Element Partitioning in Gasification-based Biomass-to-Energy systems

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The role of biomass for a sustainable energy production

Biomass is the oldest known source of energy and it is a renewable energy of great interest. Key problems regards:

✓ the unsteady availability, related to biomass seasonality and geographical distribution over the territory, which often makes the logistics complex and expensive;

✓ the energy production which should be not only environmental sustainable but also economic competitive.

Biomass can be converted to a variety of energy form, electricity, process heat for industrial facilities, domestic heating and vehicle fuels by means of biochemical (fermentation and anaerobic digestion) and thermochemical processes (combustion, pyrolysis and gasification).
Types of Biomass-to-Energy processes
Types of Biomass-to-Energy processes

Combustion is traditionally used to convert biomass energy into heat and power in process industry. It still has some drawbacks, such as:

- low energy efficiency
- high capital and maintenance costs.

Pyrolysis is the thermal degradation of biomass in a bio-oil, a solid fraction and a high-heating value gas. A wide application is still restricted by difficulties in the efficient processing of bio-oil.
Types of Biomass-to-Energy processes

**Gasification** converts biomass in a combustible gas mixture *(syngas)* mainly made of CO, H₂ and lower content of CH₄ and has several advantages over combustion of solid fuels:

- *a considerable reduction in the process gas volume*
- *a wide range of products immediately obtainable from syngas* (from electricity and heat generation in conversion devices to gaseous or liquid clean fuels, or bulk chemicals like ammonia and methanol)
- *a reduced amount of secondary wastes*
- *a good flexibility in plant size.*
Types of Biomass-to-Energy processes

Conversion Technology
- Gasification
- Combustion

Primary Products
- Fuel Gas

Product Recovery
- Chemical Synthesis
- Energy Recovery
- Gas Turbine
- Gas Engine
- Boiler

Secondary Products
- Chemicals
- Gasoline
- Methanol
- Ammonia
- Electricity + district heating
### Types of Biomass-to-Energy processes

<table>
<thead>
<tr>
<th>Aim of the process</th>
<th>Combustion</th>
<th>Gasification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>To maximize fuel conversion to high temperature flue gases, mainly CO₂ and H₂O. To maximize energy recovery.</strong></td>
<td>To maximize fuel conversion to fuel gases, mainly CO, H₂ and CH₄. <strong>To minimize residues to be sent to final landfill.</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operating conditions</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reaction environment</strong></td>
<td>Oxidizing</td>
<td>Reducing</td>
</tr>
<tr>
<td><strong>Reactant gas</strong></td>
<td>Air</td>
<td>Air, O₂-enriched air, pure O₂, steam</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td>Between 850°C and 1200°C</td>
<td>Between 550-900°C (in air gasification) and 1000-1600°C</td>
</tr>
<tr>
<td><strong>Pressure</strong></td>
<td>Generally atmospheric</td>
<td>Generally atmospheric</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process output</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Produced gases</strong></td>
<td><strong>FLUE GAS</strong>, mainly CO₂, H₂O, O₂</td>
<td><strong>FUEL GAS</strong>, mainly CO, H₂, CH₄, CO₂</td>
</tr>
<tr>
<td><strong>Pollutants</strong></td>
<td>SO₂, NOₓ, HCl, PCDD/F, particulate</td>
<td>H₂S, HCl, COS, NH₃, HCN, tar, alkali, particulate</td>
</tr>
<tr>
<td><strong>Ash</strong></td>
<td>Bottom ash can be treated (typically in an external site) to recover ferrous and non-ferrous metals (such as Al, Cu and Zn) and inert materials (to be utilized as a sustainable building material). APC residues are treated and disposed as industrial waste.</td>
<td>Metals can be recovered. Bottom ash can be produced as vitreous slag that can be utilized as backfilling material for road construction. APC residues are treated and disposed as industrial waste.</td>
</tr>
<tr>
<td><strong>Gas cleaning</strong></td>
<td>Flue gas is treated in air pollution control units to meet the emission limits.</td>
<td>It is possible to clean the syngas to meet standards of chemicals production processes or those of high e.e. efficiency conversion devices.</td>
</tr>
</tbody>
</table>
## Taxonomy of combustion-based systems

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Types</th>
</tr>
</thead>
</table>
| Reactor type             | - moving grate  
                          - fluidized bed: bubbling, circulating, internally circulating, dual  
                          - rotary kiln                                                      |
| Oxidizing agent          | - air  
                          - oxygen enriched-air                                                 |
| Number of treated fuels  | - combustion  
                          - co-combustion                                                      |
| Heat recovery            | - electric energy  
                          - district Heating  
                          - CHP (combined heat and power)                                      |
| Bottom ash status        | - dry bottom ash  
                          - vitrified slag (when coupled with a melting system)
## Taxonomy of gasification-based systems

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Types</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heat supply</strong></td>
<td>▪ auto-thermal (directly heated)</td>
</tr>
<tr>
<td></td>
<td>▪ allo-thermal (indirectly heated)</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td>▪ low-temperature (typically below 900°C)</td>
</tr>
<tr>
<td></td>
<td>▪ high-temperature (typically above 1200°C)</td>
</tr>
<tr>
<td><strong>Gasification agent</strong></td>
<td>▪ air</td>
</tr>
<tr>
<td></td>
<td>▪ oxygen enriched-air</td>
</tr>
<tr>
<td></td>
<td>▪ oxygen</td>
</tr>
<tr>
<td></td>
<td>▪ steam</td>
</tr>
<tr>
<td><strong>Number of treated fuels</strong></td>
<td>▪ gasification</td>
</tr>
<tr>
<td></td>
<td>▪ co-gasification</td>
</tr>
<tr>
<td><strong>Reactor type</strong></td>
<td>▪ fixed bed: up-draft ; down-draft; shaft furnace</td>
</tr>
<tr>
<td></td>
<td>▪ fluidized bed: bubbling, circulating, internally circulating, dual</td>
</tr>
<tr>
<td></td>
<td>▪ rotary kiln</td>
</tr>
<tr>
<td></td>
<td>▪ moving grate</td>
</tr>
<tr>
<td></td>
<td>▪ plasma: single and double stage</td>
</tr>
<tr>
<td><strong>Bottom ash status</strong></td>
<td>▪ dry bottom ash</td>
</tr>
<tr>
<td></td>
<td>▪ vitrified slag (melting system)</td>
</tr>
<tr>
<td><strong>WtE configuration</strong></td>
<td>▪ heat gasifiers</td>
</tr>
<tr>
<td></td>
<td>▪ power gasifiers</td>
</tr>
</tbody>
</table>
Autothermal gasification

**Drying**
\[ \text{fuel} \rightarrow \text{dry fuel} + \text{H}_2\text{O} \]

**Pyrolysis**
\[ \text{dry fuel} \rightarrow \text{gas} + \text{char} + \text{tar} \]

**Partial Oxidation**
\[
\begin{align*}
\text{C} + \frac{1}{2} \text{O}_2 & \rightarrow \text{CO} \\
\text{H}_2 + \frac{1}{2} \text{O}_2 & \rightarrow \text{H}_2\text{O} \\
\text{C}_n\text{H}_m + \frac{n}{2} \text{O}_2 & \rightarrow n \text{CO} + \frac{m}{2} \text{H}_2
\end{align*}
\]

**Gasification**
\[
\begin{align*}
\text{C} + \text{CO}_2 & \leftrightarrow 2\text{CO} \\
\text{C} + \text{H}_2\text{O} & \leftrightarrow \text{CH}_4 \\
\text{C}_n\text{H}_m + n\text{H}_2\text{O} & \leftrightarrow n \text{CO} + (n+m/2)\text{H}_2 \\
\text{C}_n\text{H}_m + n\text{CO}_2 & \leftrightarrow 2n \text{CO} + m/2 \text{H}_2
\end{align*}
\]

**Producer Gas**
- H\text{_2}O
- Tar
- CH\text{_4}
- CO\text{_2}
- H\text{_2}O
- C\text{_nH}_m (n>2)
- CO
- H\text{_2}
**Scope**

- to provide data for a careful description of the performances and critical comparison of biomass-to-energy options, by means of element partitioning studies in different type of combustion and/or gasification-based processes.

Data from experimental pilot plant reactors or commercial units in operation has been processed by a Material and Substance Flow Analysis (MFA/SFA).

MFA/SFA defines and compare the patterns of some crucial elements of solid waste throughput the different units of the compared plants/processes, in order to obtain reliable information about their partitioning.
Assessment tool: MFA/SFA

Fuel and thermal process data (fuel amount and composition, transfer coefficients, gas and solid residues, etc.)

Technical tools (material balances, energy balance, allocation models, etc.)

Energy system definition

Analytical tools

Material Flow Analysis

Substance Flow Analysis

Life Cycle Analysis

Element partitioning
Small scale biomass-to-energy gasification-based systems
**Scope**

- to evaluate and compare the technical and economic performance of the most promising design configurations for the small scale industrial application of gasification-based biomass-to-energy cogenerators.

To this end, a number of tests with a selected natural biomass was carried out in a pilot scale BFB air gasifier. The collected experimental data were processed by mass and energy balances and MFA/SFA analyses, in order to obtain information useful to define design solutions and configurations suitable for different electricity generation devices.
The FluGas reactor
## The FluGas reactor

### Geometrical parameters
- ID: 0.381m; total height: 5.90m; reactive zone height: 4.64m; wall thickness: 12.7mm

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedstock capacity</td>
<td>100 kg/h</td>
</tr>
<tr>
<td>Thermal output</td>
<td>up to about 400kW</td>
</tr>
<tr>
<td>Typical bed amount</td>
<td>145 kg</td>
</tr>
<tr>
<td>Feeding system</td>
<td>over-bed air-cooled screw feeder</td>
</tr>
<tr>
<td>Gasifying agents</td>
<td>Air (but also: oxygen, steam, carbon dioxide)</td>
</tr>
<tr>
<td>Range of bed temperatures</td>
<td>700-950°C</td>
</tr>
<tr>
<td>Range of fluidizing velocities</td>
<td>0.3-1m/s</td>
</tr>
<tr>
<td>Flue gas treatments</td>
<td>cyclone, scrubber, flare</td>
</tr>
<tr>
<td>Safety equipments</td>
<td>water seal, safety valves, rupture disks, alarms, nitrogen line for safety inerting</td>
</tr>
</tbody>
</table>

![Diagram of the FluGas reactor](image)

*HEAT*<br>INERT BED MATERIAL<br>FEEDSTOCK<br>STREAM<br>20°C 3barG<br>AIR<br>CO₂<br>N₂<br>WATER<br>0.3 barG<br>80°C 200°C-600°C<br>CO₂<br>HEAT01<br>20°C 3barG<br>HEAT02<br>180°C 3barG<br>500°C 3barG<br>850°C 1bar<br>CYCLONE<br>250°C 1bar<br>SCRUBBER<br>FLARE<br>50°C 1bar<br>DRAINS
### The materials tested

#### Ultimate analysis, % wt, ar

<table>
<thead>
<tr>
<th></th>
<th>natural wood</th>
<th>SRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>45.7-46.1</td>
<td>41.2-45.4</td>
</tr>
<tr>
<td>H</td>
<td>5.6</td>
<td>6.0-6.5</td>
</tr>
<tr>
<td>N</td>
<td>0.33</td>
<td>0.66-0.70</td>
</tr>
<tr>
<td>S</td>
<td>0.01</td>
<td>0.1-0.3</td>
</tr>
<tr>
<td>Cl</td>
<td>&lt;0.1</td>
<td>0.1-0.2</td>
</tr>
<tr>
<td>O (by diff.)</td>
<td>6.9-7.1</td>
<td>22.9-24.2</td>
</tr>
<tr>
<td>Moisture</td>
<td>1.3</td>
<td>3.7-9.1</td>
</tr>
<tr>
<td>Ash</td>
<td>1.2-1.4</td>
<td>18.5-20.4</td>
</tr>
</tbody>
</table>

#### Heating value, MJ/kg fuel, ar

<table>
<thead>
<tr>
<th></th>
<th>natural wood</th>
<th>SRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHV</td>
<td>15,900</td>
<td>16,600-19,200</td>
</tr>
</tbody>
</table>

#### Ash composition, mg/kg db

<table>
<thead>
<tr>
<th></th>
<th>natural wood</th>
<th>SRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al2O3</td>
<td>150</td>
<td>10,500-17,900</td>
</tr>
<tr>
<td>Sb</td>
<td>&lt;50</td>
<td>&lt;50</td>
</tr>
<tr>
<td>As</td>
<td>&lt;50</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Cd</td>
<td>&lt;50</td>
<td>&lt;50</td>
</tr>
<tr>
<td>CaO</td>
<td>1750</td>
<td>62,500-82,600</td>
</tr>
<tr>
<td>Cr</td>
<td>0.95</td>
<td>&lt;50-130</td>
</tr>
<tr>
<td>Co</td>
<td>0.17</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Cu</td>
<td>-</td>
<td>106-319</td>
</tr>
<tr>
<td>Zn</td>
<td>314-386</td>
<td>87-162</td>
</tr>
<tr>
<td>MgO</td>
<td>465</td>
<td>3130-6720</td>
</tr>
<tr>
<td>MnO</td>
<td>15</td>
<td>3140-35,200</td>
</tr>
<tr>
<td>Hg</td>
<td>0.1</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Ni</td>
<td>0.35</td>
<td>&lt;50-67</td>
</tr>
<tr>
<td>P2O5</td>
<td>n.d.</td>
<td>2460-3200</td>
</tr>
<tr>
<td>K2O</td>
<td>330</td>
<td>5410-9070</td>
</tr>
<tr>
<td>Na2O</td>
<td>&lt;50</td>
<td>&lt;50</td>
</tr>
<tr>
<td>V</td>
<td>314-386</td>
<td>1200-1950</td>
</tr>
<tr>
<td>Cl</td>
<td>&lt;50</td>
<td>&lt;50</td>
</tr>
</tbody>
</table>

#### Olivine

**Chemical composition, %**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>39-42</td>
</tr>
<tr>
<td>MgO</td>
<td>48-50</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>8-10.5</td>
</tr>
<tr>
<td>CaO</td>
<td>&lt;0.4</td>
</tr>
<tr>
<td>K2O</td>
<td>-</td>
</tr>
<tr>
<td>TiO2</td>
<td>-</td>
</tr>
<tr>
<td>Al2O3</td>
<td>0.8</td>
</tr>
<tr>
<td>Cr2O3</td>
<td>0.8</td>
</tr>
<tr>
<td>Mg3O4</td>
<td></td>
</tr>
</tbody>
</table>

**LOI (loss of ignition)**: 0.20

**Size range, μm**: 200 ÷ 400

**Sauter mean diameter, μm**: 298

**Particle density, kg/m³**: 2900

#### Mg-Fe silicate

**Chemical composition, %**

<p>| | |</p>
<table>
<thead>
<tr>
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</tr>
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<tbody>
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<tr>
<td>CaO</td>
<td>&lt;0.4</td>
</tr>
<tr>
<td>K2O</td>
<td>-</td>
</tr>
<tr>
<td>TiO2</td>
<td>-</td>
</tr>
<tr>
<td>Al2O3</td>
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<tr>
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<td>Mg3O4</td>
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**LOI (loss of ignition)**: 0.20

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**Sauter mean diameter, μm**: 298

**Particle density, kg/m³**: 2900
The experimental procedure
Possible design configurations

The configurations for the gasification-based industrial plants are a combination of three sections:

- Syngas production
- Syngas utilization
- Syngas/flue gas cleaning.

The relative succession of the utilization and cleaning sections defines the two possible configurations of biomass-to-energy gasification system:

- Power gasification where the syngas is first cleaned than burned,
- Heat gasification where the syngas is first burned than cleaned.

where the syngas is first burned than cleaned.
### Types of energy devices for BtE systems

- **Boiler and steam turbine**
- **Low NOₓ gas burner**
- **Gas engine**
- **Gas turbine**

#### LEVEL OF SYNGAS CLEANING

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Boiler</th>
<th>Gas Engine</th>
<th>Gas Turbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHV, MJ/m³_N</td>
<td>Unlimited</td>
<td>≥ 4</td>
<td>≥ 4</td>
</tr>
<tr>
<td>Tar, mg/m³_N</td>
<td>Unlimited</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>Particulate, mg/m³_N</td>
<td>Unlimited</td>
<td>50</td>
<td>2.5</td>
</tr>
<tr>
<td>Alkalies (Na, K), ppmw</td>
<td>Unlimited</td>
<td>0.025 – 0.1</td>
<td>0.025 – 0.1</td>
</tr>
<tr>
<td>Heavy metals (Pb, Hg, V), ppmw</td>
<td>Unlimited</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>H₂S, ppmv</td>
<td>unlimited</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>
Gasification section_MFA/SFA-alternative

Total mass [kg/h]

Carbon [g/h]

Feedstock energy [MJ/h]
## Energy generation section

<table>
<thead>
<tr>
<th>Energy Conversion Device</th>
<th>Gasification Plant Net Elec. Eff.</th>
<th>Main advantages</th>
<th>Main disadvantages</th>
</tr>
</thead>
</table>
| Steam Turbine            | 10-20%                            | • Turbine components are isolated from combustion products  
 • Long maintenance intervals, high availability  
 • High specific work (kJ/kg yielded for working fluid) | • Expensive  
 • Electrical efficiency is low at small sizes  
 • Partial load decreases efficiency significantly  
 • Plants is extremely large due to space requirements for the condenser and the boiler |
| Externally Fired Gas Turbine | 10-20%                            | • Turbine components are isolated from combustion products  
 • Electrical efficiency is acceptable even at small sizes  
 • Long maintenance intervals, high availability  
 • Ideal for cogeneration plants (CHP) due to high exhaust temperatures | • Expensive  
 • Heat exchanger is exposed to high temperature, aggressive combustion gases  
 • Partial load decreases efficiency |
| Gas Turbine              | 15-25%                            | • Electrical efficiency is good even at small sizes  
 • Compact assembly  
 • Long maintenance intervals, high availability  
 • Ideal for cogeneration plants (CHP) due to high exhaust temperatures | • Turbine components are exposed to combustion products  
 • Partial load decreases efficiency significantly  
 • Moderately expensive |
| Gas Engine               | 13-28%                            | • High electrical efficiency also at small sizes  
 • Relatively inexpensive  
 • Durable and reliable  
 • Partial load effects efficiency only marginally | • Engine components are exposed to combustion products  
 • Short and expensive maintenance intervals, low availability |
Gas Engine configuration: mass and energy balances

**Gasification section**: BFB reactor and Cyclone

**Conditioning and cleaning section**: Air preheating heat exchanger, Dissipator, Scrubber, Chiller and demister.

**Electricity generation section**: Gas engine and exhaust gas treatment section.
Externally-Fired Gas Turbine configuration: mass and energy balances

**Gasification section**: BFB reactor and Cyclone

**Combustion and heat recovery section**: Syngas combuster, Gasification air preheater, High Temperature Heat Exchanger, Air pollution Control.

**Electricity generation section**: Externally-fired gas turbine and an Auxiliary burner.
Conclusions

The industrial application of gasification based, biomass-to-energy cogenerators in the 100-600 kWe range has been investigated and the performances of two promising design configurations, which implement a GE and an EFGT respectively, have been evaluated.

Mass/energy balances and MFA/SFA analyses drawn for each design solution were based on the experimental data obtained from a pilot scale BFB air gasifier and on the basis of the performance data claimed by the manufacturers. Although the two alternative plant configurations are based on an identical gasification section, they differ in their energetic and environmental performance.
Conclusions

• In the gas engine configuration, the cleaning section (air preheating heat exchanger, dissipator, scrubber, chiller and demister) plays the role of an interface between the characteristics of the producer gas and those required by the generator set. This solution offers the higher reliability and provides the higher IRR.

• In the gas turbine configuration, the cleaning section is the typical APC system (pre-treatment of the syngas to remove contaminants before it goes into the combustor, high temperature heat exchanger and air pollution control for flue gas cleaning). This solution has a great potential of improvement in technical and economic performances.

• The choice has to account for site specific variables such as the presence of a heat demand and the costs of waste streams treatment and disposal. APC system
Element partitioning in combustion- and gasification-based waste-to-energy units
**Scope**

- to investigate the partitioning of crucial elements in combustion and gasification WtE units, with particular attention to low-boiling-point heavy metals and to their concentrations in solid residues with reference to reuse or disposal scenarios.

The recovery of metals and inert materials from output solid streams defines the possible recovery of valuable materials such as Cu, Fe, Al and, above all, the amount of residues to be sent to final disposal.

This aspect is becoming crucial since the shortage of traditional disposal sites, together with stricter requirements for location and more severe environmental controls, have resulted in a strong reduction of the number of adequate sites for safe landfills, especially in areas at high density of population.
Many factors can influence whether and in what form a trace element eventually ends up in the gaseous or particulate phase:

i) how the trace element resides in the fuel
ii) presence of halogens (in particular, of chlorine)
iii) presence of sorbent compounds
iv) system temperature and pressure
v) oxidizing or reducing conditions
Mass balance of a Combustion-based WtE

Oxidant medium: air
ER: 1.7
Urea: 4.6 kg/t_{waste}
Hydrated lime: 10 kg/t_{waste}
Activated Carbon: 1 kg/t_{waste}

All the values are in t/d

Source: Arena and Di Gregorio, Waste Management (2013) 33: 1142-1150
Oxidant medium: air and O₂ enriched air (O₂ = 36%)
ER: 0.26
Urea: 4.6 kg/t_waste
Hydrated lime: 6.5 kg/t_waste
Activated Carbon: 0.5 kg/t_waste
Input data: Gasification-based WtE

- High-temperature and reducing atmosphere
- Gas combustion and energy recovery
  - Combustible gases with low content of NOx, SOx, HCl and other hazardous components

- Drying & Preheating Zone: 300 to 400°C
- Thermal Decomposition Zone: 400 to 1,000°C
- Combustion Zone: 1,000 to 1,700°C
- Melting Zone: 1,700 to 1,800°C

Molten materials:
- Recycling as slag and metal
- The produced slag is harmless which has almost the same quality as natural sand.

- High-temperature Reducing Atmosphere
  - 1,700 ~ 1,800°C

- Coke bed

Pb, Zn, PbO, ZnO, CO, CO
Input data: waste composition

Organic: 35.4
Paper: 20.5
Plastics: 11.0
Glass: 4.9
Metals: 2.8
Textiles: 3.8
Others: 21.6

Source: CEWEP, 2009
WtE combustion-based: typical mass flows

Mass flows (t/d)

- Residual waste: 1,000.0 t/d
- Air: 6,350.0 t/d
- Urea: 4.6 t/d
- Residues Recovery: 220.0 t/d
- Fly ash: 22.2 t/d
- Bottom ash: 27.3 t/d
- Hydrated lime: 10.0 t/d
- Activated carbon: 1.0 t/d
- Uncleaned flue gas: 7,129.5 t/d
- Cleaned flue gas: 7,118.3 t/d

Approximately 22% of the mass flows are related to residues recovery, and approximately 3% are related to solid residues.
WtE gasification-based: typical mass flows

Shin-moji plant (JP):
4.2% landfill; 8.6% slag; 1.4% metal

Akita center (JP):
2.8% landfill; 11.0% slag; 1.7% metal
Fate of Chlorine

All the values are in kg/d

12%

87.4%

KCl, PbCl₂, ZnCl₂

0.4%

98.9%

All the values are in kg/d
Many factors can influence whether and in what form a trace element eventually ends up in the gaseous or particulate phase:

i) how the trace element resides in the fuel
ii) presence of halogens (in particular, of chlorine)
iii) presence of sorbent compounds
iv) system temperature and pressure
v) oxidizing or reducing conditions
Fate of Zinc

- **ZnSiO₄**: 45%
- **ZnAl₂O₄**: 55%
- **ZnCl₂**: 0.9%

All the values are in kg/d
Fate of Lead

All the values are in kg/d

55%

45%

1.9%

98.1%
## Slag leaching tests in two HT gasifiers

<table>
<thead>
<tr>
<th>Element</th>
<th>Regulation (JIS K0058)</th>
<th>Plant A (Nippon Steel DMS)</th>
<th>Plant B (JFE G+MS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
</tr>
<tr>
<td>Cd</td>
<td>&lt; 0.01</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Pb</td>
<td>&lt;0.01</td>
<td>&lt;0.005</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Cr$^{6+}$</td>
<td>&lt;0.05</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>As</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>T-Hg</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Se</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;0.002</td>
</tr>
<tr>
<td>F</td>
<td>&lt;0.8</td>
<td>-</td>
<td>&lt;0.08</td>
</tr>
<tr>
<td>B</td>
<td>&lt;1.0</td>
<td>-</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>
**Summary of MFA/SFA results**

<table>
<thead>
<tr>
<th>mass flow rates</th>
<th>Combustion-based WtE</th>
<th>Gasification-based WtE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom Ash</td>
<td>APC residues</td>
<td>Flue Gas</td>
</tr>
<tr>
<td>mass, kg/t_{waste}</td>
<td>220</td>
<td>27.3</td>
</tr>
<tr>
<td>C, kg/t_{waste}</td>
<td>2.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Cl, g/t_{waste}</td>
<td>432</td>
<td>3145</td>
</tr>
<tr>
<td>S, g/t_{waste}</td>
<td>650</td>
<td>624</td>
</tr>
<tr>
<td>Pb, g/t_{waste}</td>
<td>110</td>
<td>90</td>
</tr>
<tr>
<td>Zn, g/t_{waste}</td>
<td>324</td>
<td>396</td>
</tr>
</tbody>
</table>

Source: Arena and Di Gregorio, Waste Management (2013) 33: 1142-1150
Conclusions

The study developed a SFA for the two most common technologies of combustion- and gasification-based WtE units, so estimating the partitioning of mass flows of materials and elements on the basis of data coming from commercial units.

Moving grate combustion process is a sustainable WM option that allows a significant amount of energy and a considerable waste volume reduction. The concentrations of low-boiling-point heavy metals (Pb and Zn) are equally distributed between bottom ash and APC residues: this implies that bottom ash from CB-WtE units cannot be considered as immediately recyclable.
Conclusions

In the gasification melting process the volatilization of low-boiling-point heavy metals (Pb and Zn) is almost 100%: these metals volatilized as metals in the melting furnace and then were condensed as sulphides as the gas temperature decreases by the APC system.

At the same time, most of high-boiling-point metals (Fe and Cu) are mainly distributed in metal stream at rates of about 90%.

These results, coupled with those of slag leaching and acid-extraction tests, indicate that slags are generally recyclable, allowing a reduction of about 20% of the amount of waste to be sent to final landfill.
Thank You for your attention