Increasing WtE Thermal Efficiency: Sharing Energy with Industry

two cases from Sweden and the UK

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Waste-to-Energy in 1980s

- stand-alone facilities
- publicly owned
- processing bulky MSW (< 10 MJ/kg)
- ‘simple’ power cycle: boiler - turbine - condensor
- plant efficiency < 24%
- main income: ‘gate fee’ + electricity & recovered materials

ISVAG, Antwerp (Belgium)
Keppel Seghers construction: 1980 & 1999
Plant availability 2009: 95%
## Technological Developments (EU)

<table>
<thead>
<tr>
<th>Year</th>
<th>Developments</th>
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</table>
| 1980 | - landfilling dominant  
      - combustion of bulky household waste  
      - experiences with corrosion damage  
      - focus on reducing emissions: dioxines, Cl & S  
      - efficiency no issue  
      - local/regional laws |
| 1990 | - growing knowledge on corrosion  
      - focus on optimizing WtE-boiler design  
      - emissions remain important  
      - experiences with RDF and sorted waste (LHV ≥ 11 MJ/kg)  
      - EU waste policy ("Lansink’s ladder") |
| 2000 | - corrosion prevention & monitoring  
      - optimization of combustion (control)  
      - increasing focus on efficiency & CO₂  
      - emissions: NOx, PM  
      - residues  
      - EU waste policy: WID → WFD |
| ≥ 2010 |                  |

*Keppel Seghers - Solutions for a Cleaner Future*
## Fuels: Chemical Composition

<table>
<thead>
<tr>
<th>mass % (dry)</th>
<th>coal</th>
<th>biomass</th>
<th>waste</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>black</td>
<td>lignite</td>
<td>avg</td>
</tr>
<tr>
<td>C</td>
<td>70</td>
<td>60 - 75</td>
<td>45</td>
</tr>
<tr>
<td>H</td>
<td>4 - 6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>O</td>
<td>3 - 10</td>
<td>15 - 40</td>
<td>~ 0.5</td>
</tr>
<tr>
<td>N</td>
<td>~ 1.5</td>
<td>0.5 - 1.5</td>
<td>~ 0.5</td>
</tr>
<tr>
<td>S</td>
<td>~ 1 (0.1 - 2.5)</td>
<td>0.5 - 3</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Cl</td>
<td>~ 0.1 (0.01 - 0.8)</td>
<td>&lt;0.1</td>
<td>0.01 - 0.2</td>
</tr>
<tr>
<td>Na</td>
<td>0.02</td>
<td>&lt;0.5</td>
<td>0.02 - 0.05</td>
</tr>
<tr>
<td>K</td>
<td>0.06</td>
<td>&lt;0.15</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>LHV (MJ/kg)</td>
<td>40 – 45</td>
<td>10 – 20</td>
<td>~18</td>
</tr>
</tbody>
</table>
Limiting Corrosion (high Temp)

- corrosion limit \( \rightarrow \) boiler efficiency limit
- steam *standard* 400°C @ 40 bar = econ. optimum
- higher steam parameters = maintenance cost increase

1. Fouling
2. \( \text{Cl}_2 \): diffusive reaction
3. \( \text{SO}_2 \): amplification
Limiting LHV

- LHV: Coal > Biomass > Waste (MSW)
- Origin of cost difference (per $MW_{EL}$ installed)

<table>
<thead>
<tr>
<th></th>
<th>$LHV_{coal} / LHV_{waste}$</th>
<th>$\approx 40/10$</th>
</tr>
</thead>
<tbody>
<tr>
<td>plant efficiency correction</td>
<td>$\times (25% / 40%)$</td>
<td></td>
</tr>
<tr>
<td>WtE-boiler protection materials</td>
<td>$+ 10%$</td>
<td></td>
</tr>
<tr>
<td>boiler investment WtE / coal</td>
<td>$\approx 3$</td>
<td></td>
</tr>
</tbody>
</table>

- Production of RDF/SRF $\rightarrow LHV_{MSW} \times 2$ (roughly)
  - mechanical & thermal treatment $\rightarrow$ energy consuming $\rightarrow CO_{2, EQ} \uparrow$
  - composting & anaerobic digestion $\rightarrow$ quality issues residues
- RDF $\rightarrow$ Cl $\uparrow$ $\rightarrow$ corrosion risk $\uparrow$ $\rightarrow$ maintenance cost $\uparrow$
Climate Impact

• RDF-production sensible as part of integrated waste management approach
  - regional/national level → coherent policy required
  - match energetic debits & credits of waste processing sites

• Waste-to-Energy = reducing carbon footprint
  - sole major energy contributor in waste treatment ‘chain’
  - plant energetic efficiency = key control parameter
  - combined heat & power → net reduction of CO$_2$,$_{\text{EQ}}$ !
Climate Impact

Ragoßnig et al. (2009)

Case Study Austria

Ragoßnig et al. (2009)

Climate Impact

![Graph showing CO\textsubscript{2}eq emissions for different processes: RDF co-comb (clinker production), WtE CHP 75%, WtE El-only 25%, and Landfill + LFG. The graph indicates a net GHG emission reduction for RDF co-comb and WtE CHP compared to WtE El-only and Landfill + LFG.](image)
Two CHP examples

Greater Manchester Waste (Runcorn, UK)
Nordic Paper (Åmotfors, Sweden)
Case 1: Åmotfors (Sweden)

Commissioned: 2010
Combustion Design

- 9.5 Mg/h @ 10.5 MJ/kg
- municipal waste mix
- max. steaming range: 9.5 – 14 MJ/kg
- 1 line @ 27.8 MW_{th}
Steam Cycle Design

- **SH steam from WtE**
- **Backup boiler**
- **Accu**
- **Condenser**
- **District Heating**
- **To Paper Mills**
- **To DH**
- **Condensate returns**
- **Feedwater to WtE-boiler**

- **41 bara @ 380°C**
- **7.0 bara**
- **1.2 bara**

- **7 bar steam to PM**
  - *fluctuating* demand
  - down to 50%

- **Winter mode**
  - 7 bar steam to DH
  - turbine LP stage out
  - electricity: internal load

- **Summer mode**
  - condenser heat to DH
  - turbine full operation

- **Flexible steam buffer**
  - 1<sup>st</sup>: accu
  - 2<sup>nd</sup>: backup (gas)

- **h = 64%**
- **R1 = 0.85**

Keppel Seghers
Solutions for a Cleaner Future
Financials

### Revenues Distribution WTE-CHP
- Gate Fee: 72%
- Electricity Sale: 12%
- Heat Sale: 16%

### Cost Distribution WTE-CHP
- Depreciation: 44%
- Maintenance: 18%
- Fuel Cost: 11%
- Electricity Cost: 11%
- Disposals: 7%
- Chemicals: 5%
- Staff & Services: 4%

### Past vs Future ('000 EUR/year)

<table>
<thead>
<tr>
<th></th>
<th>Past</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenues</td>
<td>/</td>
<td>5,200</td>
</tr>
<tr>
<td>Cost (&amp; Depreciation)</td>
<td>-6,100</td>
<td>-7,000</td>
</tr>
<tr>
<td><strong>NET RESULT</strong></td>
<td>-6,100</td>
<td>-1,800</td>
</tr>
</tbody>
</table>

- Yearly steam generation cost reduced to 30% of original (incl. depreciation of investment)
- Independence from oil prices
Case 2: Greater Manchester (UK)

commissioning expected: end 2012
Combustion Design

- 24.1 Mg/h @ 13 MJ/kg
- RDF & digestate mix
- max. steaming range: 11.5 – 16 MJ/kg
- 2 (4) lines @ 87 MW\textsubscript{th}
Steam Cycle Design

- 17 bar steam to INEOS
  - large flow: 70-140 ton/h
  - *continuous* demand

- turbine / condensor
  - 2-stage: HP & LP
  - small LP → more efficient
  - limited steam extraction
  - water-condensing → higher electricity prod.

- auxiliary steam saving
  - grate heat in FW PH
  - air PH with 17 bar-steam

- feedwater (return)
  - high salt content
  - storage tanks: autonomy!

**h = 48%**

**R1 = 0.86**
Waste-CHP design principles

• Understanding the client’s process
  - average demands/returns
  - variations through time → importance of historical data

• Defining the nominal operation point for the WtE
  - reliable data of waste source, composition & LHV!
  - anticipate to LHV changes

• Boiler design: primarily a financial issue
  - elevated steam parameters technically well possible
  - but … which budget affordable for maintenance?
  - reduced boiler outlet temp = ‘easy’ efficiency gain
Waste-CHP design principles

• Turbine & condensor
  – cope with all load & bypass conditions
  – avoid partial load during majority of time
  – limit number & flows of steam extractions
  – water condensor → limit % moisture @ turbine outlet

• Flue Gas Cleaning system
  – at reduced temperature
  – simple = robust & reliable

• Auxiliary equipment
  – maximise internal heat recovery (grate cooling)
  – buffers between combustion process and extern
Conclusions

• Increasing WtE-boiler steam parameters
  - rather limited gain in efficiency (<10%)
  - maintenance intensive & costly
  - dependent on development of protection materials

• Waste-fired CHP plants (where possible)
  - make large efficiency \textit{jump} possible (>50%)
  - ecologically \textit{essential} in advanced waste management
  - a matter of \textit{intelligent engineering}
Conclusions

• CHP-plant optimization possible by exploiting
  – advantage of *scale* (~ conventional power plants)
  – advantage of *flexibility*

• Waste-fired CHPs = financially interesting
  – reduction of industrial energy production cost
  – independency of insecure oil market
  – opportunity for private investors
Selected Literature

