EGTEI Methodology
Work to update costs for LCP
SO$_2$, NO$_x$ and PM abatement techniques

Third meeting
11 June 2012

Agenda

- Main conclusions of the last EGTEI meeting of 31 January 2012
- Questionnaires developed
- First information obtained (LSFO, SCR, Deduster)
- Possible structure of the EXCEL tool to be developed
- Biomass co-firing
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Scope of the work

- Mandate to EGTEI: continue to update the methodology to update costs for LCPs
- Consider combustion larger than 50 MW (not only > 500 MWth as in the previous work) (cost function to be probably developed according to ranges of size of combustion installations (50-100; 100-300 [500]; > 300 [500])
- Boilers and gas turbines (stationary engines to be considered later)
- Coal, heavy fuel, light distillate fuel, natural gas, biomass (Non commercial fuels considered later)
- Costs for new and existing plants
- Investment costs, annualised costs, fixed and variable operating costs
- As far as possible, finish the data collection for cost estimation by the end of the year
Main conclusions of the last meeting

Retrofit factor for existing plant

- Compared to the equipment of a new plant (greenfield), EGTEI proposals for average retrofit factors between + 30 % to + 40 % according to the reduction techniques
- It was recommended to define classes of techniques
- The retrofit factor will be made variable in the methodology of cost estimation with default values proposed by EGTEI (default values to be updated according to data received)

Information received since the last meeting:
In utility boilers in small combustion installations (50 to ± 200 MWth) and in some activities such as the chemical industry, retrofit factors can be very large. Factor from 2 to more than 3 according to experts.

Expected difficulty to define the retrofit factor
Most information on investments should be delivered for existing plant. Consequently, difficulty to have a correct estimation of the retrofit factor in absence of data for greenfield plants

Main conclusions of the last meeting

Dry and real waste gas flow rates

Boilers:
- For solid fuels (coals): \( F_{\text{ref}} = 350 \text{Nm}^3/\text{GJ} (6\% \text{O}_2, \text{dry}) \) (EGTEI hypothesis)
- For liquid fuels: \( F_{\text{ref}} = 280 \text{Nm}^3/\text{GJ} (3\% \text{O}_2, \text{dry}) \) (EGTEI hypothesis)
- For gaseous fuels: \( F_{\text{ref}} = 270 \text{Nm}^3/\text{GJ} (3\% \text{O}_2, \text{dry}) \) (EGTEI hypothesis)
- For wood: \( F_{\text{ref}} = 333 \text{Nm}^3/\text{GJ} (6\% \text{O}_2, \text{dry}) \)

Gas Turbines:
- Conversion of 270 Nm³/GJ (3% O₂) to 810 Nm³/GJ (15% O₂)

Standard in preparation
Values of the standard in preparation not yet obtained
Dry and real waste gas flow rate required in the questionnaires
Main conclusions of the last meeting

Inclusion of biomass

Rates of inclusion considered: 5, 10, 20% but also 35% (35% possible as described in the emerging technique report)

Main conclusions of the last meeting

Costs to be collected

Focus the research of the most recent figures (after 2000 only)

Use the chemical engineering cost index to express the costs in Euro 2010 (or 2011 if the latest figures are provided)

\[
I_b = I_{act} \times \left( \frac{p_b}{p_{act}} \right)
\]

\(I_b\) = Investment (€ base year)
\(I_{act}\) = Investment (€ actual year)
\(p_i\) = CEPCI price level for year \(i\)
Main conclusions of the last meeting

DeSOx techniques

Techniques covered:
- LSFO process (Limestone forced oxidation with gypsum production)
- LSNO process (Limestone natural oxidation) - possibly for medium size installation
- Dry injection and spray dryer absorption to be considered for plants from 50 to 200 MW – techniques described as BAT in the existing LCP BREF

Main conclusions of the last meeting

DeSOx technique operating costs

Questionnaire to be used to collect information on:
- reagent demand (with reagent costs)
- water consumption (water costs)
- electricity consumption, (electricity costs)
- by product production (waste disposal costs or recovery)
- operator demand (with costs of operators)
Main conclusions of the last meeting

DeNOx techniques

Techniques covered:

- FGR (flue gas recirculation)
- Low NOx burners (3 generations: 1st (600 - 800 mg/Nm³), 2nd (400 - 600 mg/Nm³), 3rd (300-400 mg/Nm³))
- SNCR (Selective Non Catalytic Reduction)
- SCR (Selective Catalytic Reduction)

Main conclusions of the last meeting

DeNOx technique operating costs

Questionnaire to be used to collect information on:

- inlet concentrations
- efficiency of the SCR (information which could also be available in the questionnaire of IPTS)
- catalyst demand
- catalyst regeneration frequency
- catalyst cost
- operator demand
- electricity consumption: to be calculated according to the pressure drop
Main conclusions of the last meeting

Dedusters

Techniques considered:
- ESP
- FF

Questionnaire to be used to collect information on:
- electricity consumption
- lifetime of bags
- operator demand

Questionnaires

A first questionnaire developed to collect investments and operating costs from combustion installations recently equipped with DeNOx, DeSOx and/or deduster (preferably investments made after 2000) (EXCEL file developed to be as simple as possible)

Questionnaire (DOC file) developed to obtain comments on parameters used in functions developed by EGTEI to calculate operating costs (with default values used by the EGTEI technical secretariat provided) (resulting from suggestions of the last meeting participants explaining the previous document was not easy to comment)

See the questionnaires.

One remaining question: what status of answers to questionnaires? Do we consider them confidential, yes, no? Can we made them available on the web if the manes of authors are masked
Comments from KEMA received for the last meeting but not presented (due to late arrival)

- The wages should be in the fixed operating costs, not in the variable operating costs, since they are independent of the operating hours
- Fixed operating costs: 4% of the investment seems to be too much, even when wages are included in the fixed cost

In EGTEI, wages (or labour intensity for the operation of the reduction techniques and their maintenance) included in variable annual operating costs (In line with the BREF economics and cross media (pages 39, 42))
In EGTEI fixed operating costs depend on the capacity of the installation, i.e. on the investment and are expressed as a percentage of the technique investment. They include costs of maintenance and repair (but not the human resources), insurance, administrative overhead, etc (Taxes are not included in order to be coherent with GAINS)

Obtain additional information to validate the 4% or not

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One EXCEL questionnaire received

Questionnaire developed
LSFO: comparison of Investment collected with the EGTEI existing data

Investment LSFO - Euros 2010

Results of several feasibility studies to equip existing coal fired LCPs with lime dry injection and Fabric Filter
Investments for dry duct injection of lime and fabric filters in coal fired boilers

<table>
<thead>
<tr>
<th></th>
<th>inlet concentration mg/Nm³ à 6%</th>
<th>VLE mg/Nm³ à 6%</th>
<th>Efficiency %</th>
<th>Thermal capacity MWth</th>
<th>Investment € 2011</th>
<th>£/MWth</th>
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</thead>
<tbody>
<tr>
<td>Lime + fabric filter</td>
<td>1100</td>
<td>250</td>
<td>80</td>
<td>116</td>
<td>6.2</td>
<td>53.4</td>
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<td>200</td>
<td>79</td>
<td>149</td>
<td>7</td>
<td>47.0</td>
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<td>Lime + fabric filter</td>
<td>1450</td>
<td>250</td>
<td>80</td>
<td>72</td>
<td>4.6</td>
<td>63.9</td>
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<tr>
<td>Lime + fabric filter</td>
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<td>300</td>
<td>72</td>
<td>97</td>
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<td>79</td>
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<tr>
<td>Lime + fabric filter</td>
<td>1200</td>
<td>400</td>
<td>70</td>
<td>93</td>
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<tr>
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<td>400</td>
<td>70</td>
<td>93</td>
<td>2.9</td>
<td>31.2</td>
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<td>Lime + fabric filter</td>
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<td>200</td>
<td>64</td>
<td>225</td>
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<td>37.0</td>
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<tr>
<td>Lime + fabric filter</td>
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<td>200</td>
<td>64</td>
<td>225</td>
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<td>1350</td>
<td>250</td>
<td>81</td>
<td>52</td>
<td>2.9</td>
<td>55.8</td>
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<tr>
<td>Carbonate + fabric filter</td>
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<td>250</td>
<td>83</td>
<td>90</td>
<td>8.8</td>
<td>97.8</td>
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<td></td>
<td>35.43</td>
<td>70.9</td>
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<td>95</td>
<td>500</td>
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<td>41.11</td>
<td>82.2</td>
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</table>

Investment for lime duct injection and fabric filters in existing coal fired boilers

Investment k€/MWth for lime injection in duct and FF

For comparison LSFO EGTEI data

<table>
<thead>
<tr>
<th>Thermal power MWth</th>
<th>Investment k€/MWth</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>31.2</td>
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<tr>
<td>40</td>
<td>55.8</td>
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<td>60</td>
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<td>80</td>
<td>72.2</td>
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<tr>
<td>100</td>
<td>97.8</td>
</tr>
<tr>
<td>120</td>
<td>100</td>
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</table>

For comparison LSFO EGTEI data

<table>
<thead>
<tr>
<th>Thermal power MWth</th>
</tr>
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<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>200</td>
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<tr>
<td>300</td>
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<td>400</td>
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<tr>
<td>500</td>
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<tr>
<td>600</td>
</tr>
<tr>
<td>700</td>
</tr>
<tr>
<td>800</td>
</tr>
<tr>
<td>900</td>
</tr>
</tbody>
</table>
Operating annual costs for lime duct injection and fabric filters in existing coal fired boilers

![Graph showing total operating costs in k€/year for lime injection in duct and FF.](image)

Operating costs for lime injection in ducts and fabric filters in existing coal fired boilers

![Graph showing total annual operating costs in k€/year/MWth for lime injection in duct and FF.](image)
**Investments for fabric filters and ESPs from a manufacturer**

**Dust removal**

**Existing EGTEI data:**

Deduster identified according to the PM concentrations obtained (no distinction between FF and ESP)

Cost function (for a greenfield installation):

\[
\text{INV} (k\text{€}) = \text{Inv var} (k\text{€/MWth}) \times P (\text{MWth}) + \text{inv fix} (k\text{€})
\]

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Technology</th>
<th>ELV mg/Nm(^3)</th>
<th>Inv var k\text{€/2010MWth}</th>
<th>Inv fix k\text{€2010}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard Coal and brown coal</td>
<td>Deduster 1</td>
<td>300</td>
<td>7.7</td>
<td>1398</td>
</tr>
<tr>
<td></td>
<td>Deduster 2</td>
<td>100</td>
<td>10.0</td>
<td>1398</td>
</tr>
<tr>
<td></td>
<td>Deduster 3</td>
<td>45</td>
<td>11.5</td>
<td>2795</td>
</tr>
<tr>
<td></td>
<td>Deduster 4</td>
<td>20</td>
<td>14.0</td>
<td>2795</td>
</tr>
<tr>
<td>Heavy Fuel oil</td>
<td>Deduster 1</td>
<td>10</td>
<td>6.7</td>
<td>1342</td>
</tr>
</tbody>
</table>
Dust removal

Comparison of EGTEI existing data with a set of manufacturer data in terms of investments (greenfield installation):

![Graph showing investments in k€/MWth for different dust removal methods.]

Dust removal

With ESP: Bi-Corona and High-frequency technology allow emissions < 10 mg/Nm³

Elements for operating cost determination:

Bag lifetime: around 30 000 hours (according to experience of plant operators)

For a boiler 800 MWe, Coal: to achieve 5 mg/Nm³ (6% O₂) (Manufacturer data)

ESP:
High Voltage Supply: 510 kW
Pressure Drop (3 to 4 mbar): 350 kW

FF
Pressurised Air: 200 kW
Pressure Drop (10 to 12 mbar): 1060 kW
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**The Problem:**

- too many variables (fuels, size, techniques, etc.)
- emissions are plant-specific (fuel & combustion specific: type, size, etc.)
- fuel inputs vary during the year / lifetime
- cost figures are site specific

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**The Idea:**

Providing a calculation sheet with manual input of main variables. Assistance is given by providing default data for „reference cases“.
**Visualisation:**

**Calculation Sheet:**

- **Chosen Plant Size:** 1750 MWth
- **Chosen Operating Hours:** 4,535 hours per year
- **Chosen Fuel:** 350 Nm³/GJ, S-content in %

**Working Parameters (results):**

Flue Gas Flow: $\text{MWth} \times \text{hrs/yr} \times \text{Nm³/GJ} = 10 \times 10^9 \text{Nm}^3/\text{yr}$

Boiler Outlet $c_{SO2} = \text{MWth/hrs/yr} \times x_S \times M_{SO2} = 2,000 \text{mg/Nm}^3$

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**Assistance Box I:**

- **Common Power Plant Sizes**
  - Large HC plants: 1,750 MWth
  - 2,400 MWth
  - CoGen NG plant: 500 MWth

**Assistance Box II:**

- **Operating Hours**
  - HC Baseload: 6,000 hrs/yr
  - HC Medium Load: 4,500 hrs/yr
  - BC Baseload: 7,000 hrs/yr

**Assistance Box III:**

- **Flue Gas Factors**
  - Coals: 350 Nm³/GJ
  - Wood: 333 Nm³/GJ
  - Nat. Gas: 270 Nm³/GJ

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**Visualisation (cont’d):**

**Calculation Sheet:**

- Preliminary Results:
  - $c_{SO2} = 2,000 \text{mg/Nm}^3$
  - Flue Gas Flow: $10 \times 10^9 \text{Nm}^3/\text{yr}$

- **Chosen abatement percentage:** 95%

- **Chosen Reducing Agent:**
  - SR: 1.05 kg/kg SO2
  - Price: 25 €/t

**Working Parameters (results):**

- Red. Agent Demand: $c_{SO2} \times \text{Nm}^3/\text{yr} \times \text{SR} = 21,000 \text{t/yr}$
- Red. Agent Cost: Demand $\times$ Price = 525,000 €/yr

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**Assistance Box IV:**

- **SO2 abatement technique**
  - HC high eff. wet FGD: 95%
  - CaCO3 SR: 1.05
  - HC avg. Wet FGD: 80%
  - CaCO3 SR: 1.02

**Assistance Box V**

- **Reducing Agent Cost**
  - CaCO3 Germany, 2010: 20 €/t
  - CaCO3 France, 2010: 25 €/t

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**ALL FIGURES ARE EXAMPLES FOR CALCULATORY PURPOSE AND DO NOT REPRESENT THE REALITY!**
Why?

- lack of data to be representative
- too much site specific cases, especially when referring to cost!
- we are providing a methodology [SCOPE OF WORK]
- allows maximising applicability with limited working data
- easy to update/extend
- every expert might fill in his data and can revert to our default data in case he needs it

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How can we include Biomass (Wood) Co-Firing?

- Fuel N-content (Darvell et al.):
  - Wood: 0.2 – 0.4 % w/w N
  - Wood bark: few % w/w N
  - Straw & Grasses: 0.4 - 0.6% w/w N
  - Agricultural wastes: several % w/w N
  - Coal: 1 – 2% w/w N, mainly 1.5% w/w

- Main mechanisms of fuel-NO:
  - NO from fuel-NH3
  - NO from fuel-HCN

"High nitrogen content coals may not necessarily be high NOx generators."
(Australian Black Coal Utilisation Research Ltd.)

Source: P. Keleher, „The significance of coal nitrogen content in the combustion process“
How can we include Biomass (Wood) Co-Firing?

- Limit type of co-firing to hard coal PC units with discrete amount of co-firing shares (i.e. 5%, 10%, 20%).
- Effect Calculation:
  
  a) Define 100% biomass-only numbers (derive from e.g. Swedish data) and calculate co-firing cases by taking the weighted average
  
  or
  
  b) Take values from existing Co-Firing cases (if accessible)

To be done for: emissions at equipment inlet / outlet, equipment abatement efficiency, equipment lifetime (if applicable)

How can we include Biomass Co-Firing?

Case: Biomass-Only (100%)

- Rodenhuize Plant („MaxGreen“, BE, GDF Suez)
  - 200 MWe, 100% wood pellets
  - Biomass LNB + OFA: 400 mg/Nm³ @ 6% O2
  - NOx limit: 90 mg/Nm³ @ 6% O2
- Dordrecht Plant (75 MWth): permit: 180 mg/Nm³ NOx
- 19 Swedish plants (wood)
  - 50 – 230 MWe, 100% wood (chips, pellets, etc.)
  - Various PM (OFA; FGR, etc.) + NH3-SNCR
  - NOx emissions: 30-52 mg/MJ [via 333 Nm³/GJ: 90-155 mg/Nm³]
  - Only 1 SCR (incl. FGR): 50 mg/MJ [150 mg/Nm³, 105 MWe]
How can we include Biomass Co-Firing?

Case: Co-Firing of wood with hard coal plants

- For hard coal, different types exist:
  - co-crushing in coal mills: << 10%, depending on wood type (chips, pellets, …)
  - separate modified coal mills
  - direct biomass injection (biomass mills, biomass burners)
  - > 10% LHV/LHV with refined biomass (dried, LHV -> 20 MJ/kg)

- NL permits:
  - RWE Essent, 2x800 MWe, ~10% biomass, 60 mg/Nm³ NOx
  - E.On Maasvlakte 3: 1,100 MWe, ~20% biomass, 65 mg/Nm³ NOx
  - Electrabel Maasvlakte, 800 MWe, ~50% biomass, 50 mg/Nm³ NOx

- only lab scale co-firing with lignite known
  (50% share: reduction 20-30%)

Effects of Biomass (Wood) Co-Firing - NOx

- Reduction of pre-SCR NO\textsubscript{x} emissions due to lower combustion temperature. This effect will decrease for newer LN Bs.
  
  *see Rodenhuize baseload emissions of 400 mg/Nm\textsuperscript{3}*

- Higher catalyst deactivation rates => Shorter operating cycles between regeneration.

- Effect on possible no. of regenerations not known.

- Experiences: Mainly in DK and NL, in SE with biomass-only plants.
  
  => results of Haldor-Topsoe study:
Effects of Biomass (Wood) Co-Firing - NOx

<table>
<thead>
<tr>
<th>Ash</th>
<th>Bituminous coal</th>
<th>PRB coal</th>
<th>Heavy fuel oil</th>
<th>PC boiler</th>
<th>Wood CFB boiler</th>
</tr>
</thead>
<tbody>
<tr>
<td>mg/Nm³</td>
<td>0.15</td>
<td>0.5</td>
<td>-</td>
<td>0.3</td>
<td>5.2</td>
</tr>
<tr>
<td>Soluble potassium</td>
<td>0.12</td>
<td>0.5</td>
<td>1.5</td>
<td>0.2</td>
<td>15</td>
</tr>
<tr>
<td>Nickel</td>
<td>-</td>
<td>0.5</td>
<td>1.5</td>
<td>-</td>
<td>0.7</td>
</tr>
<tr>
<td>Vanadium</td>
<td>-</td>
<td>-</td>
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<td>0.01</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>-</td>
<td>-</td>
<td>0.1</td>
<td>-</td>
<td>0.15</td>
</tr>
<tr>
<td>Calcium</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.1</td>
<td>15</td>
</tr>
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</table>

SCR catalyst deactivation
% per 10,000 hours
<table>
<thead>
<tr>
<th>Bituminous coal</th>
<th>PRB coal</th>
<th>Heavy fuel oil</th>
<th>PC boiler</th>
<th>Wood CFB boiler</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>20</td>
<td>5</td>
<td>60</td>
<td>46</td>
</tr>
</tbody>
</table>

Table 1  Fly ash characteristics of various fuels

Effects of Biomass (Wood) Co-Firing - NOx

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Deactivation rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% straw</td>
<td>50% per 1,000 hours</td>
</tr>
<tr>
<td>Wood:</td>
<td></td>
</tr>
<tr>
<td>- Pulverised-fuel boiler</td>
<td>60% per 10,000 hours</td>
</tr>
<tr>
<td>- CFB boiler</td>
<td>45% per 10,000 hours</td>
</tr>
<tr>
<td>- Grate-fired boiler</td>
<td>25% per 10,000 hours</td>
</tr>
<tr>
<td>Peat-fired boiler</td>
<td>30% per 10,000 hours</td>
</tr>
<tr>
<td>Coal-fired boiler</td>
<td>10% per 10,000 hours</td>
</tr>
<tr>
<td>Heavy fuel oil fired boiler</td>
<td>5% per 10,000 hours</td>
</tr>
<tr>
<td>Gas-fired boiler</td>
<td>2% per 10,000 hours</td>
</tr>
</tbody>
</table>

Table 2  Typical SCR catalyst deactivation rates. Actual deactivation rate depends on specific fuel composition
Effects of Biomass (Wood) Co-Firing - NOx

Catalyst Deactivation at the Lagerlo plant
(2x250 MWe, Electrabel, BE)

**Fuel:**
86% low alkaline RSA-coal,
7% wood dust,
4% dried sewage sludge,
3% olive residue

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Effects of Biomass (Wood) Co-Firing - NOx

Comparison of reactive catalyst activity at Studstrup 2 (DK)
Effects of Biomass (Wood) Co-Firing - NOx

Summary of Haldor-Topsoe-Study:

- up to 20% good biomass: no extraordinary deactivation compared to 100% HC firing
- for 100% biomass up to 60% in pulverised fuel-fired boilers, lower for grate-fired boilers

Source: Jensen-Holm, H.; Thogersen, J. and Lindenhoff, P.: Impact of biomass co-combustion on SCR DeNOx operation, Haldor Topsoe, 2009

Lessons to be learned

- SCR catalyst deactivation depends on:
  - boiler type (PC/CFB)
  - ash characteristics of biomass AND coal
  - some 100% biomass PP use coal fly-ash injection
- Co-Firing: Need to find a linear (?) relation between biomass share and catalyst lifetime reduction
- 100% biomass would rather take SNCR (see Sweden!) due to size and required NOx abatement
Lessons to be learned

- Boiler outlet emissions (large scale co-firing):
  - high reduction effect for older LNB generations
  - smaller to no (?) effect for newest LNBs

- Separate biomass burner vs. co-injection

- Boiler heat rate decreases:
  - fuel LHV: biomass LHV 14 – 20 MJ/kg (PP capacity)
  - air preheating temperature decreases (thermal losses)

Agenda

- Main conclusions of the last EGTEI meeting of 31 January 2012
- Questionnaires developed
- First information obtained (LSFO, SCR, Deduster)
- Possible structure of the EXCEL tool to be developed
- Biomass co-firing
- Other questions