EGTEI Methodology
Work to update costs for LCP

SO_2, NO_x and PM abatement techniques

Third meeting
11 June2012

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

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

Scope of the work

- Mandate to EGTEI : continue to update the methodology to update costs fro 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_{ref} = 350 Nm^3/GJ (6 % O_2, dry) (EGTEI hypothesis)
- For liquid fuels: F_{ref} = 280 Nm^3/GJ (3 % O_2, dry) (EGTEI hypothesis)
- For gaseous fuels: F_{ref} = 270 Nm^3/GJ (3 % O_2, dry) (EGTEI hypothesis)
- For wood: F_{ref} = 333 Nm^3/GJ (6% O_2, dry)

Gas Turbines:

- Conversion of 270 Nm^3/GJ (3% O_2) to 810 Nm^3/GJ (15% O_2)

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)

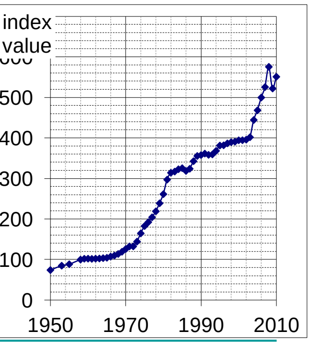
Main conclusions of the last meeting

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)

Year	CEPCI	Year	CEPCI	Year	CEPCI
1990	357.6	2000	394.1	2010	550.8
1989	355.4	1999	390.6	2009	521.9
1988	342.5	1998	389.5	2008	575.4
1987	323.8	1997	386.5	2007	525.4
1986	318.4	1996	381.7	2006	499.6
1985	325.3	1995	381.1	2005	468.2
1984	322.7	1994	368.1	2004	444.2
1983	316.9	1993	359.2	2003	401.7
1982	314	1992	358.2	2002	395.6
1981	297	1991	361.3	2001	394.3
1980	261.2				



$$I_b = I_{act} \times (p_b/p_{act})$$

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 nm/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 meting 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

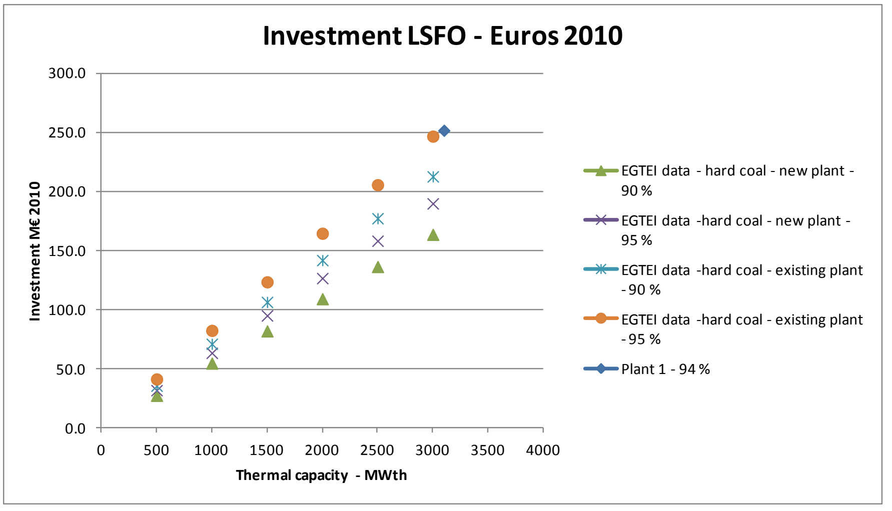
Agenda

- 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

One EXCEL questionnaire received

Questionnaire developed

LSFO : comparison of Investment collected with the EGTEI existing data

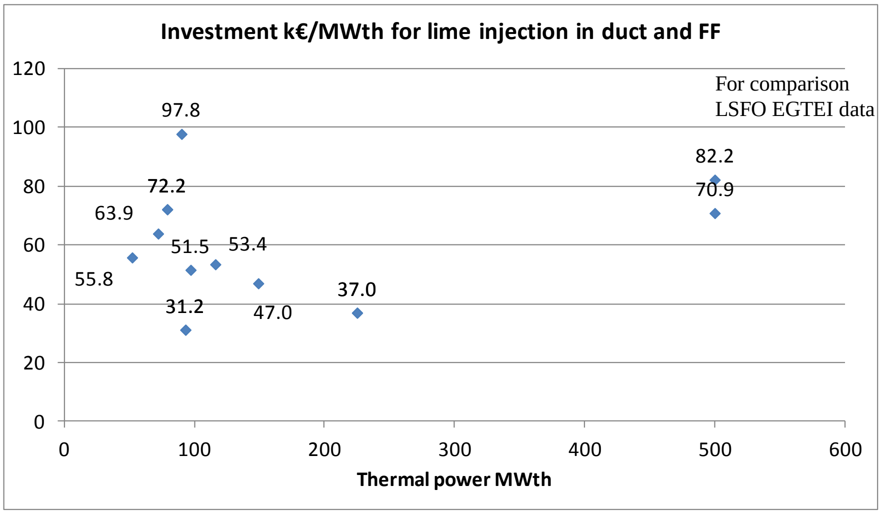


Results of several feasibility studies to equip existing coal fired LCPs with lime dry injection and Fabric Filter

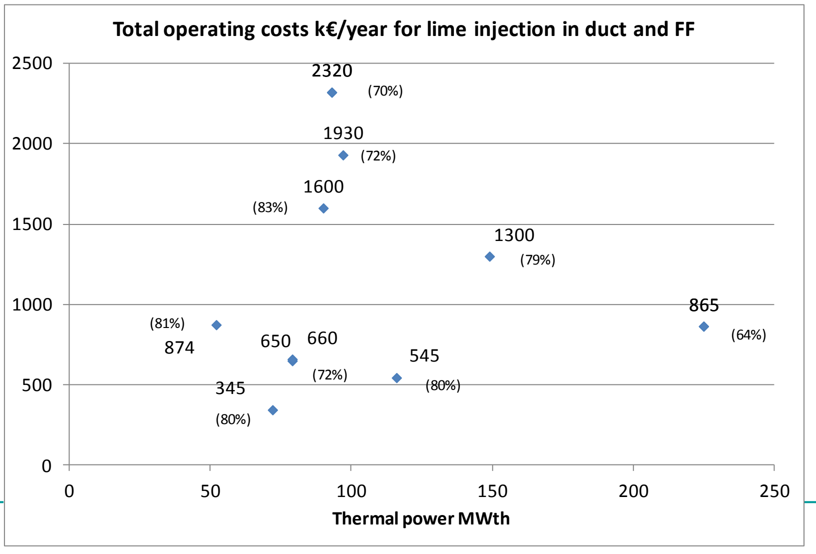
Investments for dry duct injection of lime and fabric filters in coal fired boilers

	inlet concentration mg/Nm3 à 6 %	VLE mg/Nm3 à 6 %	Efficiency %	Thermal capacity MWth	Investment € 2011	K€/MWth
Lime + fabric filter	1100	250	80	116	6.2	53.4
Lime + fabric filter	1050	200	79	149	7	47.0
Lime + fabric filter	1450	250	80	72	4.6	63.9
Lime + fabric filter	1300	300	72	97	5	51.5
Lime + fabric filter	1400	400	71	79	5.7	72.2
Lime + fabric filter	1400	400	71	79	5.7	72.2
Lime + fabric filter	1200	400	70	93	2.9	31.2
Lime + fabric filter	1200	400	70	93	2.9	31.2
Lime + fabric filter	348	200	64	225	8.32	37.0
Lime + fabric filter	368	200	64	225	8.32	37.0
carbonate + fabric filter	1350	250	81	52	2.9	55.8
carbonate + fabric filter	1470	250	83	90	8.8	97.8
LSFO EGTEI data			90	500	35.43	70.9
LSFO EGTEI data			95	500	41.11	82.2

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

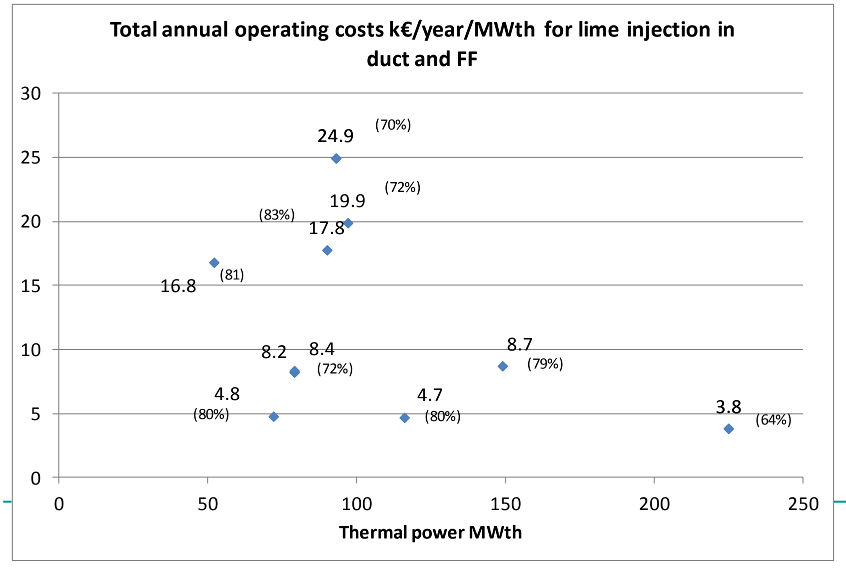


Operating annual costs for lime duct injection and fabric filters in existing coal fired boilers



23

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



24

Investments for fabric filters and ESPs from a manufacturer

Dust removal

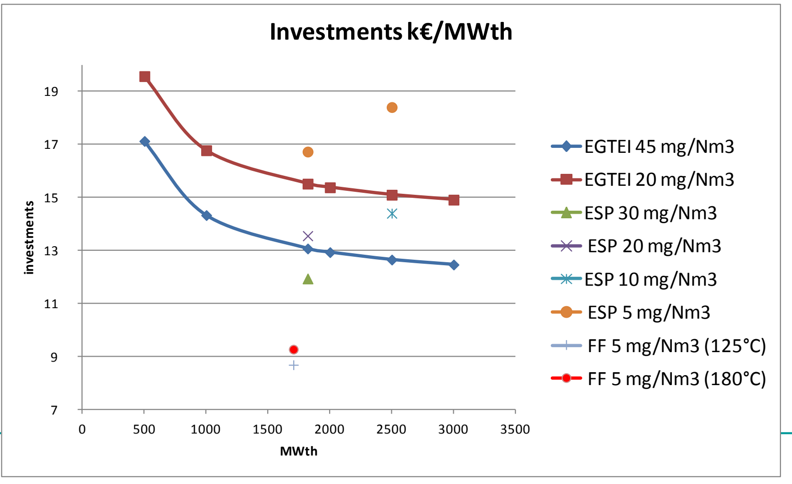
Existing EGTEI data:

Deduster identified according to the PM concentrations obtained (no distinction between FF and ESP)
Cost function (for a greenfield installation) :
INV (k€) = Inv var (k€/MWth) x P (MWth) + inv fix (k€)

Fuel	Technology	ELV	Inv var	Inv fix
		mg/Nm^3	k€/$_{2010}$MWth	k€$_{2010}$
Hard Coal and brown coal	Deduster 1	300	7.7	1398
	Deduster 2	100	10.0	1398
	Deduster 3	45	11.5	2795
	Deduster 4	20	14.0	2795
Heavy Fuel oil	Deduster 1	10	6.7	1342

Dust removal

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



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% O_2) (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

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

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

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: *manual input!*

1750 MWth

Chosen Operating Hours:

4,535 hours per year

Chosen Fuel:

350 Nm³/GJ

S-content in %

Working Parameters (results):

Flue Gas Flow: MWth*hrs/yr*Nm³/GJ: 10×10^9 Nm³/yr

Boiler Outlet c_{SO2}: $\frac{MWth*hrs/yr*x_S*M_{SO2}}{M_S*Nm^3/yr*MJ/kg}$ 2,000 mg/Nm³

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

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

Visualisation (cont'd):

Calculation Sheet:

Preliminary Results:

c_{SO2}: 2,000 mg/Nm³

Flue Gas Flow: 10×10^9 Nm³/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}*Nm³/yr*SR: 21.000 t/yr

Red. Agent Cost: Demand * Price: 525.000 €/yr

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

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 refering 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

Agenda

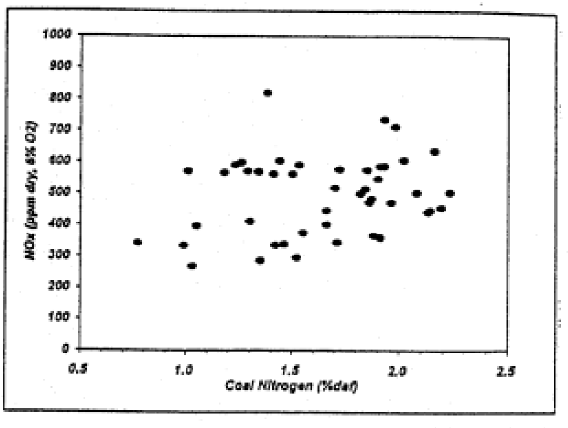
- ◈ Main conclusions of the last EGTEI meeting of 31 January 2012
- ◈ Questionnaires developed
- ◈ First information obtained (LSFO, SCR, Deduster)
- ◈ Possible structure of the EXCEL tool to be developed
- ◈ **Biomass co-firing**

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 NO_x generators."
(Australian Black Coal Utilisation Research Ltd.)

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



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)

37

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]

38

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%)

39

Effects of Biomass (Wood) Co-Firing - NOx

- Reduction of pre-SCR NO_x emissions due to lower combustion temperature. This effect will decrease for newer LNBs.

  see Rodenhuize baseload emissions of 400 mg/Nm³
- 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:

40

Effects of Biomass (Wood) Co-Firing - NOx

		Bituminous coal	PRB coal	Heavy fuel oil	Peat PC boiler	Wood CFB boiler
Ash	mg/Nm^3	15,000	6,000	100	6,000	1,500
Soluble potassium	wt %	0.15	0.5	-	0.3	5.2
Soluble sodium	wt %	0.12	1.5	1.5	0.2	0.7
Nickel	wt %	-	-	20	0.01	-
Vanadium	wt %	-	-	20	0.01	-
Phosphorous	wt %	0.1	0.8	-	1	15
Calcium	wt %	0.5	22	1.1	15	5
SCR catalyst deactivation % per 10,000 hours		12	20	5	60	46
(model simulation cf. Figure 1)						

Table 1 Fly ash characteristics of various fuels

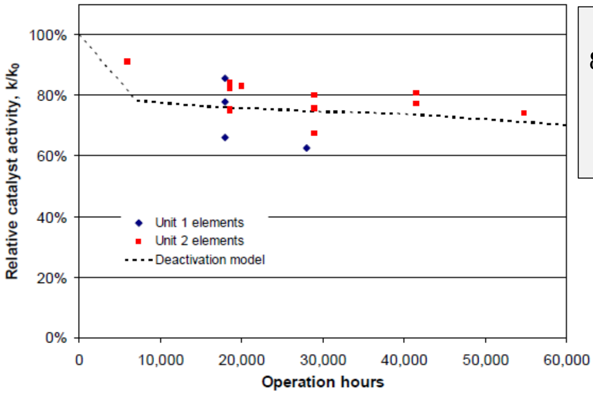
Effects of Biomass (Wood) Co-Firing - NOx

Fuel	Deactivation rate
100% straw	50% per 1,000 hours
Wood:	
- Pulverised-fuel boiler	60% per 10,000 hours
- CFB boiler	45% per 10,000 hours
- Grate-fired boiler	25% per 10,000 hours
Peat-fired boiler	30% per 10,000 hours
Coal-fired boiler	10% per 10,000 hours
Heavy fuel oil fired boiler	5% per 10,000 hours
Gas-fired boiler	2% per 10,000 hours

Table 2 Typical SCR catalyst deactivation rates. Actual deactivation rate depends on specific fuel composition

Effects of Biomass (Wood) Co-Firing - NOx

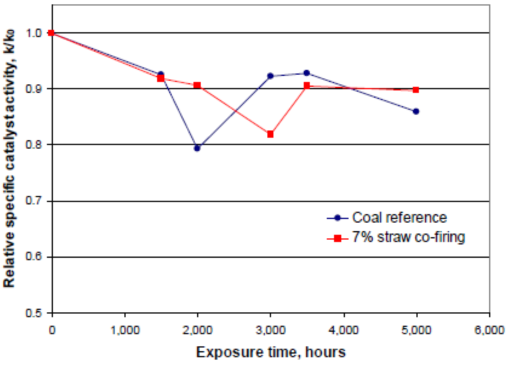
Catalyst Deactivation at the Lagerlo plant
(2x250 MWe, Electrabel, BE)



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

Effects of Biomass (Wood) Co-Firing - NOx

Comparison of relactive 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