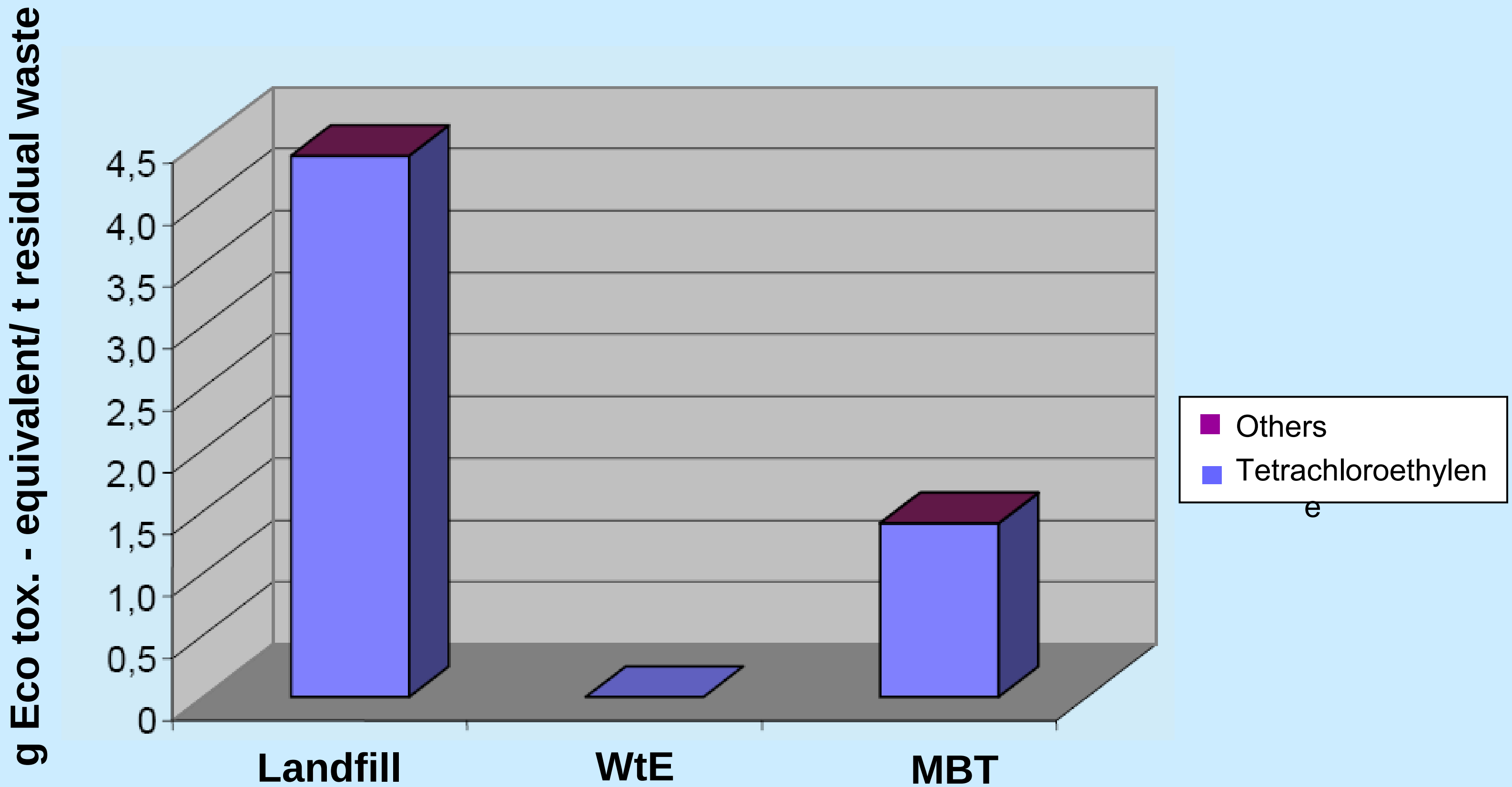
MBT emits more ammonia, while the eco-toxicity potential of the landfill originates mostly from hydrogen sulfide emissions.



Eco toxicology potential – Water emissions

According to the EU-Dangerous Substances Ordinance, Tetrachloroethylene (Tetrachlorethen) is the only water pollutant that is emitted in considerable amounts.



Total toxicology potential*

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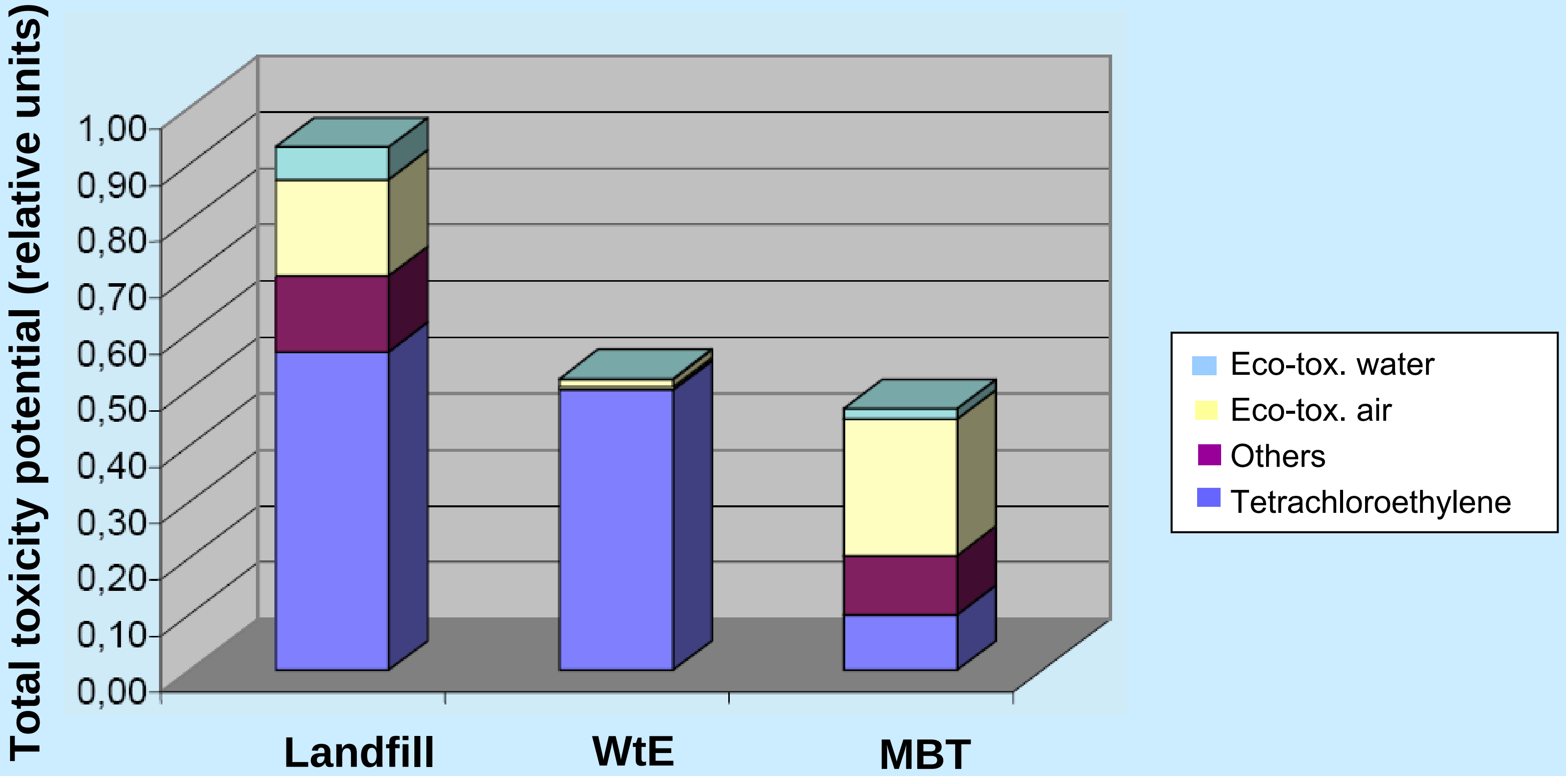
In the overall evaluation of the toxicity potential landfills and WtE are heaviest impacted by the Human-toxic pollutants while MBT is mostly impacted by the Eco-toxic pollutants.



*Human - and Eco toxicity potential for air and water emissions are weighted as follows: Human- to Eco toxicity potential: 70:30; Air to Water emissions (according to relevance factors): 81:19.

The toxicity potential of the emissions

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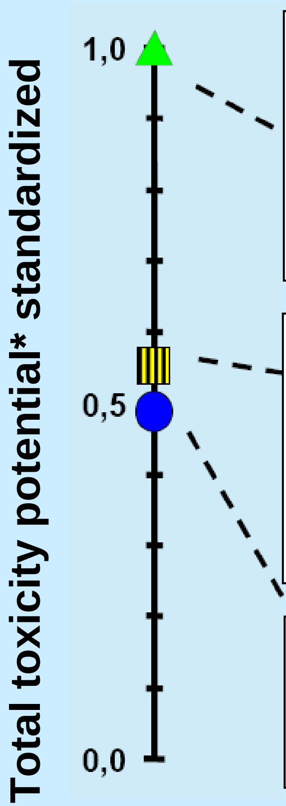
stemming from the remaining wastes can be significantly reduced through the pretreatment of the waste.



Landfill

- Landfilling releases the most human - and eco-toxic emissions into the air and waste water/ground water.
- Within this assessment the most problematic substances were nitric oxide, hydrogen sulfide and the organic leachate pollution.

WtE

- From an eco-toxicity potential WtE is the most recommended alternative. However, the human toxic potential is of importance and should be given consideration.
- The total toxicity potential is mostly characterized by the nitric oxides.

MBT

- Despite the high eco-toxic potential, which stems mostly from ammonia, MBT scores best in the toxicity assessment.

*Human - and Eco toxicity potential for air and water emissions are weight as follows: Human - to Eco toxicity potential: 70:30; Air to Water emissions (adequate relevance factors): 81:19.

The evaluation of the danger potential takes

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place half quantitative by a credit system from 0 to 3 for chosen problem areas.

	Landfill	WtE	MBT
Accidental risks*	2,0	2,5	3
Hygiene**	2,7	0	3
Noise***	2,8	3	2,9
Drifts****	3	0	0,5
Smell	3	0	2,9
Total credits	**13,5**	**5,5**	**12,3**

- Work and transport accidents (information from German's employer liability insurance association and the automobile industry association)

** possible contamination through pathogens for employees, neighborhood and the surrounding region of the individual technical process facilities for garbage

*** Noise from road transport

**** Aesthetical damage of landscape view by flying plastic and paper

Source: Own determination after "BG Chemie"; VDA, 2000; Doedens & Bogon, 1991

Each method has specific weaknesses

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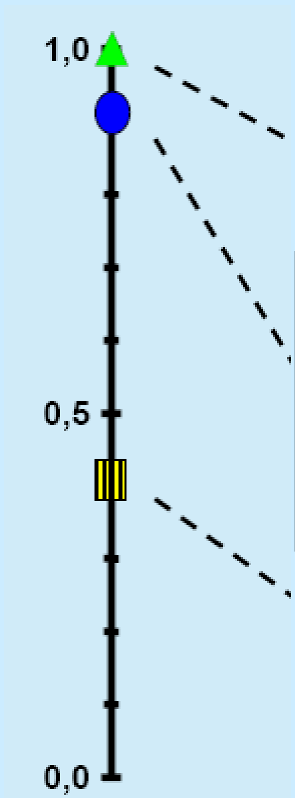


Landfill

- Landfills have the worst aesthetical impairment caused by flying paper and plastics as well as from bad odor.
- Birds and insects may spread pathogen germs.

MBT

- When using conventional air filtration via bio-filter, MBT shows especial weaknesses in relation to smell and hygiene.
- The higher accidental risk originates from comparatively high numbers of employees.

WtE

- Due to the often long transport ways of the collected garbage to the facility road noise and accidental risk rise.
- There are no problems caused by WtE regarding hygiene, smells and drifts.

Scenarios

Scenarios

- **Scenario 1 ”Incineration of the MBT- light materials”**

  The high calorific value of the light material fraction of the MBT (ca. 15 MJ/kg) is burnt in the cement plant with use of the energy content.

- **Scenario 2 “Thermal emission cleaning MBT”**

  The required emission limits of the 30th Ordinance of the Federal Emissions Control Act call for more effective waste air treatment.

- **Scenario 3 “Waste incineration costs”**

  The impact of the treatment costs in relation to the eco efficiency is examined in a scenario, where incineration costs vary between 180 DM/t and 600DM/t.

- **Scenario 4 “Electricity versus district heating”**

  The Eco efficiency is determined with the assumption that WtE (1) with maximum district heating extraction and (2) with max. electricity extraction.

- **Scenario 5 “Worst case WtE”**

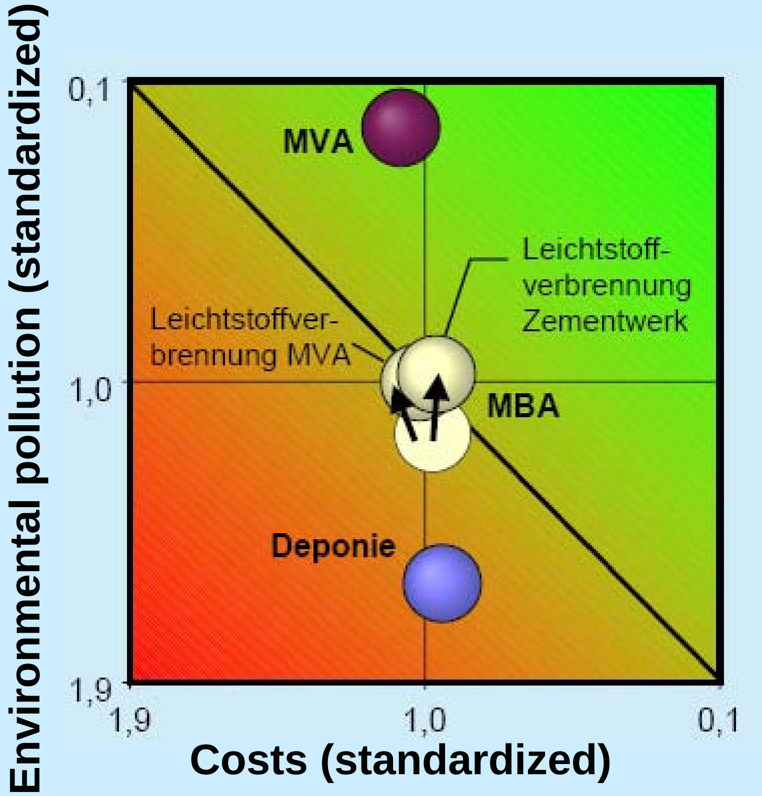
  The worst case for the incineration process is considered that assumes a 600DM/t treatment cost and the landfilling of the slag.

Incineration of the high calorific MBT-light

materials improves the Eco-efficiency whether utilized in a WTE or in a cement facility.

Scenario 1

Disposal of 1 t residual Waste*



Considered alternatives

- MBT
- WtE
- Landfill

* 9,8 MJ/kg

Leichtstoffverbrennung MVA= Incineration of light materials in the WTE
Leichtstoffverbrennung Zementwerk = Incineratin of the light materials in the Cement facility

The ecological evaluation of MBT is improved

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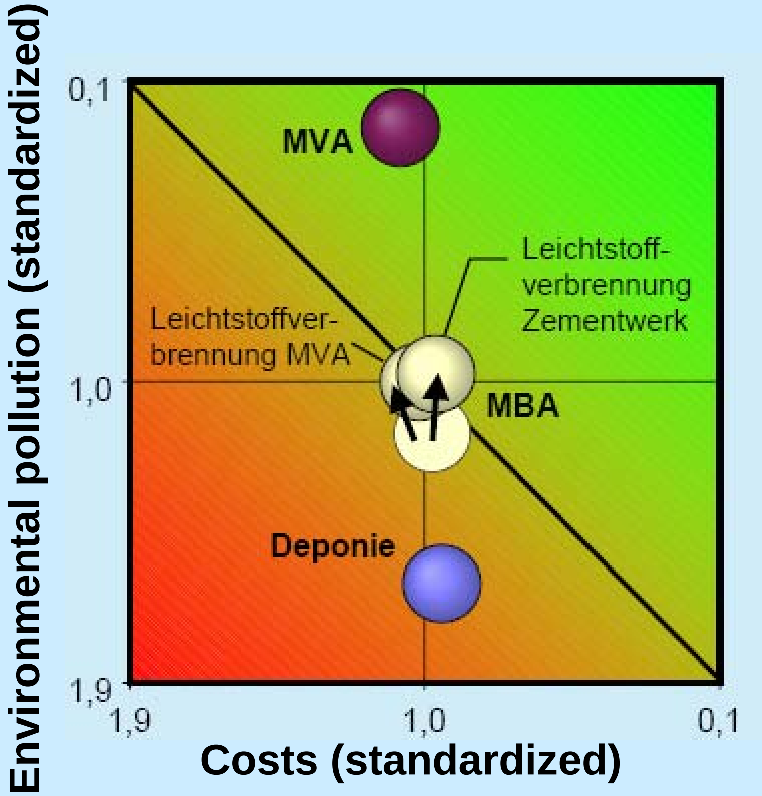
significantly through enhancing the flue gas treatment system**.

Scenario 2

Disposal of 1 t residual Waste*

*9,8 MJ/kg



Considered alternatives

- MBT
- WtE
- Landfill

Leichtstoffverbrennung MVA= Incineration of light materials in the WTE
Leichtstoffverbrennung Zementwerk = Incineratin of the light materials in the Cement facility
**The additional costs for thermal waste air purification system are not included.

The portfolio shows the range of specific

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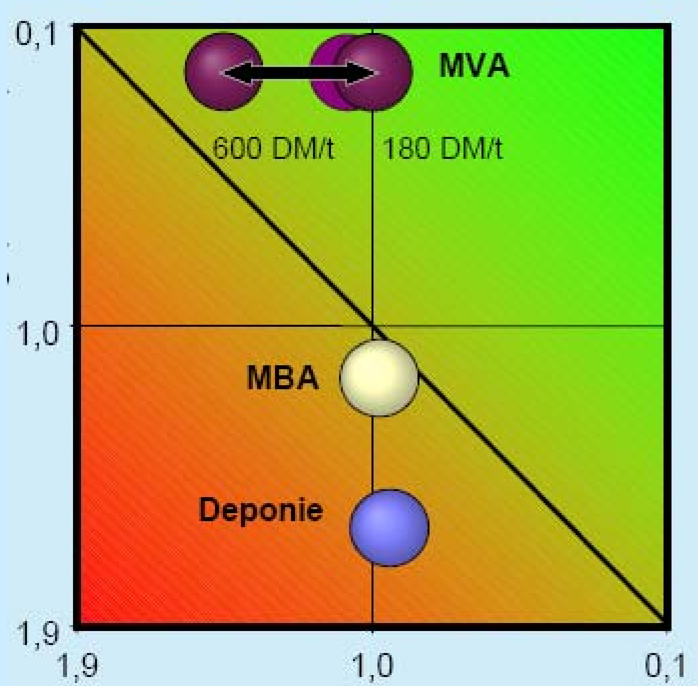
treatment costs of German incineration facilities. The big difference in price influences the assessment of the Eco-efficiency, but even the more expensive WtEs are more eco-efficient than the evaluated MBT.

Scenario 3

Disposal of 1 t residual Waste*

*9,8 MJ/kg

Environmental pollution (standardized)



Costs (standardized)

Considered alternatives

- MBT
- WtE
- Landfill

Although the utilization of energy in form of

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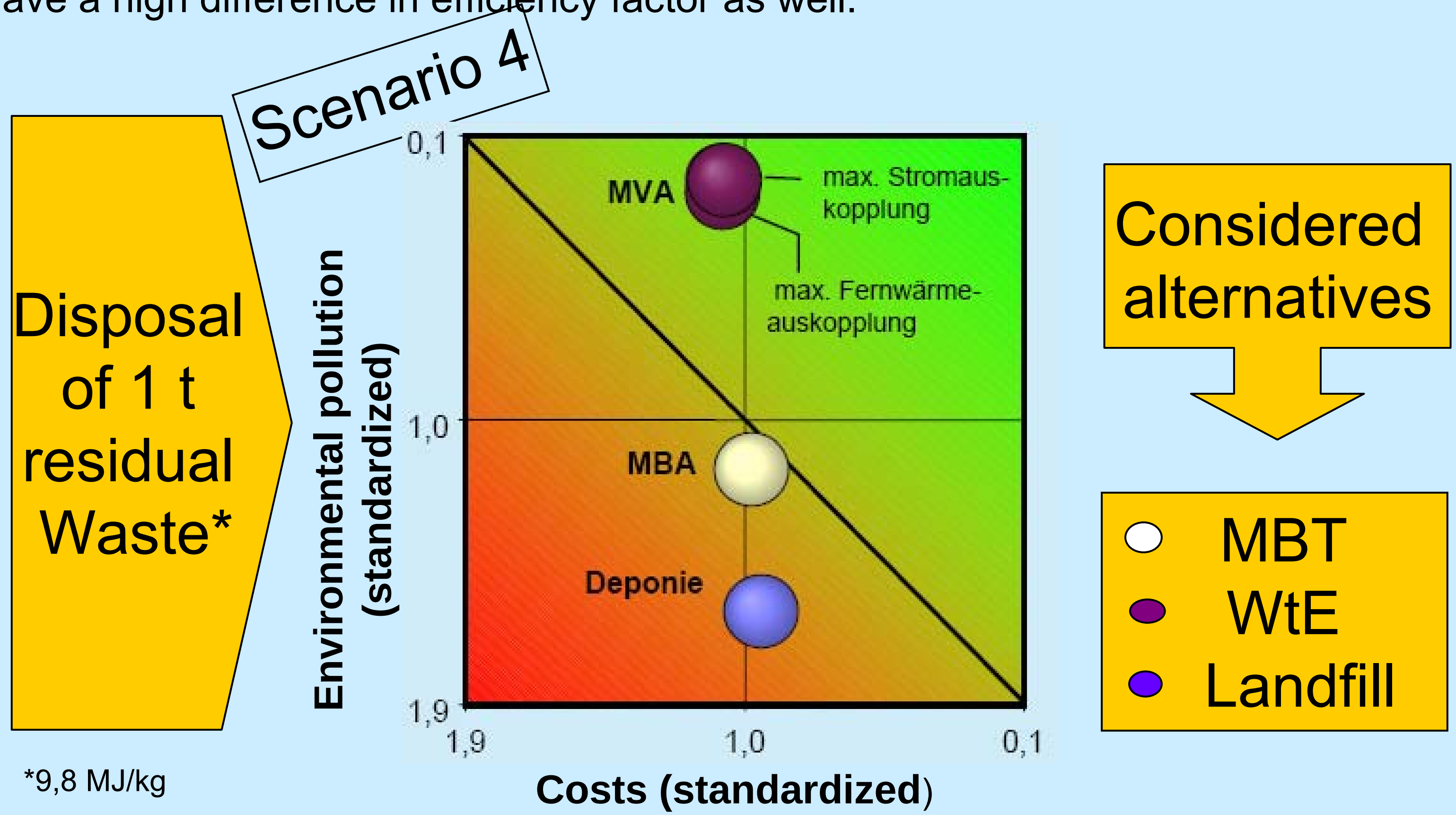
steam is three times higher than in from of electricity, the type of energy utilized has almost no influence on the eco-efficiency of WTE. Electricity and district heating save approximatetely the same amount of primary energy, since the substituted products - electricity from the german power plant mix or steam from natural gas – have a high difference in efficiency factor as well.



*9,8 MJ/kg

Even in the „worst case“ scenario WTE

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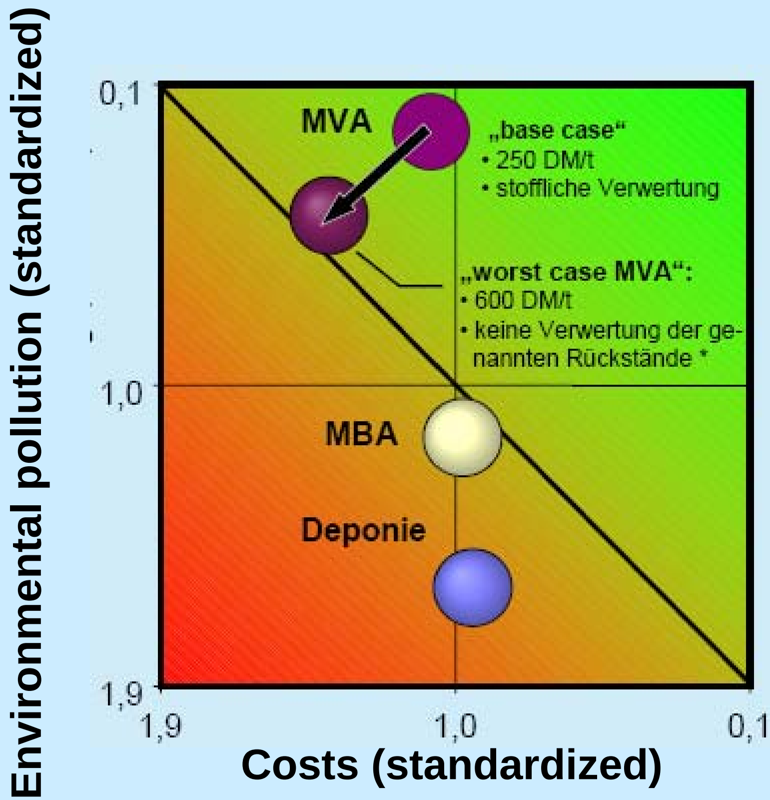
remains the most eco-efficient method of residual waste disposal.

Scenario 5

Disposal of 1 t residual Waste*

*9,8 MJ/gk



Considered alternatives

- MBT
- WtE
- Landfill

*Disposal of slag at the residual waste landfill, and filter dust at down hole hazardous waste landfill
“stoffliche Verwertung”= material use
“keine Verwertung der genannten Rueckstaende” no use of name remnants*

From the Eco-efficiency analysis we can

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derive Research and Development goals as well as marketing instruments

Research and development goals

MBT:
- Improved material and energy use from the residual waste.
- Reduction of the waste amount which would have to be landfilled.

WtE:
- Continuous improvements of the energy utilization.
- Demonstrate the safe utilization of bottom ash/slag in road construction.

Marketing/ Communication from view of the WtE

- WtE utilizes the "resource" remaining waste energetically and materialistically most efficient. Through the created substitutes (electricity, district heating, scrap metal and others) environmental damaging production steps of other processes can be avoided.
- The amount of waste which would have to be dumped into a landfill can be reduced significantly through waste incineration.
- The higher cost of WtE are from a holistic point of view a justifiable through the ecological advantages offered.

Appendix

Procedure for determination of water emissions

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The water pollution was evaluated with the help of the **"Critical Volume"** model. For each pollutant emitted into the water the theoretical Water volume is calculated until the individual pollutant would reach the legal limit value (critical load). The calculated partial volumes for each pollutant are added up to the "critical volume".

The factors for the calculation of the critical volume are indicated in the table to the right. The appendices of the waste water regulation (AbwV) specified requirements for the location of the waste water discharge into local waters serve as the foundation for these factors.

These limit values are generally based on the relevance of the emitted material to the environment. In some instances for the determination of these classifications technical aspects were also taken into consideration. Despite these restrictions BASF preferred this procedure because:

- of the complete database for most emissions;
- of the large degree of awareness of the waste water regulation and it's broad acceptance of the limit values of the appendices.

Table: Water emissions; Model of the critical water volume; applied calculation factors

Parameter	Requirements of waste water (mg/l)	Factors for the calculation of the "critical volume"	Appendix for waste water regulation (AbwV)
COD	75	1/75	No. 1
BOD5	15	1/15	No. 1
N total	18	1/18	No. 1
NH4-N	10	1/10	No. 1
P total	1	1	No. 1
AOX	1	1	No. 9
heavy metals	Ø1	1	No. 9
Hydrocarbons	2	½	No. 45

COD: Chemical Oxygen Demand, BOD5: Biochemical Oxygen Demand; N total: Total amount of nitrogen; NH4-N: Ammonia-Nitrogen, P total: Total amount of phosphor; AOX: Absorbable organically bound halogens; heavy metals: Sum of copper, zinc, cadmium, lead, chrome, mercury; hydrocarbons: Sum of hydrocarbons

Evaluation of the environmental impact

The determined values of life cycle inventory analysis (LCI) and impact analysis (greenhouse potential, ozone destruction potential, photochemical ozone creation potential, acidification potential, quantity of contaminated water, quantity of waste, energy and resource consumption) are combined to one evaluation factor to determine the environmental impact.

The evaluation criteria consist of:

- a social factor:

What value does society place on the reduction of the individual potentials?

- a relevance factor:

What share of Germany's total emissions has each considered emission?

Social evaluation factors of emissions

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- Area consumption - quantitatively (10%)
- Energy consumption - quantitatively (20%)
- Material consumption - quantitatively (20%)
- **Emissions - quantitatively (20%)**
- Toxicity - qualitative (20%)
- Risk potential - qualitative (10%)

Emissions:

- **Air emissions (50%)**
- **Water emissions (35%)**
- **Garbage (15%)**

Air emissions:

- **Global warming potential (GWP) (50%)**
- **Ozone destruction potential (20%)**
- **Photochemical Ozone formation potential (20%)**
- **Acidification potential (10%)**

Calculation of the relevance factors

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	Gesamtmenge D												
	1000 t/a										Relevanzfaktoren	Gesellsch.	Rechen
					Deponie	MVA	MBA	Alternative 3	Alternative 4	Alternative 5	Max	Faktoren	Faktoren
CO2	861000		GWP:	Relevanz	5,7433%	57,1465%	6,9285%	0,0000%	0,0000%	0,0000%	57,1465%		19%
SOX	1845		1.010.524	normiert	6,7%	66,0%	14,6%	#DIV/0!	#DIV/0!	#DIV/0!	39%	50%	64%
NOX	1859		ODP	Relevanz	53,5291%	4,8456%	21,9605%	0,0000%	0,0000%	0,0000%	53,5291%		7%
CH4	4724		8,00	normiert	62,4%	5,6%	46,2%	#DIV/0!	#DIV/0!	#DIV/0!	36%	20%	24%
KW	1868		POCP	Relevanz	15,5987%	4,1380%	13,6271%	0,0000%	0,0000%	0,0000%	15,5987%		2%
Halogen. KW	8		810,16	normiert	18,2%	4,8%	28,7%	#DIV/0!	#DIV/0!	#DIV/0!	11%	20%	7%
NH3	651		AP	Relevanz	10,8928%	20,4808%	4,9986%	0,0000%	0,0000%	0,0000%	20,4808%		1%
N2O	228		4.370,18	normiert	12,7%	23,6%	10,5%	#DIV/0!	#DIV/0!	#DIV/0!	14%	10%	5%
HCl				Mittelwert	21,4410%	21,6527%	11,8767%	0,0000%	0,0000%	0,0000%			
				Summe					Summe		145,7551%		30%
CSB(t/a)	1278000		17.040										
BSB(t/a)	1065000		71.000						Luft		50,7957%	50%	5%
N-Ges (t/a)	710000		39.444								10%		26%
NH4(t/a)	71000		7.100										
PO4(t/a)	39500		39.500		Deponie	MVA	MBA	Alternative 3	Alternative 4	Alternative 5	Max		
AOX(t/a)	5820		5.820	Relevanz	12,2677%	3,9201%	6,5992%	0,0000%	0,0000%	0,0000%	12,2677%	35%	1%
SM(t/a)	11804		11.804								2%		4%
KW(t/a)			22.749										
SO4 (t/a)	18331515		18.332										
Cl- (t/a)	37244983		37.245										
Summe			270.034										
					Deponie	MVA	MBA	Alternative 3	Alternative 4	Alternative 5	Max		
Deponieabfall (Mio t/a	30,5		30,50	Relevanz	447,4138%	0,8423%	309,3725%	0,0000%	0,0000%	0,0000%	447,4138%	15%	13%
Sonderabfall (Mio t/a)	32,1		160,50								88%		69%
Bergematerial	58,7		11,74						Summe		510,4982%		19%
Bauschutt etc	127		25,4										
Summe			228,14						Emissionen		272,112%	20%	12%
											60,7%		51%
Energie (PJ)	14454		14454		Deponie	MVA	MBA	Alternative 3	Alternative 4	Alternative 5	Max		
				Relevanz	3,3742%	68,9744%	1,3348%	0,0000%	0,0000%	0,0000%	68,974%	20%	3%
Öl (Mio t)	126		3000								15,4%		13%
Gas (Mio t)	54,6		867										
Steinkohle (Mio t)	71		444										
Braunkohle (Mio t)	91		235		Deponie	MVA	MBA	Alternative 3	Alternative 4	Alternative 5	Max		
Kalk	74		148	Relevanz	11,9555%	63,2870%	4,2840%	0,0000%	0,0000%	0,0000%	63,287%	20%	3%
Eisen	39		542								14,1%		12%
Mangan	0,0127		0,14						Summe		448,386%		19%
Kupfer	0,701		14						Mittelwert alle Relevanzen		78,2730%		
Bauxit	1,35		6,8										
Schwefel	0,163		5,4										
Steine	850		850										
Zink	0,44		17,6										
Salz	1,7		1,7										
Summe			6131										
Fläche													
jährl. Zuwachs an Siedlungs- und Verkehrsfläche					Deponie	MVA	MBA	Alternative 3	Alternative 4	Alternative 5	Max		
	436	km2		Relevanz	22,6311%	0,4261%	14,3461%	0,0000%	0,0000%	0,0000%	22,631%	10%	1%
											5,1%		2%
Risikopotenzial													
										Gesamt	Mittel		
a) Unfallrisiko											21,181%	10%	0%
angezeigte Unfälle (Arbeits- und Wegeunfälle) 1998					1.836.000						4,7%		2%
+ Beteiligte an Straßenverkehrsunfällen mit Personenschaden 1999					775.950								
					Deponie	MVA	MBA	Alternative 3	Alternative 4	Alternative 5	Max		
	2.610.950			Relevanz	0,1352%	0,3022%	0,5090%	0,0000%	0,0000%	0,0000%	0,509%		
b) Lärm von Straßentransporten													
tatsächliche Beförderungsleistung deutscher LKW 1999					0.00	0.00	0.00	0.00	ert alle Relev	0.00	Max		
	278	Mrd tkm		Relevanz	28,5942%	16,5236%	41,8535%	0,0000%	0,0000%	0,0000%	41,853%		
					Deponie	MVA	MBA	Alternative 3	Alternative 4	Alternative 5	Max		
Umsatz prod. Gewerb	2572	Mrd DM		Relevanz	9,9105%	13,0250%	11,2465%	0,0000%	0,0000%	0,0000%	13,025%		
Transporte	250	Mrd tkm							BIP-Relevanz		6,009426261		

Reference values:

- Umwelt Bundes Amt (UBA) (1997): Data about the environment. Berlin.
- Federal Office of Statistics (2000): Annual abstract of Statistics 2000. Wiesbaden.
- World index of resources and population; Aldershot, Darmouth Publishing 1994.
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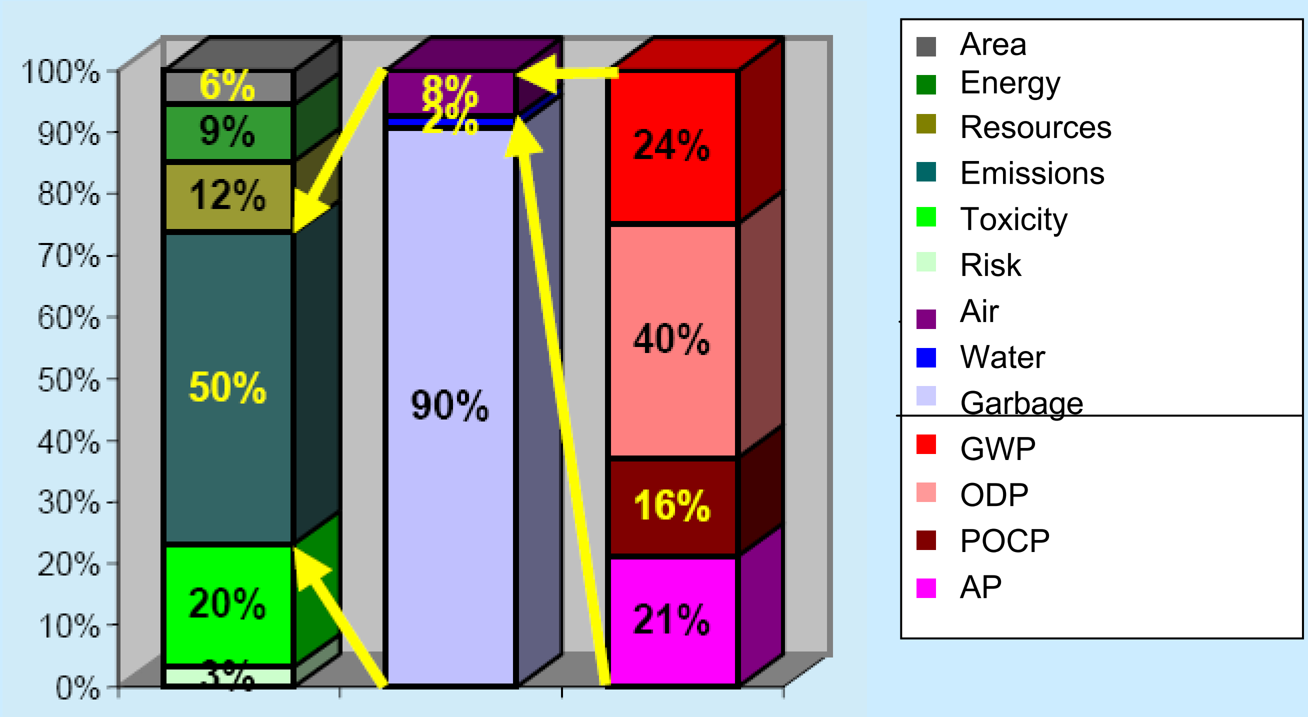
The relevance factors are utilized for the evaluation process

Relevance factors



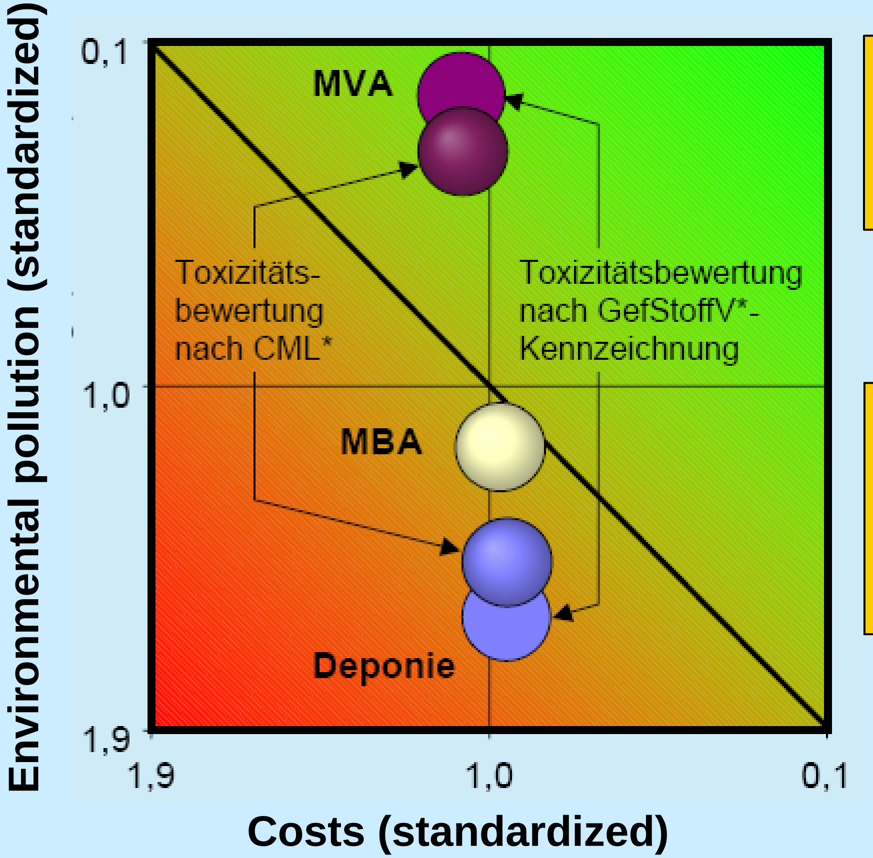
GWP: Greenhouse potential; ODP: Ozone destruction potential; POCP: photochemical Ozone creation potential, AP: Acidification potential

The Relevance factors provide the standardized part of the respective emission, of the raw material and/or the energy consumption of the total emission and total resource and/or total energy consumption of Germany.

Sensitivity analysis:

Toxicity evaluation according to CML*

Disposal of 1 t residual waste



Considered alternatives

- MBT
- WtE
- Landfill

*CML: Centre of Environmental Science (NL); Evaluation of the toxicity potential of human and eco-toxically effect potential (Guinee et al., 1996, in Schwing, 1999:33)
** GefStoffV: dangerous substances ordinance

Explanation concerning the relevance factors

- **Right column (detailed air emissions)**
  - The greenhouse potential and the ozone destruction potential play a very important role in waste treatment. Therefore they get high reference factors.
- **Middle column (emissions)**
  - Waste is rated very high because without pretreatment the amount of waste that has to be landfilled is enormous.
  - Emissions via waste water are comparatively low thus the value of the waste water has a smaller factor.
- **Left column (environmental pollution)**
  - Emissions play a very important role in the chain of residual waste disposal thus this environmental category is given a very high factor.

Reverence Guide

BASF

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