Electricity from poultry manure: a resource efficient and clean alternative to direct land application

Pieter Billen, José Costa, Jo Van Caneghem, Carlo Vandecastele
Poultry farming

- NL: 100 M hens per year
- 1.5 Mt/y poultry manure
- Total manure production: 71 Mt/y
- Supply > Demand
  → Excessive fertilization
  → Nitrate directive (91/676/EEC) and national legislation
- Compare
  - 1. land spreading, use it directly as fertiliser
  - 2. combustion to generate electricity

Source: CBS, PBL, Wageningen UR (2012)
www.compendiumvoordeeleefomgeving.nl
Land spreading

- CO$_2$
- $N_2O$
- NH$_3$
- $PO_4^{3-}$
- $NO_3^-$
- $NH_4^+$

pathogens
Poultry litter combustion

<table>
<thead>
<tr>
<th>Moisture wt%</th>
<th>Average</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>C wt% DM</td>
<td>39.1</td>
<td>1.8</td>
</tr>
<tr>
<td>H wt% DM</td>
<td>5.7</td>
<td>1.7</td>
</tr>
<tr>
<td>N wt% DM</td>
<td>4.2</td>
<td>0.7</td>
</tr>
<tr>
<td>S wt% DM</td>
<td>0.7</td>
<td>0.1</td>
</tr>
<tr>
<td>Cl wt% DM</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>Ca wt% ash</td>
<td>21.0</td>
<td>4.9</td>
</tr>
<tr>
<td>Mg wt% ash</td>
<td>3.7</td>
<td>0.9</td>
</tr>
<tr>
<td>K wt% ash</td>
<td>14.0</td>
<td>3.2</td>
</tr>
<tr>
<td>Na wt% ash</td>
<td>2.2</td>
<td>0.3</td>
</tr>
<tr>
<td>P wt% ash</td>
<td>6.7</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Poultry litter: LHV = 7.2 MJ/kg

Adapted from: Consonni, S. Energy potential of waste. Athens, 19 June 2012
**BMC Moerdijk** *(FBC for poultry manure)*

- 440 kt / year
- ca. 600 farmers contracted
- 31 MW<sub>e</sub> net (70000 households)
- 60 kt ash / year
Is combustion cleaner- sustainable production?

• UNEP: RECP (Resource Efficient and Cleaner Production)
• Advance

- Production efficiency
  optimize use of natural resources
  (materials, energy, water)

- Environmental management
  minimize adverse impacts on nature
  and the environment

- Human development
  minimize risks to people and communities, support their development
### Sustainable energy production and GHG emissions

#### Electricity production
- **Net** 31 MW\(_e\), \(\eta_{\text{net}} = 28\%\)
  - 1 ton of poultry litter replaces about 200 kg coal, avoids 425 kg of emitted CO\(_2\)-eq.
- **GHGs**
  - CO\(_2\)
  - CO: negligible
  - N\(_2\)O: 25-50 kg CO\(_2\)-eq. per t

#### Land application
- Energy content is lost
- No electricity produced
- **GHGs**
  - CO\(_2\)
  - CO: negligible
  - N\(_2\)O: 40-300 kg CO\(_2\)-eq. per t

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**Indirect:**
- Transport
- Flue gas heating (SCR)
- Lime and NH\(_3\) production

**Indirect:**
- Transport (unknown)
Sustainable energy production and GHG emissions

Combustion

- N_2O
- Avoided Emissions
- Lime
- NH_3
- SCR gas heating
- Transport

Land spreading

kg of CO_2 equivalents per ton of poultry manure

Min. Max. Min. Max.
Optimise use of materials

- Dry flue gas cleaning (no water needed)

- Ash (bottom ash, boiler ash, fly ash and APC residue) used as fertilizer/soil amendment
  - No pathogens
  - No NH$_3$ emissions
  - Odorless and dry, ensuring easy handling and transportation
Use of materials

- Ash composition
  (combined bottom ash, boiler ash, fly ash and APC residue)

<table>
<thead>
<tr>
<th>Specification</th>
<th>Composition</th>
<th>wt% DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>K$_2$O</td>
<td>&gt;11</td>
<td>12</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>&gt;4</td>
<td>5.1</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>&gt;10</td>
<td>12</td>
</tr>
<tr>
<td>SO$_3$</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>Cl</td>
<td>2.0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>wt% DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>P$_2$O$_5$ sol. in water</td>
</tr>
<tr>
<td>P$_2$O$_5$ sol. in neutral ammonium citrate</td>
</tr>
<tr>
<td>P$_2$O$_5$ sol. in 2% citric acid</td>
</tr>
</tbody>
</table>

- De facto PK fertilizer, but low P solubility
  → upgrade opportunities
- Balance the nutrient supply and demand of regions
Use of materials
Minimization of impacts on the environment

- Electricity production from fossil fuels is replaced

<table>
<thead>
<tr>
<th>BMC emissions (kg/ton wet poultry manure combusted)</th>
<th>Emissions for fossil fuel$^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$, fossil</td>
<td>0</td>
</tr>
<tr>
<td>CO</td>
<td>0.05</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>0.22</td>
</tr>
<tr>
<td>NH$_3$</td>
<td>0.017</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>0.02</td>
</tr>
<tr>
<td>HCl</td>
<td>0.004</td>
</tr>
<tr>
<td>PCDD/Fs</td>
<td>&lt; 44 · 10$^{-12}$</td>
</tr>
</tbody>
</table>

$^+$ to produce same amount of electricity as produced from 1 ton of wet poultry manure (NL)

→ less emissions to the environment, except NH$_3$
Minimization of risks to people

- **All heavy metals** in ash below limit for land application (combined bottom ash, boiler ash, fly ash and APC residue)

<table>
<thead>
<tr>
<th></th>
<th>Limit (mg/kg DM)</th>
<th>Composition (mg/kg DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>7000</td>
<td>4044</td>
</tr>
<tr>
<td>As</td>
<td>5</td>
<td>&lt;3.0</td>
</tr>
<tr>
<td>Cd</td>
<td>3</td>
<td>0.8</td>
</tr>
<tr>
<td>Co</td>
<td>20</td>
<td>5.3</td>
</tr>
<tr>
<td>Cr</td>
<td>100</td>
<td>13</td>
</tr>
<tr>
<td>Cu</td>
<td>600</td>
<td>353</td>
</tr>
<tr>
<td>Hg</td>
<td>1</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Mn</td>
<td>10000</td>
<td>1822</td>
</tr>
<tr>
<td>Ni</td>
<td>50</td>
<td>17</td>
</tr>
<tr>
<td>Pb</td>
<td>45</td>
<td>10.2</td>
</tr>
<tr>
<td>Zn</td>
<td>2400</td>
<td>1567</td>
</tr>
</tbody>
</table>
Minimization of risks to people

- Based on the $K_2O/P_2O_5$ application rate, the amount of HM spread on land is identical for ash and for manure

- **Pathogens** destructed

- **Limited formation of PCDD/Fs**, due to
  - low Cl of poultry manure
  - low HM concentration in ash (catalyst)
Community development

- Sustainable demand for manure is offered to contracted farmers

- Contribution to regional employment
  - Direct: ca. 30 jobs mainly for technically skilled persons
  - Indirect: transport, ash upgrading ...
Conclusion: RECP

- Use of ash
- Valorization of energy content
- Production efficiency
  protective use of natural resources
  (materials, energy, water)
- No water use
- Employment
- Environmental management
  minimize adverse impacts on nature and the environment
- Human development
  minimize risks to people and communities, support their development
- Biogenic CO₂
- Lower NH₃ emissions than land spreading
- Emissions < or comparable to other energy plants
- HM spreading identical
- Destruction of pathogens
- Environmental management
- Human development
Technological issue

- Agglomeration in bed due to low melting salts in the ash
- E.g. $K_2Si_4O_9$ (770°C), $KPO_3$ (810°C), ...
- Eutectics: lower $T_m$

- Consequence: Defluidization (few times a year) → downtime, cleaning of installation
  Availability < 90%
Research

Mechanism 1

Condensation and deposition of species

Bed particle

(Partially) Molten coating

Ash formation

Reactions in bed ash

Thermodynamics

Melting

Phase diagrams

Agglomeration

Roedder (1959)
**Research**

**Mechanism 2**

- Ash formation
- Melting of ash
- Agglomeration
- Reaction with bed ash
- Solidify

\[
\text{Reaction with bed ash: } \quad \text{Solidify} \\
\text{KH}_2\text{PO}_4 (s) \rightarrow \text{KH}_2\text{PO}_4 (l) \rightarrow \text{H}_2\text{O (g)} + \text{KPO}_3 (l) \rightarrow \text{Ca}_3(\text{PO}_4)_2 (s) + \text{K}_2\text{O} + \text{CaO}
\]
Research

• Variations of the fuel

<table>
<thead>
<tr>
<th></th>
<th>Layer hens</th>
<th>Broiler hens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash [wt% DM]</td>
<td>19.3</td>
<td>25.3</td>
</tr>
<tr>
<td>Al [mg/kg DM]</td>
<td>730</td>
<td>900</td>
</tr>
<tr>
<td>K [mg/kg DM]</td>
<td>31900</td>
<td>35100</td>
</tr>
<tr>
<td>Na [mg/kg DM]</td>
<td>5700</td>
<td>7000</td>
</tr>
<tr>
<td>Ca [mg/kg DM]</td>
<td>50200</td>
<td>31800</td>
</tr>
<tr>
<td>Si [mg/kg DM]</td>
<td>3400</td>
<td>4100</td>
</tr>
<tr>
<td>Mg [mg/kg DM]</td>
<td>8700</td>
<td>7700</td>
</tr>
<tr>
<td>Fe [mg/kg DM]</td>
<td>1100</td>
<td>n.r.¹</td>
</tr>
<tr>
<td>P [mg/kg DM]</td>
<td>21000</td>
<td>17400</td>
</tr>
</tbody>
</table>

Source: ECN Phyllis 2 Database

• Countermeasure: addition of CaCO$_3$