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Thermal treatment of municipal solid waste

Energetic utilization by other technologies like pyrolysis, gasification and plasma

Prof. Dr. Ing. Klaus Wiemer

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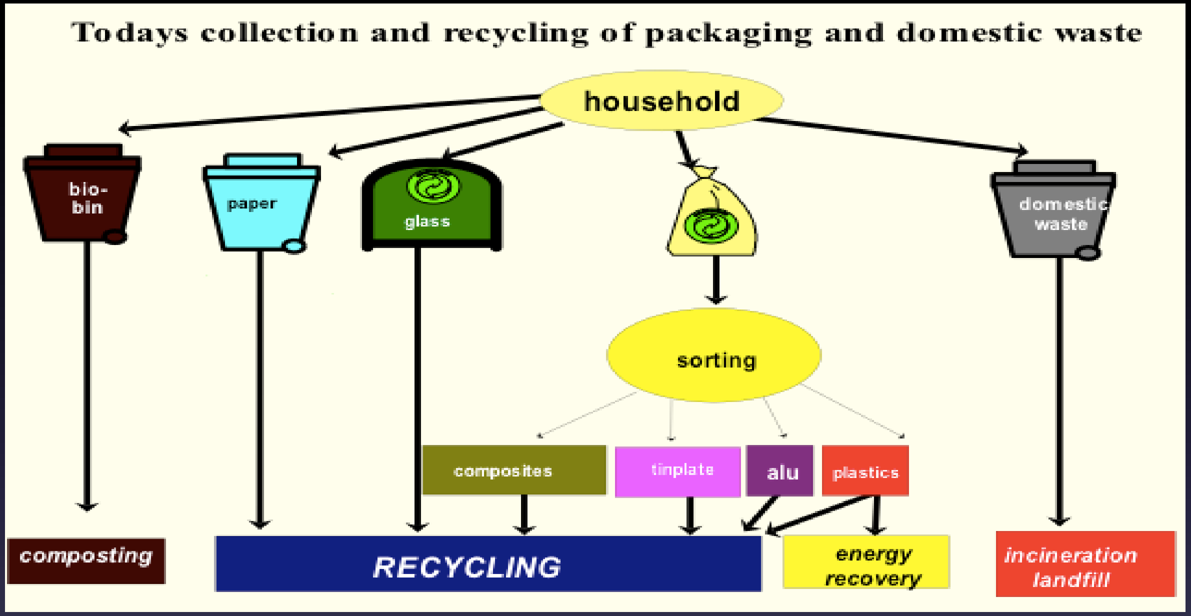
Background

of waste management
in Germany

Incineration	First plants for MSW in 1895/1900 (Hamburg/München)
Landfilling	First controlled landfill with compactors in 1973 (Deponie Wicker) landfilling for organic waste ended in Germany 2005
Pyrolysis / Carbonisation	First and only permanently permitted plant for MSW since 1982 (Burgau)
Pyrolysis / Gasification	**No permitted MSW plant in operation.** Historically numerous plants including Thermoselect operated with provisional temporary permissions
Pyrolysis / Plasma	No permitted plant for MSW in operation

Waste reduction and recovery

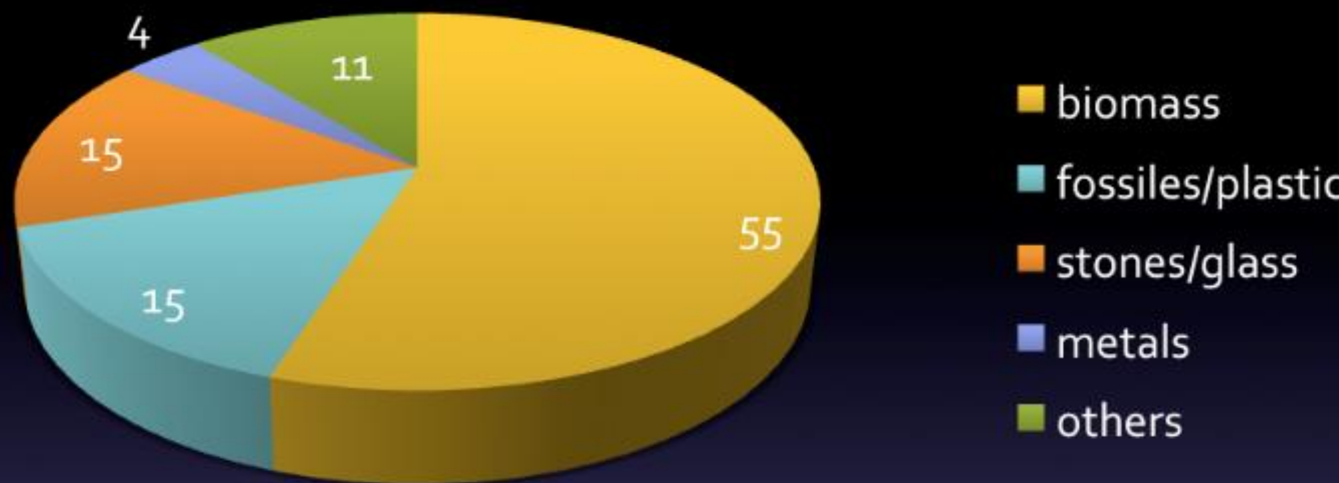
A first step to thermal treatment



We tried to reduce as much as possible

but there still remains a lot of worth giving residue

Composition of remaining waste



landfill disposal **< < <** **> > >** **thermal treatment**

- **Problem:**
- 55% of biomas and 15% of fossile carbon
- **no energy benefit**
- **substantial methan/CO_2 emissions**

Advantadge

- 55% of biomass and 15% of fossile carbon
- CO_2 substitution effects: 38 million tons/year
- Co2 due to non emitted landfill gase: 17 mio. tons/year

Change from landfill to thermal solutions:

- **reduced emission of 56 million tons of CO_2 per year,** (2010 compared to 1990)

Thermal treatment

- **best method to avoid problems in landfills**

- proven method to recover energy from biomass and fossil carbon
- contributes an important role to climate protection (more than 5 % of national CO2- output, due to the change from landfill- to thermal treatment)
- important first step in metal recycling

- more expensive than a dump but might be cheaper than a high standard landfill
- gives net. benefit under favourable conditions

provides a valid final solution for a large variety of waste streams

1989 a **break** in German history

Waste management started as a new challenge:

- Everything had to be restarted
- packaging ordinance
- More efficient recycling standards
- foreshadowed end of classical landfill
- Modernized landfill standards
- Modernized standards for **thermal treatment (1995)**

The right moment for a change into modern standards

German landfill ban

(foreshadowed in 1991 in operation since 2005)

why ?

modern landfills with the very best standards still got:
– poor emission control – disastrous climate balance – poor resource recovery – they are no sustainable solutions – are very expensive and **are polluting air and groundwater**

cheap dumps are even more a danger for advanced waste treatment technology. Waste follows the cheapest road, reason enough, that competitive best technology plants run empty.

Fatal image of thermal treatment

Dioxin

Worst case scenario
dioxins

Pollution by dioxin due to incineration

		Dioxins per year in Germany in g TE		Now
		1990	1994	2000
Metal industry	Metallgewinnung und -verarbeitung	740	220	40
Waste combustion	Müllverbrennung	400	32	0,5
Power plants	Kraftwerke	5	3	3
Industrial combustion	Industrielle Verbrennungsanlagen	20	15	< 10
household combustion	Hausbrandfeuerstätten	20	15	< 10
Trafic	Verkehr	10	4	< 1
crematorium	Krematorien	4	2	< 2
Toltal emission	Gesamtemission Luft	1.200	330	<< 70

Emission standards

Schadstoff	small plants TA Luft Allgemeine Anforderungen	power plants 13. BImSchV Großfeuerung wie Kohle >300 Megawatt	MSW Waste 17. BImSchV für MVA	practise year 2000 Waste reale MVA, gemessen
Org. Stoffe (C-ges.)	50	-	10	**1**
Kohlenmonoxid (CO)	-	200	50	**10**
Chlorwasserstoff (HCl)	30	-nicht relevant	10	**1**
Fluorwasserstoff (HF)	3	-nicht relevant	1	**0,1**
Schwefeldioxid (SO_2)	350	200	50	**1,5**
Stickoxide (NO_2)	350	200	200	**60**
Staub	20	20	10	**1**
Dioxins Dioxine	0,1 ng TE	-	0,1 ng TE	**0,005 ng TE**
Dioxine in Anlagen der Metallindustrie	0,4 ng TE	-	-	-

In 1980 **Dioxins** normal practise: **10 - 40 ng TE**
In 1990 **Dioxins** best practise without carbon filter: **1,0 ng TE**
In 2000 **Dioxins** best practise: **< 0,005 ng TE**
In 2015 **Dioxins** actual practise: **< 0,003 ng TE**

Thermal treatment and pollution

- waste incineration plants -

year	nr. of plants	capacity (megatons)
1965	7	718
1970	24	2.829
1975	33	4.582
1980	42	6.343
1985	46	7.877
1990	48	9.200
1995	52	10.870
2000	61	13.999
2005	66	16.900
2007	72	17.800

dioxins (1990) — total dioxin emissions Germany: 400 g TE

dioxins (2000) — total dioxin emissions Germany: 0,5 g TE

All technologies of thermal waste treatment have to hit the **identical emission standards**

There is no concern about air pollution any more

Development of waste treatment plants

treatment plants	1984	1990	1993	1996	2007
Incineration	46	48	56	51	72
Pyrolysis **	1	1	1	1	1
Sorting	3	45	228	522	362
Composting/ Biogas	27	75	288	383	1087
Landfill	372	295	560	426	124

* **Pyrolysis with permission for a long-time operation using MSW**
* **The only MSW Pyrolysis plant with long term permission in Germany (Burgau) will be closed in 2016**
* In all those decades there have been several MSW pilot plants with different process characters in operation, but without any long lasting permission or success

Emission **control** of MSW plants

Lets hope, that those

emission controls have not been manipulated

Mexico incineracion

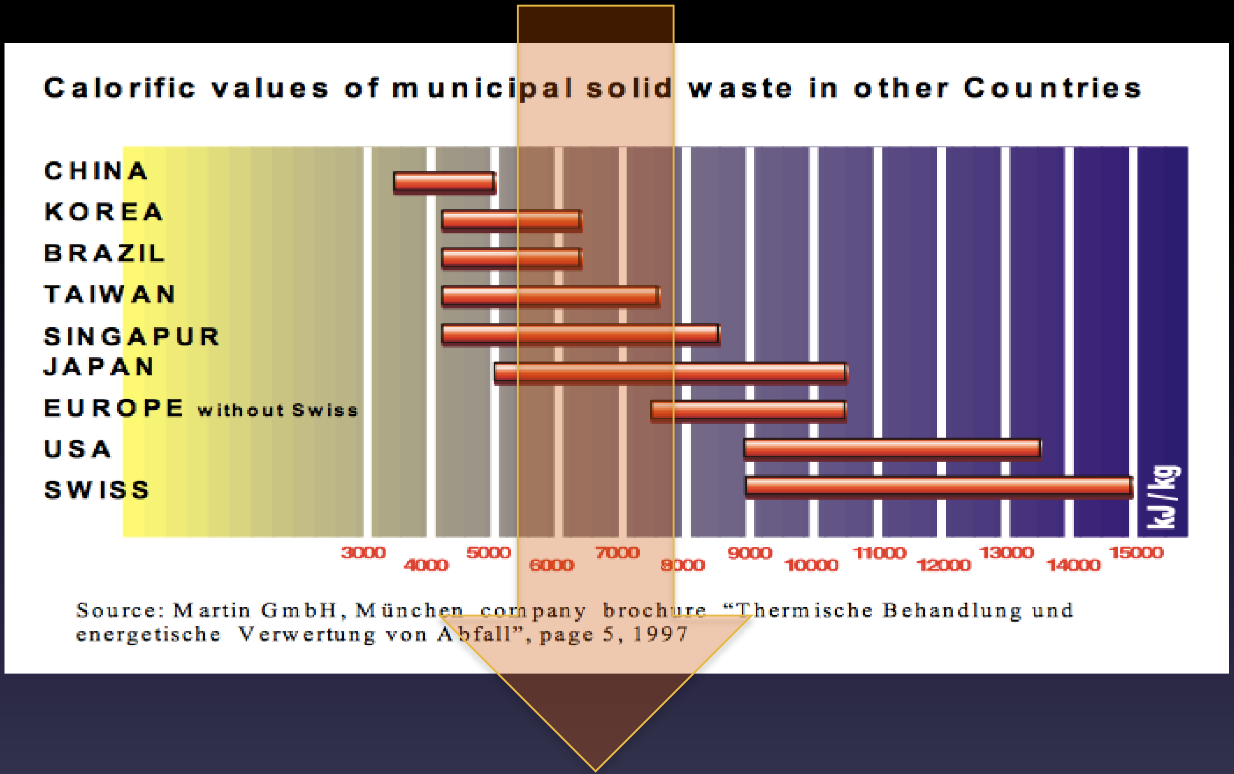
¿De que **estructuras** hablamos?

Incineration

Incineration and heating value I

Never try barbecuing on a wet coal

Incineration and heating value II



In order to achieve a reliable operation the heating value should not be much less than 7.000 kj/kg

That might be difficult in different areas of Mexico and in different times of the year

Consequences of low heating value

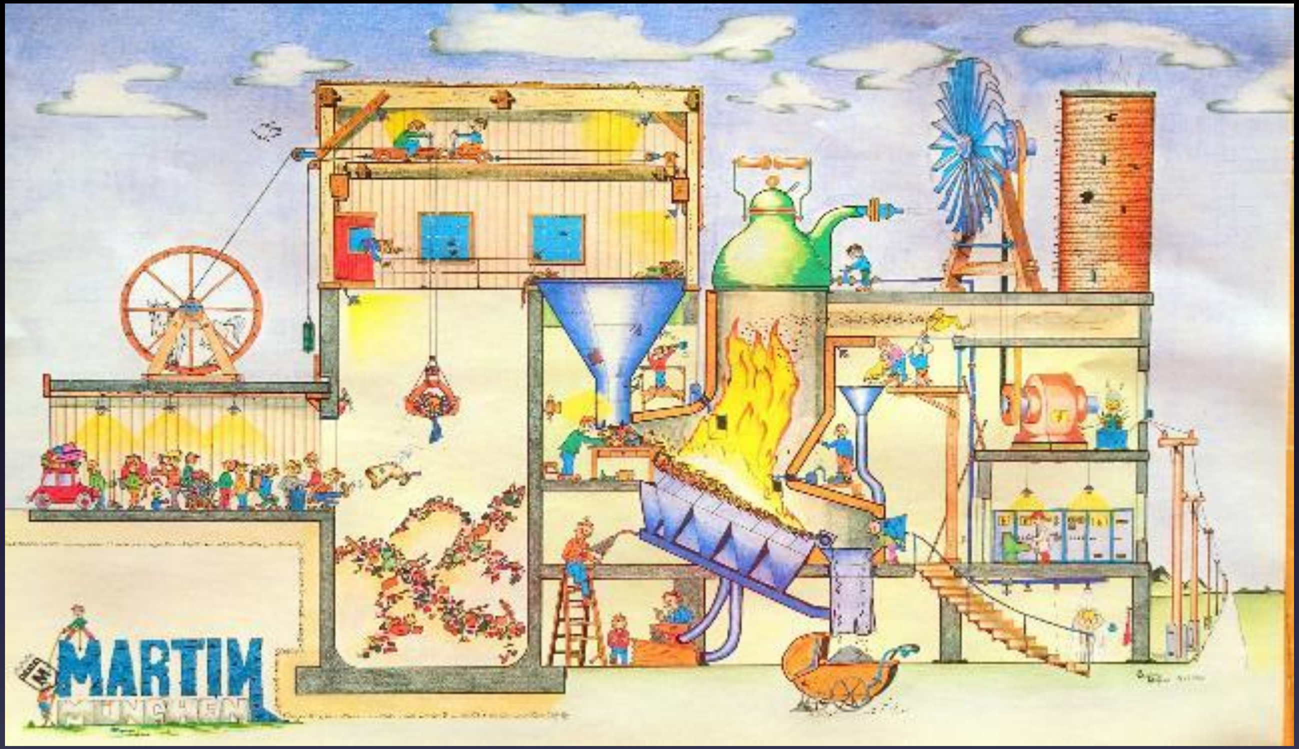
- Below a heating value (Btu) of **5000 kj/kg** the waste does not burn at all
- In order to compensate variations, the **Btu shouldn't be lower than 7000 kj/kg**

  - **MSW incineration doesn't make sense in some areas** of Mexico. Different solutions are being required
  - **Pre-treatment of waste** by sorting out high calorific fractions is the only solution for some areas in terms of waste to energy
  - **Combustion or combustion in RDF plants** are consequently required solutions
  - **Biotechnology** for the remaining rest might be an option
  - other options are **Pyrolysis, Gasification- and Plasma Technologies**

MSW and RDF plants might require **different combustion chamber designs** (grid) due to excessively thermal load

Incineration and its basic functions I

Waste



Turbine

Grid

Delivery zone

Bunker

Furnace

Flue gas cleaning system

Source: Martin GmbH, München

Incineration and its basic functions II

Industrial design

Waste

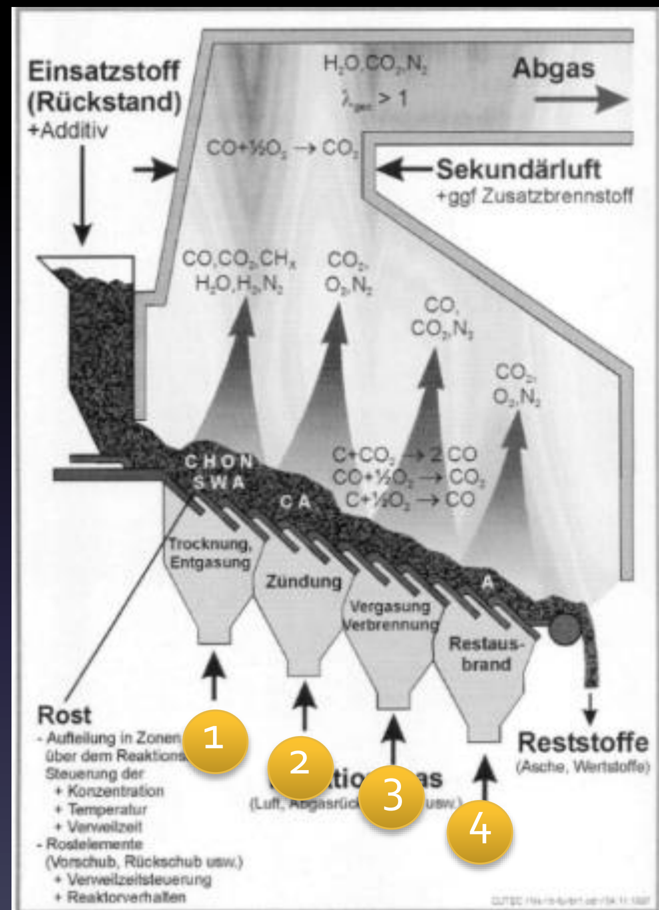
Grid

Delivery zone Bunker Furnace Flue gas cleaning system

Source: Martin GmbH, München

Incineration and its basic functions III

Waste



Flue gas

Bottom ash

1 Drying zone

2 Ignition zone

3 Gasification / Incineration zone

4 Burn-out zone

Incineration systems

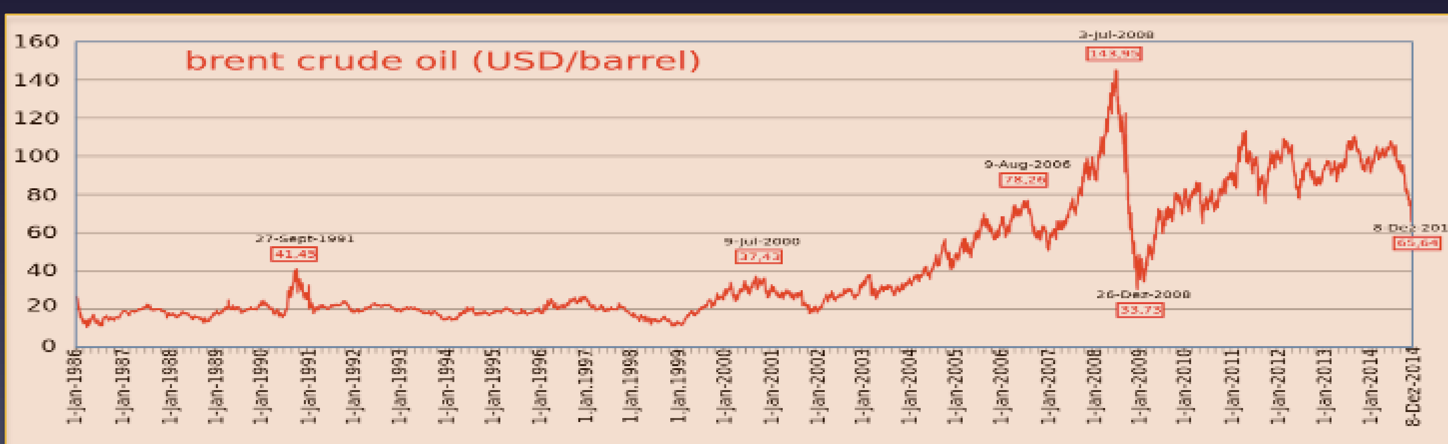
- **Wide variety of systems** on the market available
- Open tender as well as **input- and outputcriterias** decide in most cases about the selected technology

Incineration economy

Fundamental criteria

- Size of the plant
- Input quality and continuity
- Market for heat and power
- Market for recycled material
- Market or cost for bottom ash
- Infrastructural criteria
- System costs
- **Price for crude oil**

max. 143,- US $



Brent
October 21015

49,- US $

Incineration efficiency

Waste is a worth giving fuel

(if a minimum heating value is given and the market prices for oil correspond with the operational costs)

- **The plant design and operation** is mostly orientated an regulatory demand, **market prices for energy** or funding by the state. Otherwise the **competitiveness** is not been given
- **Efficiency of communal plants**: average 37% (11% power, 26% heat)*
- **Efficiency of RDF plants:** Mostly close to industry > high efficiency up to 70% heat for example
- **Efficiency of cocombustion Cement Plants:** even higher

* Source: VKS, 2010

MSW treatment costs in Germany

Landfill best practise in 2000: 80,- to 120,- €/ton
MSW incineration 2000: average costs 165,- €/ton

MSW incineration 2005: average costs 150,- € /ton*
MSW incineration 2013: average costs 112,- € /ton*

MSW 2015: spot market 32,- to 100,- €/ton

Spot market in Scandinavia: positive gate fee !!

* Source: Prognos

MSW treatment costs

Specific Investment Costs

- 1995 : 3.000 EUR / Jahrestonne
- 2005: 1.500
- 2015: 600

Treatment Costs

- 80% Capital cost
- 20% Variabel cost
- Annuity 8%

Resulting costs:

60 Euros per ton and less are feasable for Mexico

Alternative treatment

some say, alternatives are better

Pyrolysis

- **Carbonisation**
- **Gasification**
- **Plasma** Gasification or Incineration

Definitions of alternative thermal treatment

There is no universally standardised definition of Pyrolysis and Gasification. The existing definitions are inconsistent and confusing

◆ **Pyrolysis / Carbonisation is a dry distillation process**

- there is no external oxygen input
- some waste contains small amounts of oxygen, which produces internal heat
- temperature between 250 and 800 °C
- final products are: solid rest, tar, liquids, gas (BTX) and **slag with a high content of carbon (like charcoal for example)**

◆ **Pyrolysis / Gasification**

- **input of different gases**, air, oxygen or steam **into the carbonisation process ($\lambda<1$)**
- internal heating by gases, air or pure oxygen in order to enforce the distillation process
- temperatures 300 up to 1300 °C (depending on process parameters or design)
- final products: solid rest, tar, liquids, high calorific gases , depending on design parameters
- **slag with a lower or no content of carbon**
- **a slag melting process leaves no carbon at all**
- The energy efficiency is an issue of concern

Experience and tradition

The difference between dry and liquid distillation is well known in Oaxaca, Mexico for its great tradition.

(El Rey Zapoteco, fundado 1960)

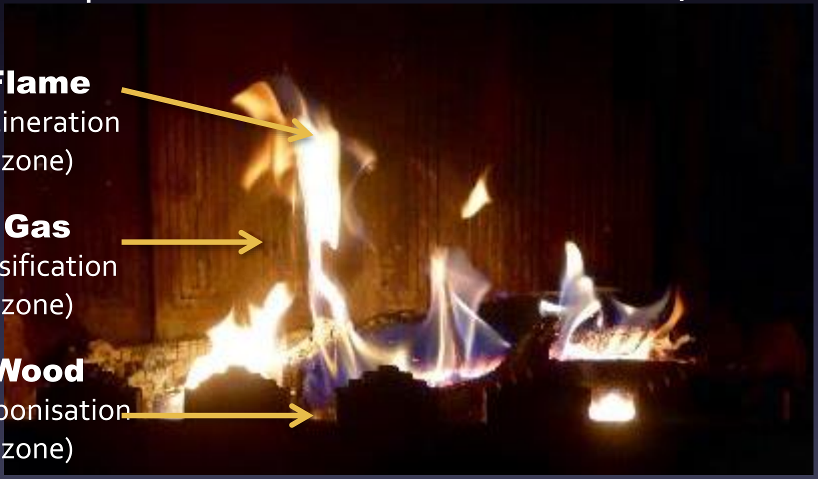
Pyrolysis process characteristics

temperature range	drying	carbonisation (Pyrolysis)	Gasification	Incineration
Step 0 >> 150°C	drying	drying	drying	drying
Step 1 250 – 800 °C		**pyrolysis** carbonisation	**pyrolysis** carbonisation	**pyrolysis** carbonisation
Step 2 300 – 1400 °C			**gasification** (additional gas)	**gasification**
Step 3				incineration

Pyrolysis /Carbonisation is always the first step of any thermal treatment process

Pyrolysis exothermic or endothermic

- **Pyrolysis / Carbonisation** is the first step of any incineration process but also a technology for itself
- It means the **thermal decomposition of organic matter** to gaseous, liquid or solid end products at elevated temperatures in the absence of oxygen (no flame at all)
- the oxidation (**Gasification**) of pyrolitic gases is the first or separate step before a following final **incineration process**
- The advantage of pyrolysis is known since thousands of years, for example for the production of tar and charcoal, **8000 before Christ**



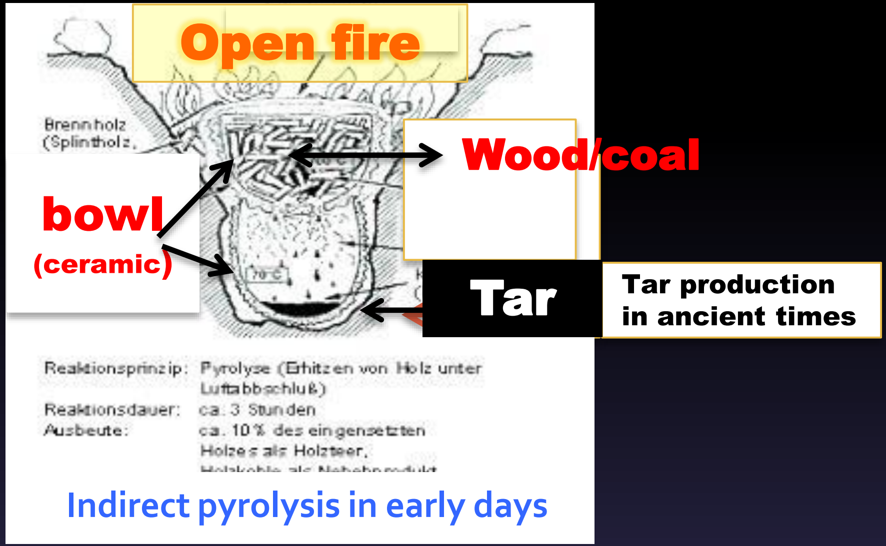
direct process (exothermic)

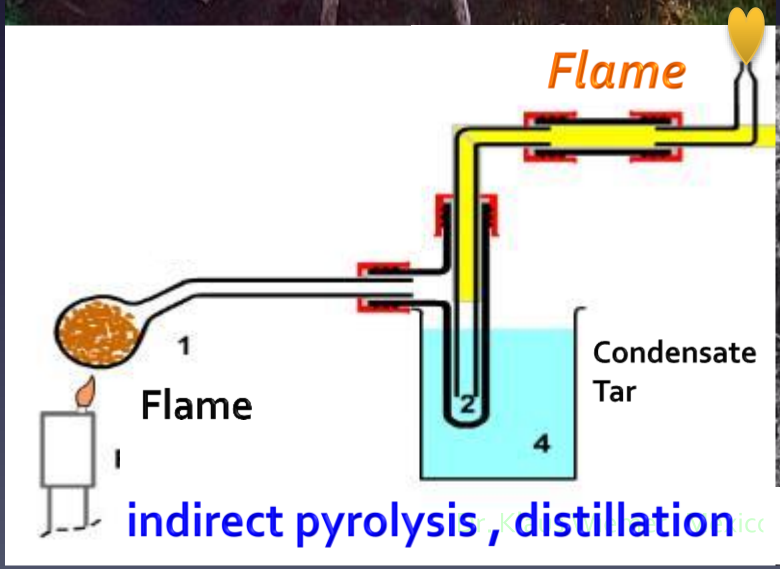
indirect process (endothermic)

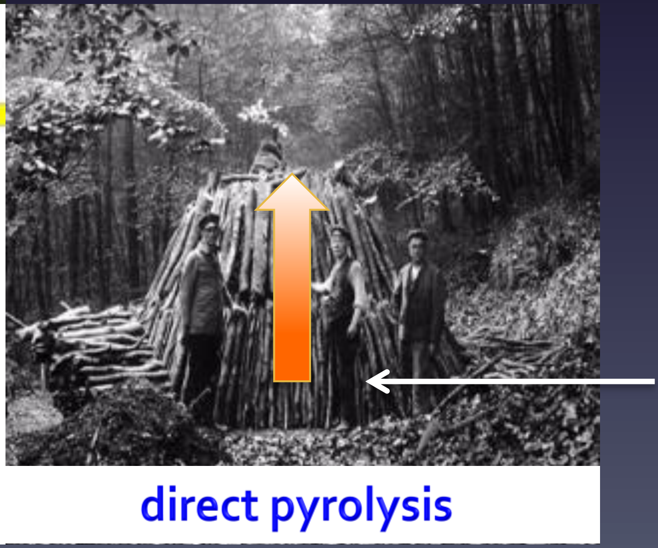
First step: *carbonisation*

Products: *gas, tar and charcoal*

Charcoal: a pyrolitic process







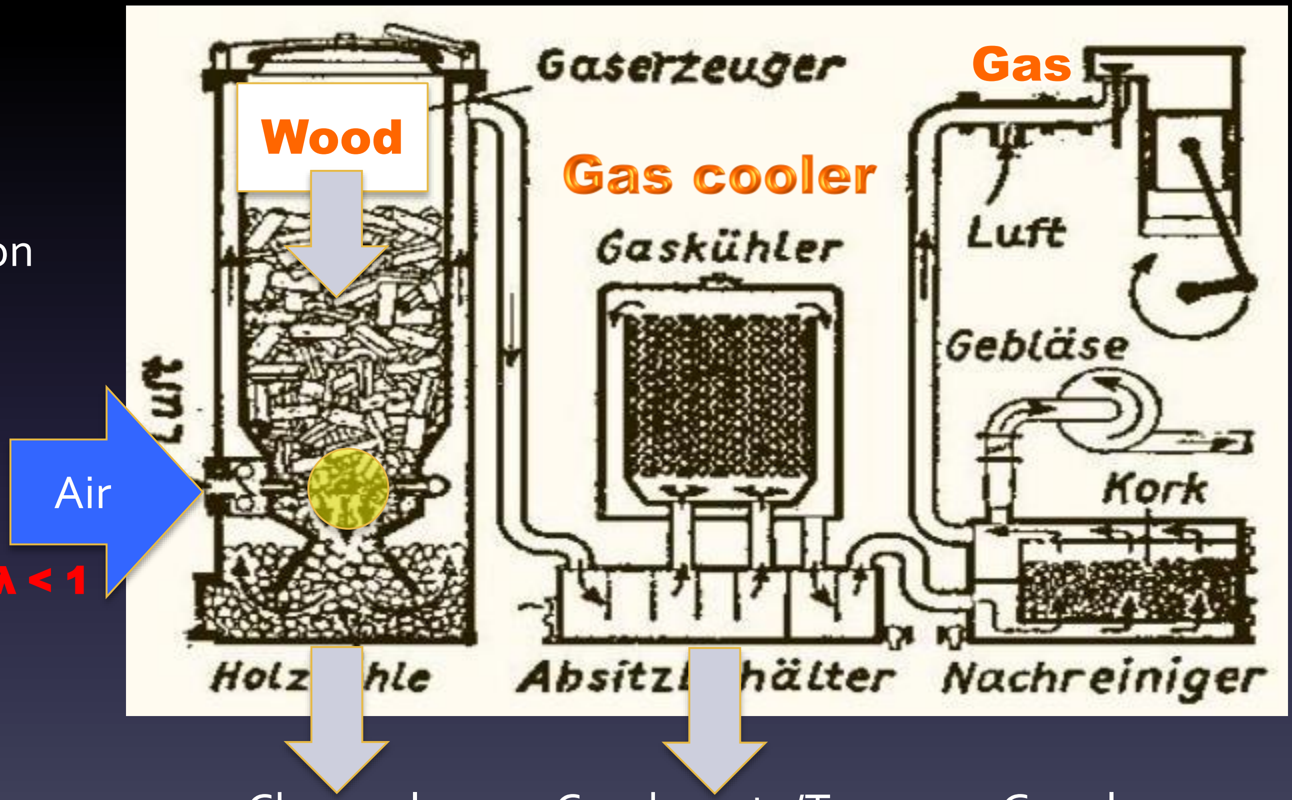
Inner chimney of burning fire with $\lambda < 1$

Early **Patents**

direct pyrolysis /Gasification

Carbonisation zone

Gasification zone



Gas engine

Fan

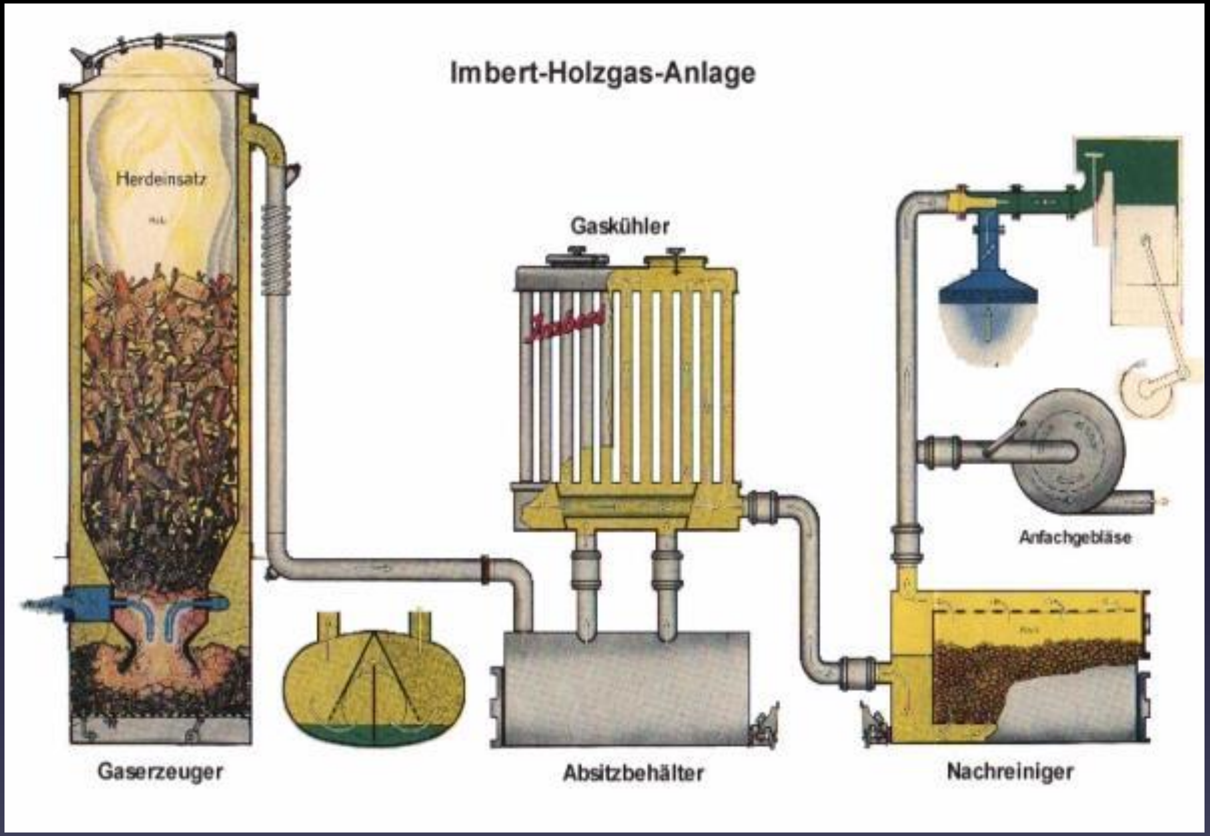
Charcoal

Condensate/Tar

Gas cleaner

Industrial design of early pyrolysis

Reactor



Engine

Pyrolysis in action you see it works

Pyrolysis a challenging technology

Almost all types of waste can be treated:

- Contaminated soil with poor heating value (indirect pyrolysis)
- Sludge
- Residues of petrol- and chemical industry
- Electronic scrap
- Municipal solid waste
- Refused derived fuel
- Plastic or tyres, hazardous qualities and other high calorific residues
- Agricultural residues, biomass
- Wood

Different types of waste need different technical designs

Pyrolysis input qualities I

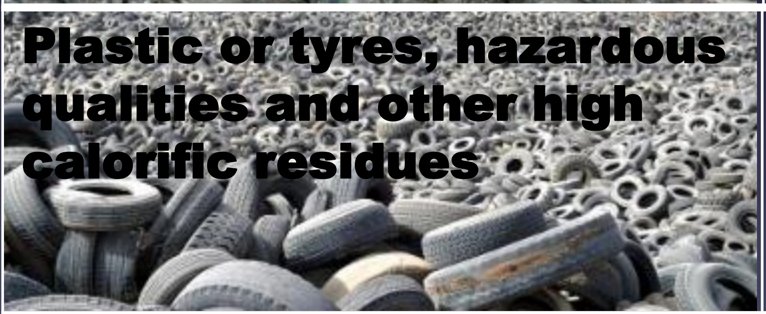
Almost no heating value at all. Its a **distillation process** to bring out volatile metal (mercury for example) or organic contaminants.
>> extremely high energy demand

Distillation process (Bayer Verfahren, low temperature conversion. End products : oil, carbon and minerals)

Various technologies. Various end products, various energy balance.

Various technologies. Various end products, various energy balance.

Pyrolysis input qualities II

Municipal Solid Waste (MSW) 	Various technologies. Various end products, various combination with other thermal plants like cement- or power plants. Various energy balance.
Refuse derived fuel (RDF) 	Various technologies. Various end products, various combination with other thermal plants like cement- or power plants. Various energy balance.
Plastic or tyres, hazardous qualities and other high calorific residues 	Various technologies. Various end products, various combination with other thermal plants like cement- or power plants. Various energy balance.

Pyrolysis input qualities III

	Various technologies. Various end products, BTX, biomass to liquid (BTL), charcoal. Various energy balance. Green energy
	Various technologies. Various end products, BTX, biomass to liquid (BTL), charcoal. Various energy balance. Green energy

Pyrolysis advantage

- Enables a **wide range of input material** with any desired heating values
- **Small gas volumes** to be treated

- **Possible first step for**

➢ gasification
➢ incineration or
➢ plasma- gasification or incineration

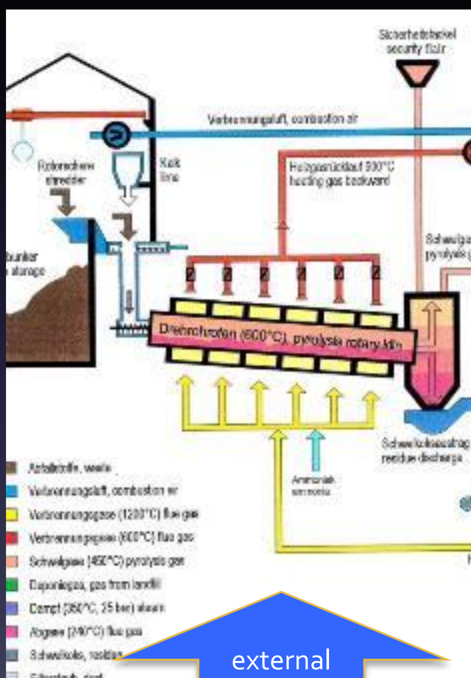
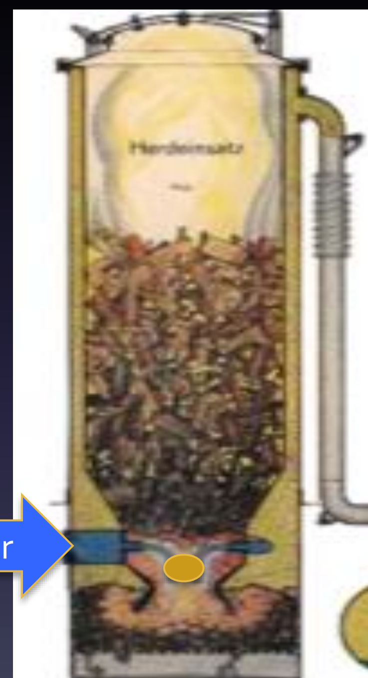
- **Storable end products** like charcoal, tar, liquid or gas
- Various possibilities to design solid, liquid or gaseous end products
- Possible combination with various subsequent thermal treatment facilities like power plants, cement industry or chemical industry

Pyrolysis operating criteria

Due to the quality of input- and the desired quality of output parameters, a wide variety of operational parameters are of concern:

- waste distribution, waste preparation or mixture inside or before the reactor
- internal / external heating
- addition of gaseous or solid additives
- temperature
- pressure
- temperature distribution as well as heating and retention characteristics inside the reactor

Variety of technological approach

Carbonisation	Gasification	Gasification + Plasma
		
external heating	internal heating	internal heating

Biomass to liquid (BTL)

Biofuel is working on the ground and in the air

Biodiesel **E10** is been sold on all German gasoline stations, **a proven technology**
(contains 5-10% Bioethanol, funded by the state)

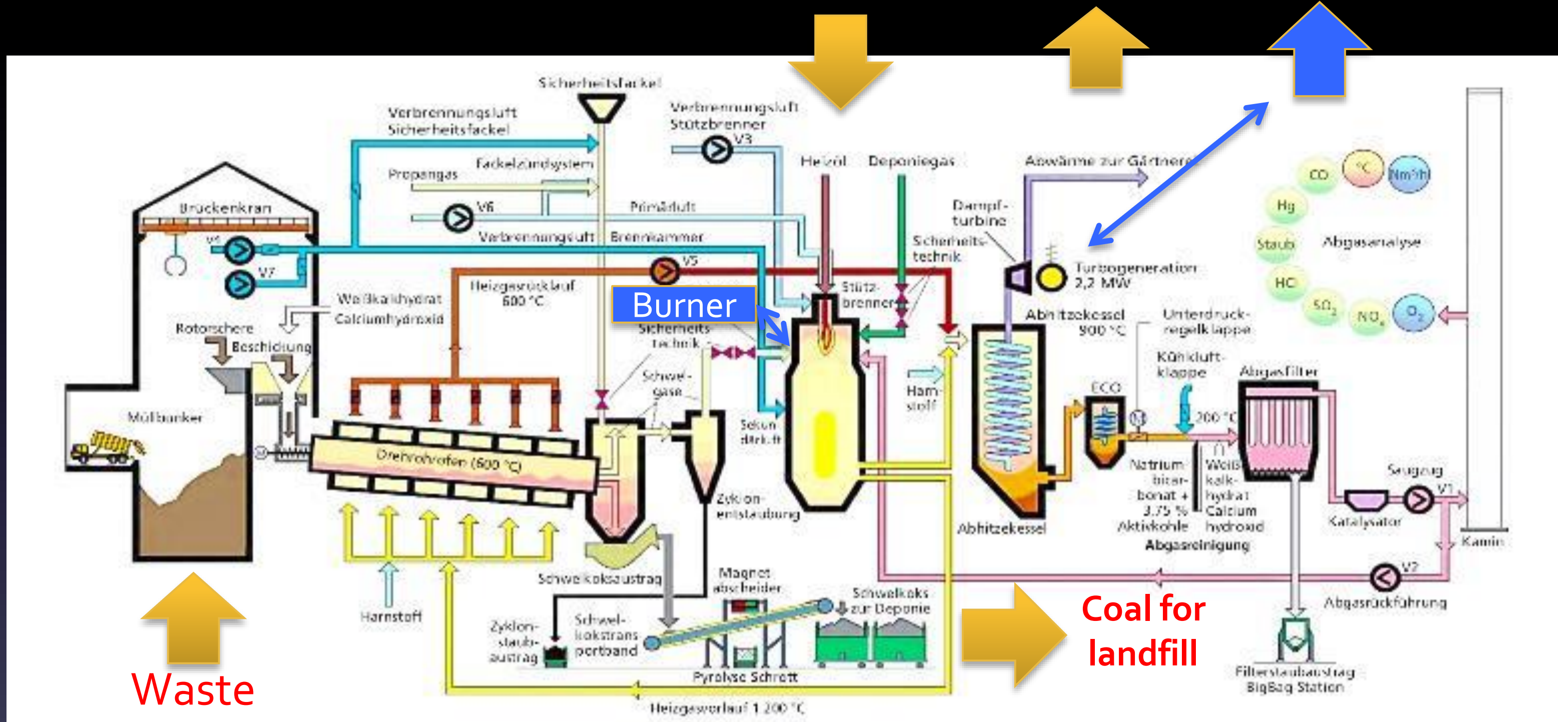
The production of fuel from **MSW** is something absolutely different although the technologies seem to be the same

Carbonisation Burgau

fuel and landfill gas

heat for greenhouse

electric power



Rotary kiln with external heating

Pyrolitic Burner

Heat exchange

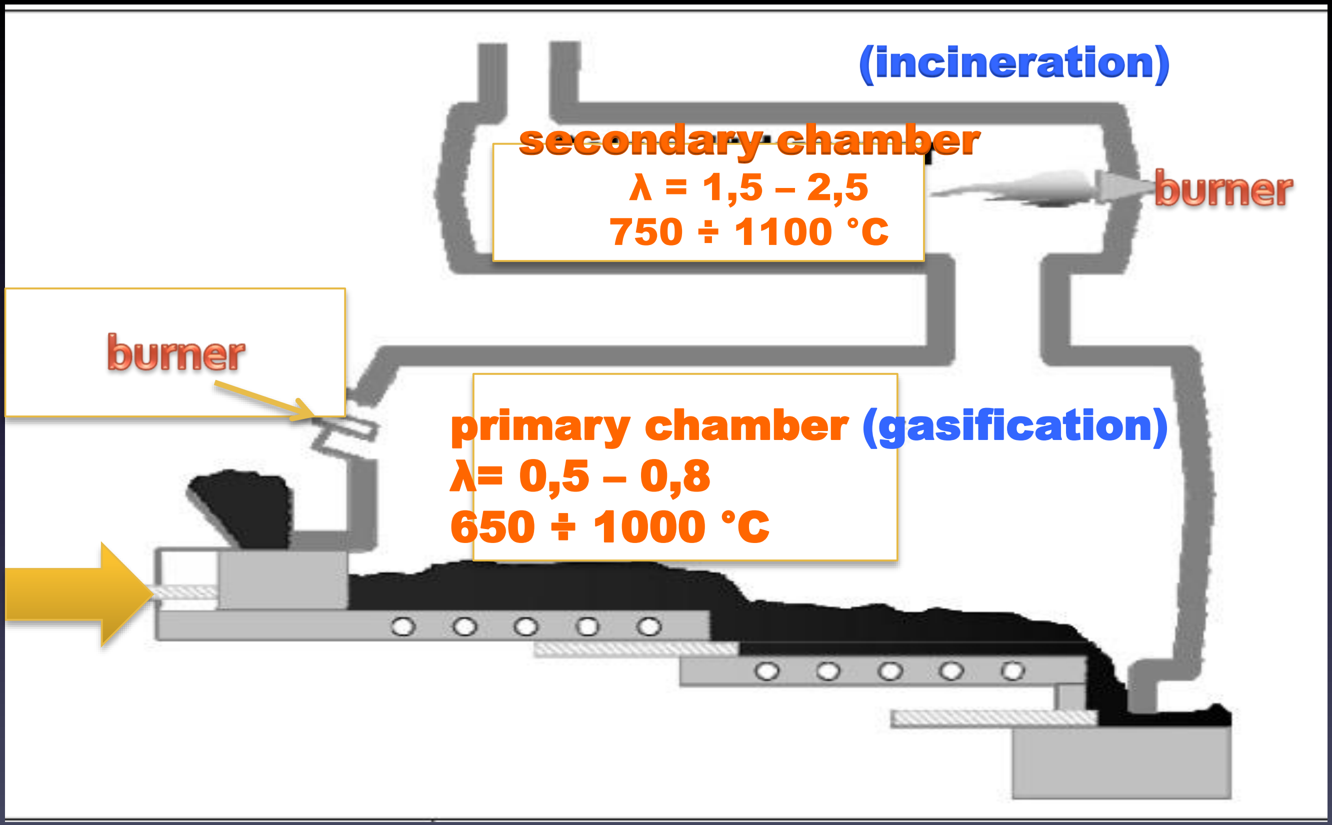
Carbonisation Burgau

- In operation since 1984
- Will be closed in the end of 2015
- Input 23.000 t/a **MSW**
- shredding
- addition of lime to the MSW
- two separate drums 3 t/hour
- economical operation from 4 t/hour on
- operation temperature 600 °C
- no problems with emission control
- thermal energy to greenhouse
- electrical energy to the grid
- using fuel and landfill gas to support the heating process
- efficiency to low to declare the installation as a recycling plant

- ◆ The solid rest (coal) got a high carbon content and is being brought to the landfill
- ◆ The plant will be closed, due to operation costs which are with 65 €/ton higher than the next MSW incineration

Gasification ⇨ incineration

Example for the separation of phases



Waste input

Gasification incineration

Thermoselect Karlsruhe, 225.000 tons / year, 1998 – 2004
Thermoselect Fondotoce, Italia, 4 tons / hour, 1992 -1999

- **Gasification process** using pure oxygen to achieve high temperatures of 1.200 °C in the reactor
- **Melting of slag** with 2.000°C for construction purposes

Both plants where closed due to:

- irreversible problems with the owners
- not hitting the standards although trying it hard for 6 ÷ 7 years
- not achieving the guaranteed throughput capacity
- The facility in Karlsruhe remains now as a ruin

Total loss for the German owner (EnBW) 400.000.000,- Euros

Plasma

Plasma gasification

- **Ionisation of gases** by strong electric current between two poles creating the plasma arc.
- **Plasma torches** are using inert gases, such as Argon
- **Torches temperatures** from 2.000 up to 14.000 °Celsius

→

- dissociation breaking down complex molecules into their individual atoms
- elemental components altered into gaseous phase

Result: highly calorific gases → Syngas

Special aptitude for hazardous waste

Problems with several builders

- **Lack of experience to achieve sufficient plant availability**
- Lack of voluntarily given, transparent information about the process under different conditions
- **Difference between builders vision and builders promise to the actually achieved performance**

- **Lack of robust results concerning**:

> Throughput capacity
> Process parameters
> Emission results
> Energy balance
> Availability
> Business performance

As long as this information is not being provided to the potential buyer it is difficult to make friends with the technology

Experience with different technologies *

Occidental Petroleum Company	• 1972 – 1979 • La Verne and El Cajon, San Diego, California • 90 t/day • Pyrolysis of **pre-treated MSW** • Ambition to win oil for power plants • Technical problems • closed due to high costs
Monsanto Enviro-Chem Systems	• 1973 – 1979 • Baltimore • 450 t/day • Pyrolysis of **shredded MSW** • Drum, 6m Diameter, 30 meters of length • Closed due to technical problems • Monsanto retired consequently from business
Kiener Pyrolysis KPA technology	• Small scale pilot reactors in the 70ties (Goldshöfe) • 1982 – 2002 (Aalen) • 3 t/hour • Pyrolysis of **pre-treated MSW** • Bankruptcy of the developer, overtaken by Siemens • Difficulties due to technical problems

* Source, M. Gleis / Umweltbundesamt and own investigations

Experience with different technologies II

PKA technology **Subsequent to KPA**	• Small plants in Aalen, Freiberg, Kawasaki , subsequent to KPA (until 2002) Freiberg plant sold to Pyral AG • Pyrolysis of **municipal solid waste (MSW)** • Cracking of gases, power production in gas motors to produce electricity • technical problems • 2007 Closed due to economical problems
Kobe Steel (Japan)	• Kobe plant for **Pyrolysis of tyres** • Rotary kiln, 2 t/hour, temperature 600 °C • several years of operation • no actual data available
PLEQ (Germany)	• Treatment plant for oil **contaminated sand** • since 1992 • 8 t/hour • Temperature up to 900 °C • successful operation for several years
Spolana (Republica Tcheca)	• Treatment plant for **dioxin contaminated soil** • Capacity 52.500 t/year • successful operation 2006 to 2008

Experience with different technologies III

Salzgitter Pyrolysis **(Germany**	• Pyrolysis of hazardous waste • operation period during the nineties • rotary kiln, corporate objective: precursor chemicals • substantial funding • technical problems • Closed due to economical problems after the end of funding
Pyrolysis Burgau **(Babkock Krauss Maffei)**	• Pyrolysis (carbonisation) of MSW (contaminated sludge from the leather industry (chrome)) • 1984 – 2015 • rotary kiln. temperature 470 – 500 °C • reliable operation • closed due to economical reasons (not competitive)
Duotherm / von Roll (RCP) **(Bremerhaven)**	• Pyrolysis of MSW • 6 t/hour (in year 2000) • Gasification with pure oxygen in combination with traditional MSW incineration (45 t/hour) • technical problems, never worked properly • closed due to technical/ economical reasons

Experience with different technologies IV

ZWT sludge conversion (Bayer Verfahren, LACOTEC)	• Pyrolysis of dried sludge (low temperature conversion) • temperature 350 – 400 °C • several demonstration plants, beginning 1987. One in Burlington, Canada, two in Brazil, one in Australia, one in Pfaffertal, Germany • substantial funding • technical problems, none of them worked properly • closed due to technical / economical reasons
GEM Graveson Energy Management (England)	• Pyrolysis • Syngas from MSW • 6.000 to 12.500 t/ year intended capacity intended • technical problems, • closed due to technical / economical reasons
Nexus (France))	• Pyrolysis • Syngas and charcoal • Demonstration plant in Chateaurenard 1995 • 1998 two contracts, one with 30.000t/year in Digny • 6.000 to 12.500 t/ year intended capacity intended • not realised due to insolvency in 2001

Experience with different technologies V

Thide Pyrolysis (France))	• Pyrolysis of MSW together with HITACH Ltd. • Syngas and charcoal • 50.000 t/year plant in ARRAS • closed due to bankruptcy in 2009
ConTherm, Hamm-Uentrop Mannesmann-PLEQ (TechTrade)	• Pyrolysis of RDF • rotary kiln 100.000 t/year • in combination with a coal fired power plant • cocombustion of pyrolitic gas, mixture of pyrolitic coal with hard coal (cogrinding) to coincineration • closed due to economical reasons
Destrugas (Denmark)	• Pyrolysis of MSW • First plant in Kalundborg 1971, • throughput 6 t/hour • other pilot plants in Japan and Berlin • all activities ended due to technical and economical reasons
Union Carbide System (PUROX)	• Gasification of MSW with clean oxygen • Demonstration plant in Charleston, USA • throughput 90 t/day • stopped further development due to technical and economical reasons

Experience with different technologies VI

Andco-Torrax (USA/Europe)	• Gasification of MSW • pilot plant in Orchard Park, NY (1971-1977) • further plants in Orlando,FL, (1982-1983), Frankfurt, Luxemburg in the eighties (closed almost directly after operation start) • Creteil 1979-1998 • closed due to insoluble technical problems and excessive demand of natural Gas to keep the process running
TPD Tsukishima Kikai System	• Gasification of MSW • Funabashi City (1983-1990) • closed due to insoluble technical problems
Brightstar Environmental, Wollonggong, Australia	• Gasification of pre-treated MSW • designed capacity 30.000 t/year • test phase 2001 to 2004 • closed due to insoluble technical and economical problems • subsequently, end of further planning of the Derby Plant in Great Britain

Experience with different technologies VII

Schwarze Pumpe (Germany) **British Gas – Lurgi (BGL)**	• Gasification to produce Syngas and transform it to Methanol • RDF and high calorific industrial waste • 30 t/hour • closed due to economical reasons. Plant is being rebuilt
Thermoselect	• Gasification of MSW • various plants, designed capacity 225.000 t/year (Karlsruhe, Germany) • technical problems in German and Italian plant • closed due to economical and technical reasons.
Noell- KRC Conversion Process, Würzburg, Germany	• Gasification of MSW • intended plant in Nordhessen • stopped, due to insolvency of the builder
Zementwerk Rüdersdorf, Germany	• Gasification of RDF • fluidised bed reactor • ZWS carburettor (Lurgi) 100 $MW_{therm.}$ • successful plant in combination with cement production

Conclusions

1. **Carbonisation**, **Gasification** and **Plasma technologies for MSW** are challenging developments in emerging markets
2. Very frequently an enormous **difference between promised and given performance** by the developer can be registered
3. In several cases the treatment **plants did not start to be built** due to overwhelming initial problems, **didn't fulfil the promised results, didn't work with the foreseen throughput** or where **closed after a relatively short time** due to disappointing results or **serious economical difficulties**
4. **The enormous funding** has not been sufficient to establish those technologies as relevant alternatives to traditional MSW incineration processes
5. It is difficult to interpret **results from Japan**, due to the specific Japanese conditions of little space, industrial density and high treatment costs of often more than 400€ per ton. There is hardly any transparent data basis available

Conclusions continued

6. It is astonishing, that even under our locational advantage of a highly developed industry in **Germany**, going along with enormous funding, neither carbonisation nor gasification or plasma for **MSW** were able to succeeded in the last decades. Neither technically, economically nor referring to energy efficiency standards

6. Different to the treatment of MSW, **far better results have been achieved with the treatment of special non MSW qualities** like:
   - Biomass from farming activities
   - Wood
   - Contaminated sand or soil
   - Tyres /plastic
   - Hazardous waste
   - electronic scrap

Conclusions continued

8. It is difficult to recommend **MSW treatment by Pyrolysis, gasification or plasma** due to numerous problems in the past

9. The experience has shown, that it was relatively often extremely difficult for those technologies:

   - to fulfil **reliable throughput criteria ,**
   - to achieve **acceptable energy efficiency**
   - to meet the **requirements for pollution control**
   - to achieve the **promised availability** and
   - to provide **competitive gate fees**

10. Other than for **MSW**, those technologies were able to give **valid solutions for special non MSW categories**

Recommendations

Its not easy, to find adequate alternatives to traditional MSW incineration

Better than almost all considered MSW alternatives
modern incineration plants are able to provide
low emissions, good energy efficiency
an often proven reliability
and acceptable gate fees.
Why not take those?

Thank you for your attention

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