Worldwide Pollution Control Association

ESKOM Scrubber Seminar

April 12th – 13th, 2007

Visit our website at www.wpca.info

State-of-the-art FGD Technology
An Independent View of a Long-term FGD-Experience of an Operator and Owner's Engineer

Dr. Hermann Brüggendick

STEAG encotec

Development Emission Regulation in Germany

steag encotec

1964	Technical Instructions on Air Quality Control (Clean Air Act) Revised 1974 / 1984
	Requirements of emissions monitoring systems
1974	Emission Protection Law (BImSchG)
1983	**L**arge **C**ombustion **P**lants **D**irective (LCPD) – 13. BImSchV
	Requirements for continuously operating emission monitoring systems SO_2 < 400 mg/m³ (i.N.)dry, SO_2 – Removal efficiency > 85 %
20.7.2004	Regulation for Large Combustion and Gasturbine Plants (13. BImSchV)
	Reheating of flue gas downstream FGD cancelled SO_2 < 300 / 200 mg/m³ (i.N.) dry

Emissions Limits for existing and new Plants in Germany

	German National Regulations		
	old, since 1983	existing- /new plants new, since 20.07.2004	
Emission- Limits (EL)	EL daily average value	EL daily average value	EL 1/2 h - average value
	• No daily average value > EL plus • No 1/2 h average value > 2 x EL plus • 97% of 1/2 h average values ≤ 1.2 x EL	• No daily average value > EL	• No 1/2 h average value > 2 x EL
Emission Limits (EL)	mg/m³ i.N. dry, 5/6% O_2	mg/m³ i.N. dry, 6% O_2	
• Dust	50	20 / 20	60 / 40
• NOx	200	200 / 200	400 / 400
• SO2	400	300 / 200	600 / 400
• Hg	-	0.03	0.05

STEAG's Development of FGD-Technology

1968	5,000 m³/h (stp)	Pilot plant at STEAG power station Lünen
1971	140,000 m³/h (stp)	Pilot plant at STEAG power station Lünen (Bischoff-Process)
1974	150,000 m³/h (stp)	Pilot plant at STEAG power station Lünen (ACT - Process)
1981	750 MW	First commercial FGD plant at STEAG power station Bergkamen
1999	10,000 m³/h (stp)	Pilot plant at STEAG power plant Herne (Ammonia water process)
		FGD Operating experience
Today	~ 9,000 MW	Total capacity of operational FGD - system
	> 2.0 million	Total FGD operating hours
	> 25 years	FGD operating experience
	~ 10,000 MW	Total capacity of designed STEAG FGD - system
	> 12,000 MW	Total capacity of internat. engineering services as Owner's engineer
	> 20,000 MW	Total capacity of FGD retrofits

STEAG Power Stations with wet FGD-Installations

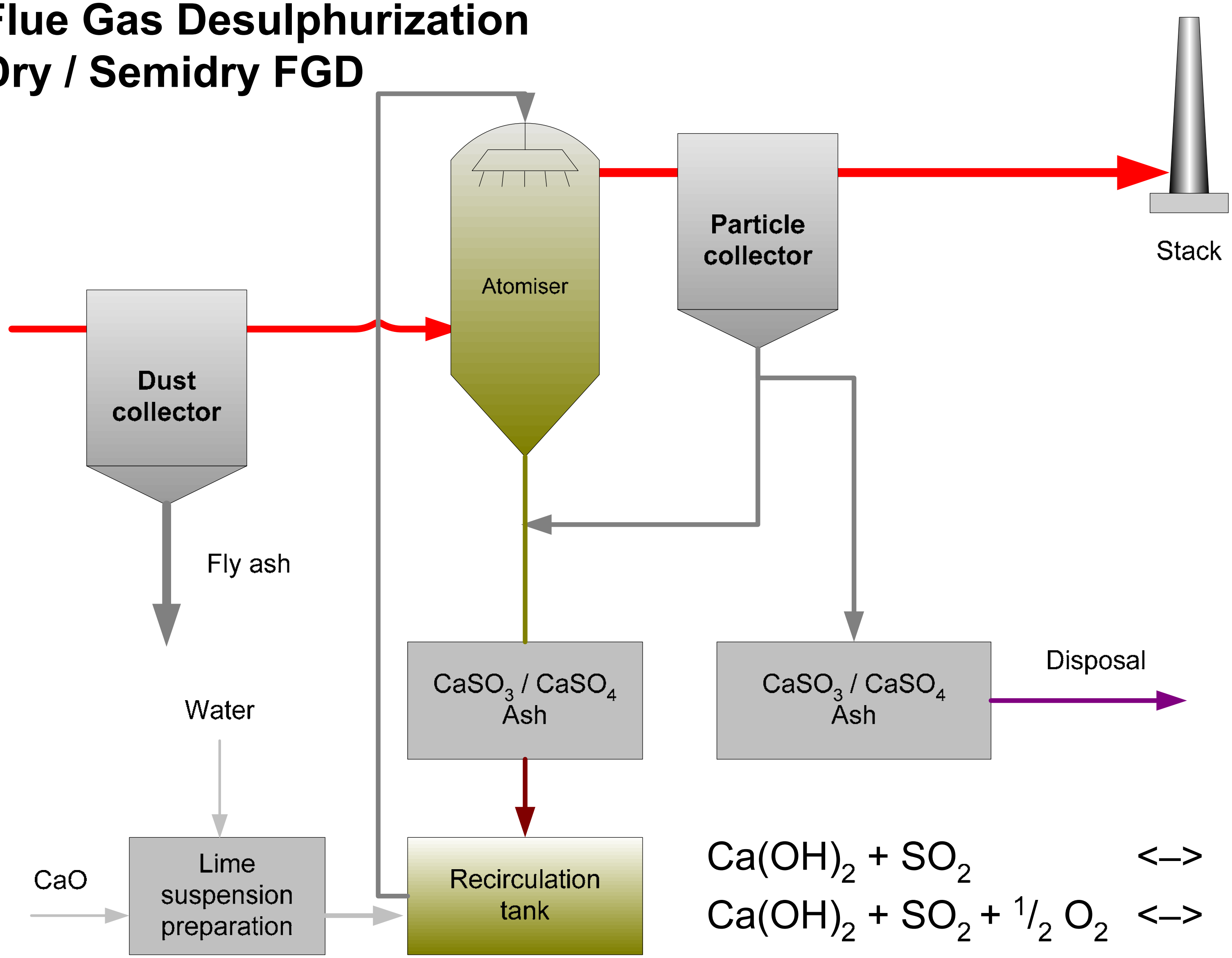
Power Stations	Capacity [MW]	Furnace System	FGD Design Data: SOx-Inlet Conc. [mg/m³ normal cond.]	Process / Absorbent	Byproduct (Gypsum) [t/h]	Approx. Operat. Hours (until 04/2007)	Operation since
Bergkamen	750	dry ash	2,600	wet scrubber lime	18.0	172,000	Oct. 81
Voerde A Voerde B	760 760	dry ash dry ash	2,600	wet scrubber lime	14.5	146,000 146,000	Oct. 82 / 2005
Herne 1/2 Herne 3 Herne 4	2 x 150 1 x 300 500	slag tap slag tap dry ash	4,300 4,650	wet scrubber lime/limestone	13.5 30.0	124,000 137,000 129,000	Jan 87 - Jan 04 Jan 87 Sep 89
Luenen 10 Luenen 11	150 350	dry ash slag tap	3,850	wet scrubber lime/limestone	6.0 12.5	119,000 139,000	Apr 88
Walsum 7 Walsum 9	410 150	dry ash slag tap	4,000	wet scrubber lime/limestone	6.5 18.0	44,000 150,000	Oct. 88
West 1 West 2	350 350	slag tap slag tap	3,850	wet scrubber lime/limestone	12.5	139,000 139,000	Feb 88
Leuna	3 x 162 t/h 115 electricity	heavy oil	7,000	wet scrubber lime/limestone	7.0	78,000	Dez 96
Godorf	230 steam 103 electricity	heavy oil	7,000	wet scrubber lime/limestone	8.0	21,500	Sep 04
Bexbach	775	dry ash	2,250	wet scrubber lime/limestone	17.0	134,000	Apr 88
Fenne 1 Fenne 2	300 230	dry ash dry ash	2,200	wet scrubber lime/limestone	6.5 5.0	134,000 134,000	Feb 88
Weiher 3	710	dry ash	2,250	wet scrubber lime/limestone	15.5	139,000	Feb 88
Iskenderun 1 Iskenderun 2	660 660	dry ash dry ash	33,200	wet scrubber lime/limestone	24.5	25,000 25,000	2003
	Σ 9,000 MW					Σ 2,300,000	

steag encotec

Advantages and Disadvantages of the different FGD Systems

	Dry/Semidry FGD	*Limestone FGD*	*Ammonia FGD*
Features	• Low/medium sulphur • Removal efficiency 90-95% • Smaller flue gas flow • No liquid waste • Small footprint • Low capital costs	• High sulphur • Removal efficiency > 95% • Larger flue gas flow • Rather complex system • Low cost reagent • By-product flexibility • High maintenance costs • Rather high capital costs	• High sulphur • Removal efficiency > 95% • Larger flue gas flow • No liquid waste • High cost reagent • High value by-product • Low maintenance costs • High capital costs
Reagent	Quick lime	Limestone	Ammonia
By-product	Non-marketable mixture of ash, reagent, calcium sulphite and calcium sulphate	Ash from ESP and marketable gypsum	Ash from ESP and marketable fertiliser ammonium sulphate

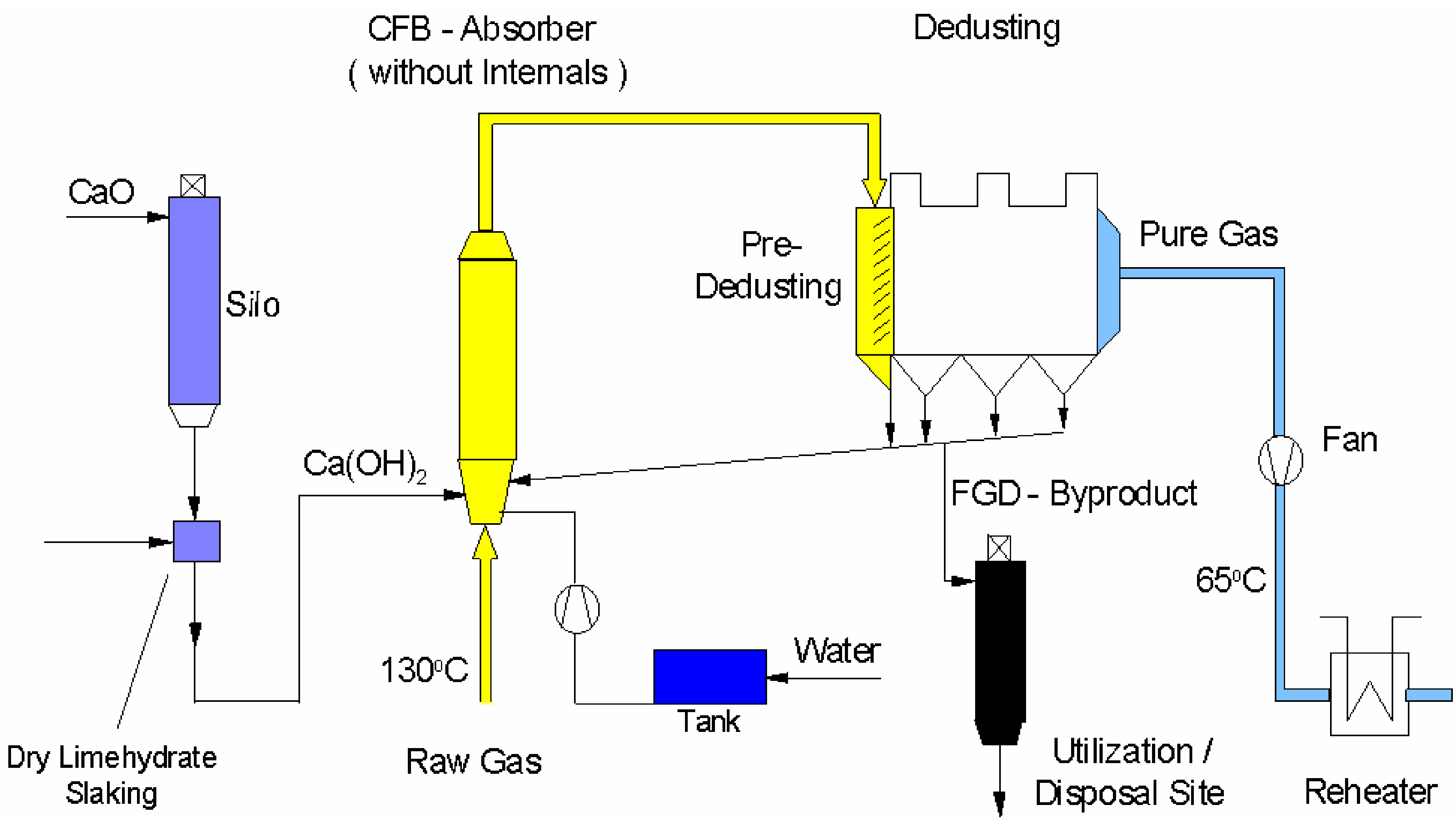
Flue Gas Desulphurization
Dry / Semidry FGD



$$Ca(OH)_2 + SO_2 \;<\!\!-\!\!> \; CaSO_3 + H_2O$$

$$Ca(OH)_2 + SO_2 + {}^1/_2\, O_2 \;<\!\!-\!\!> \; CaSO_4 + H_2O$$

Dry Desulphurization Process



Desulphurisation with Wet FGD
Limestone / Lime - Sum Reactions -

Desulphurisation

Limestone: $CaCO_3 + SO_2 \rightarrow CaSO_3 + CO_2$

Lime: $CaO + SO_2 \rightarrow CaSO_3$

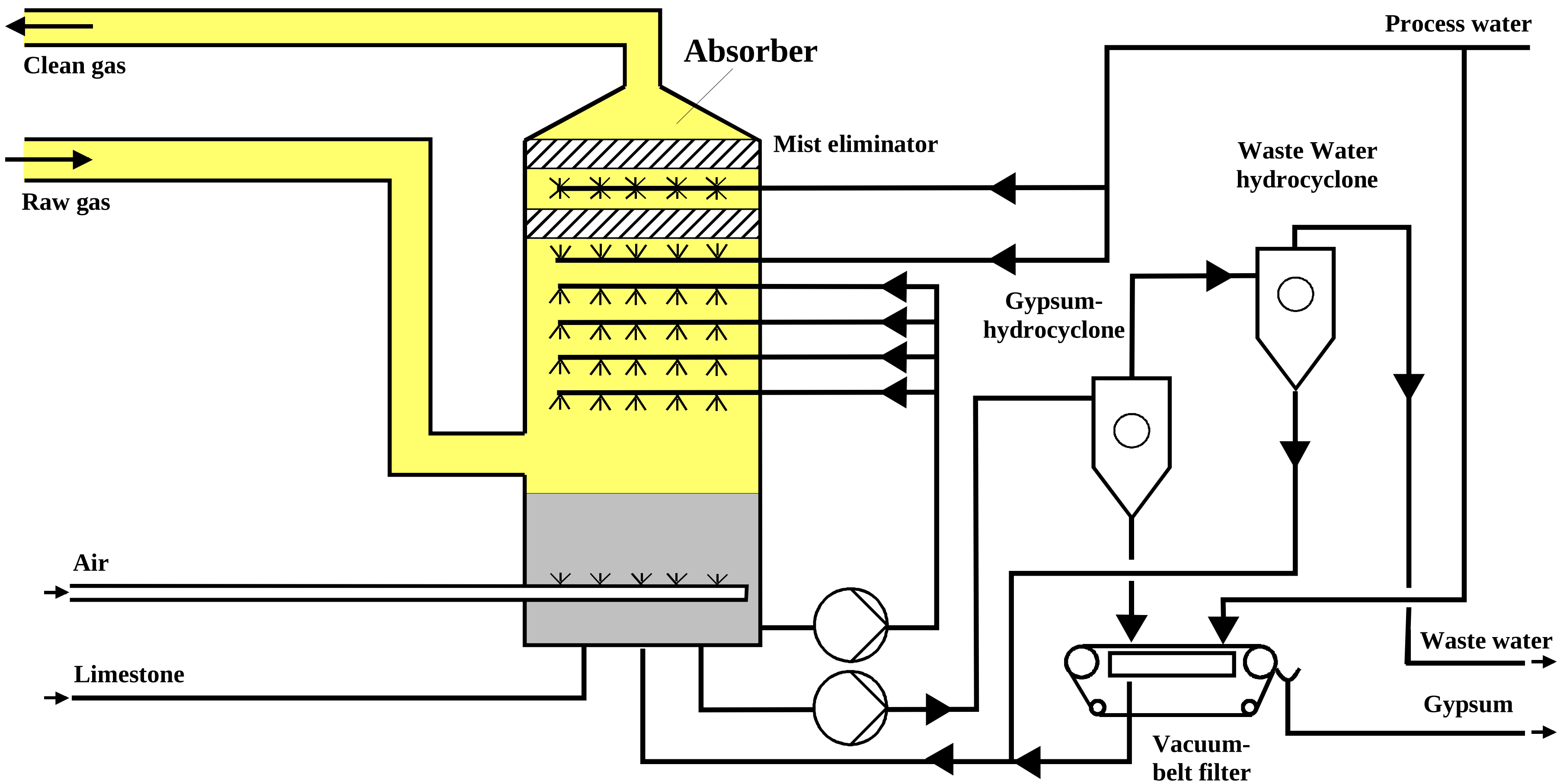
Lime hydrate: $Ca(OH)_2 + SO_2 \rightarrow CaSO_3 + H_2O$

Oxidation

$2\ CaSO_3 \bullet H_2O + H_2O + O_2 \rightarrow 2\ CaSO_4 \bullet 2\ H_2O$

Calcium sulfite — Gypsum dihydrate

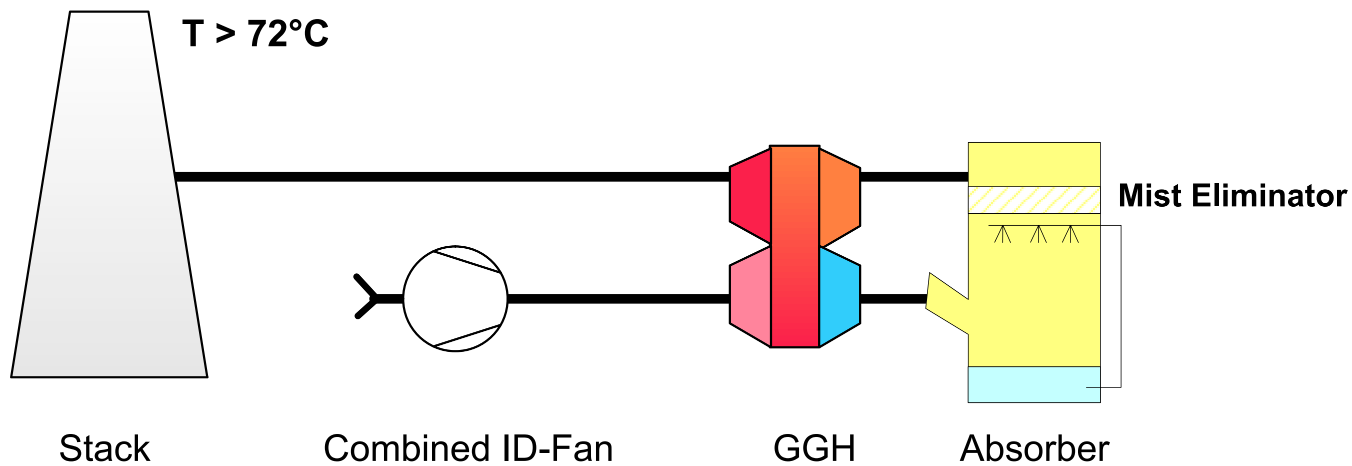
Wet FGD – Process
Flow Sheet Limestone Process



Wet FGD – Process
State-of-the-art Arrangements

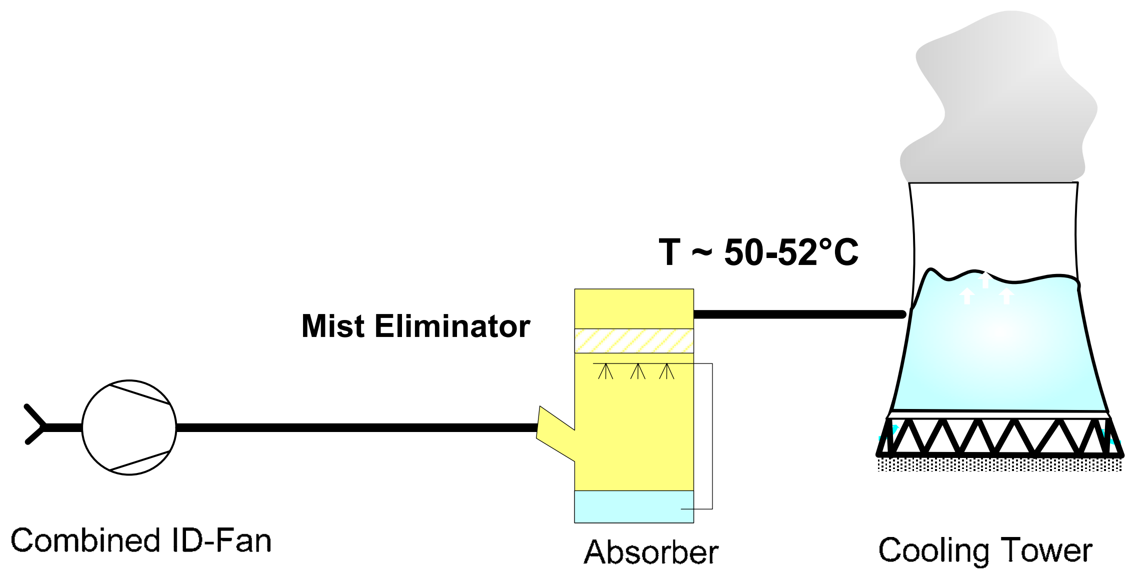
Variant 1

Absorber
with Flue Gas Reheating



Variant 2

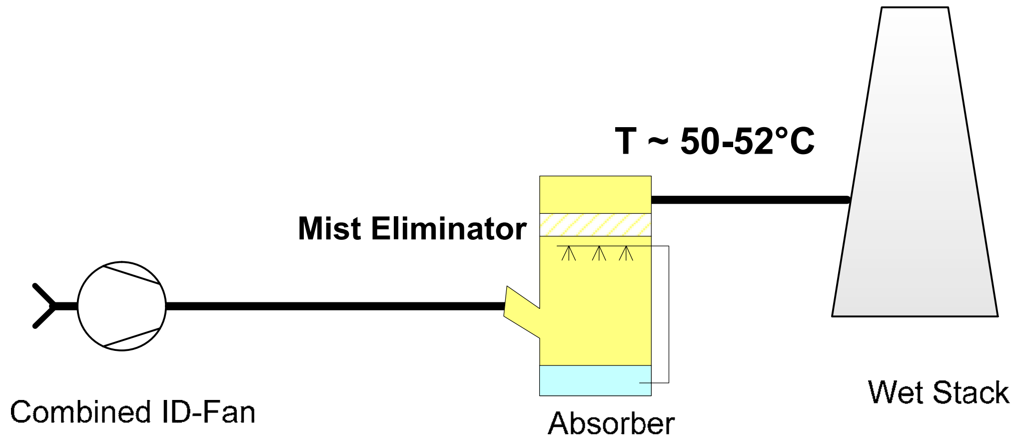
Discharge
via Cooling Tower



Wet FGD – Process
State-of-the-art Arrangements

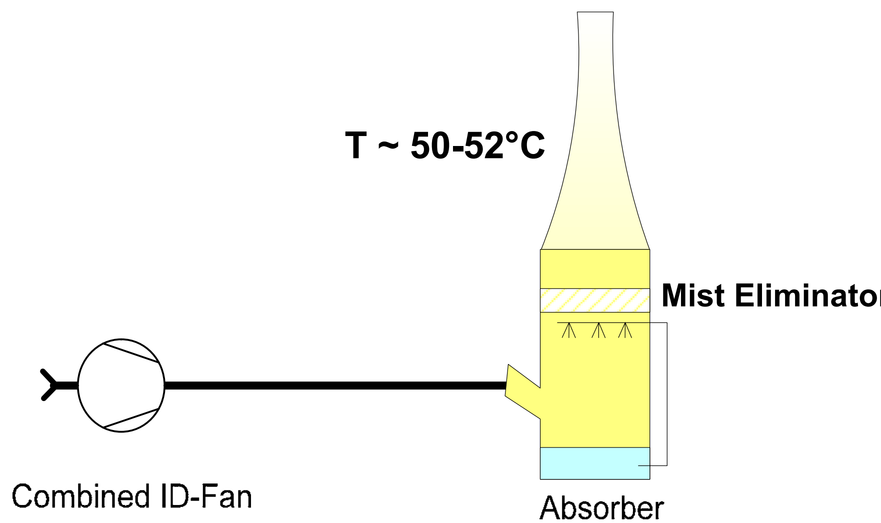
Variant 3

Discharge
via Wet Stack



Variant 4

Combined Absorber/Stack
Arrangement



Comparison of Quicklime / Limestone

Operating and Cost Parameter	Absorbent	
	Quick Lime	Limestone
Power Consumption of scrubber pumps	60 - 75%	100%
Mol. Stoichiometric ratio	< 1.01	1.02 – 1.04
Gypsum Quality		
Purity	98 - 99%	95 - 98%
Whiteness	> 80%	~ 60%
Solid waste Generation from FGD effluent treatment	60 - 70%	100%
Maintenance Cost	80 - 90%	100%
Transport cost of absorbent	54%	100%

Coal Qualities for STEAG Power Stations

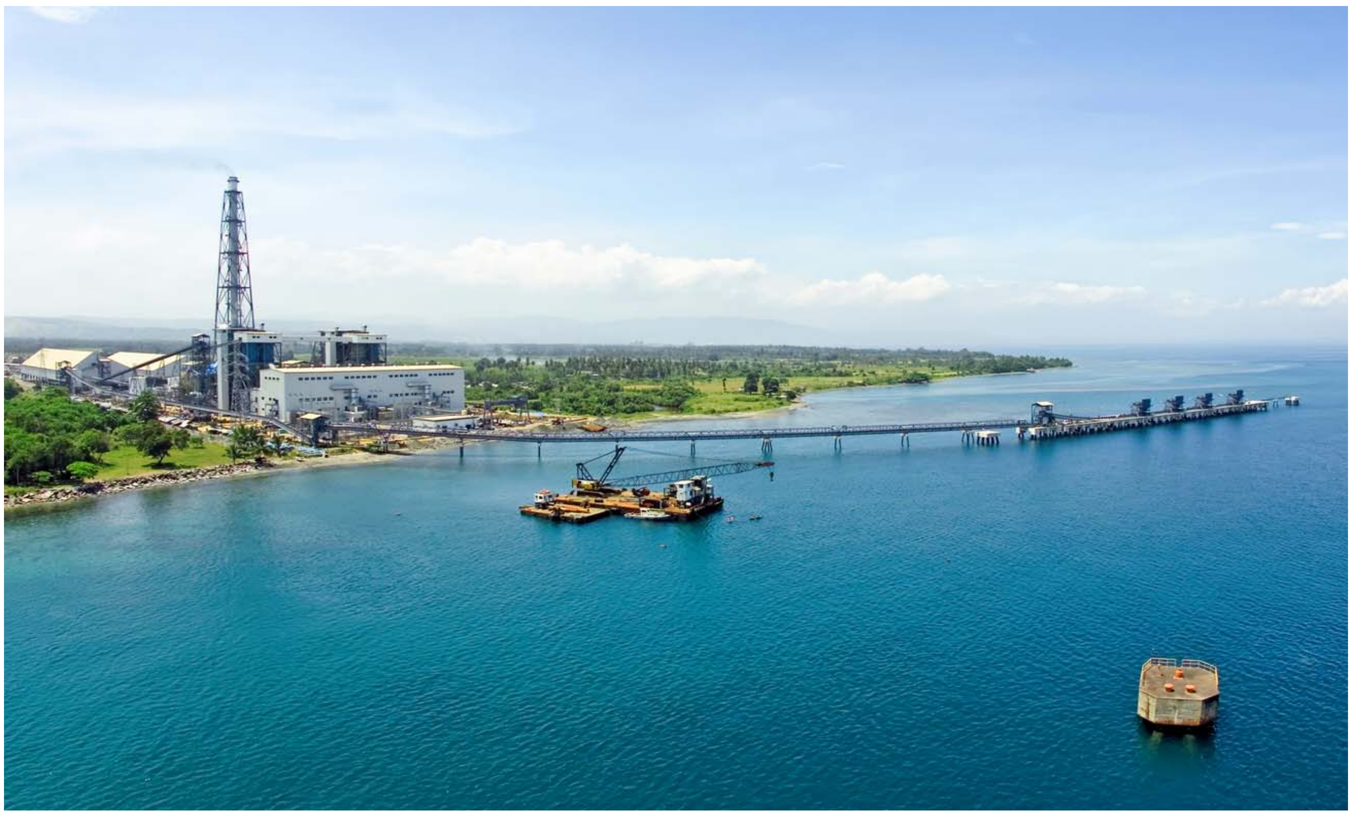
steag

encotec

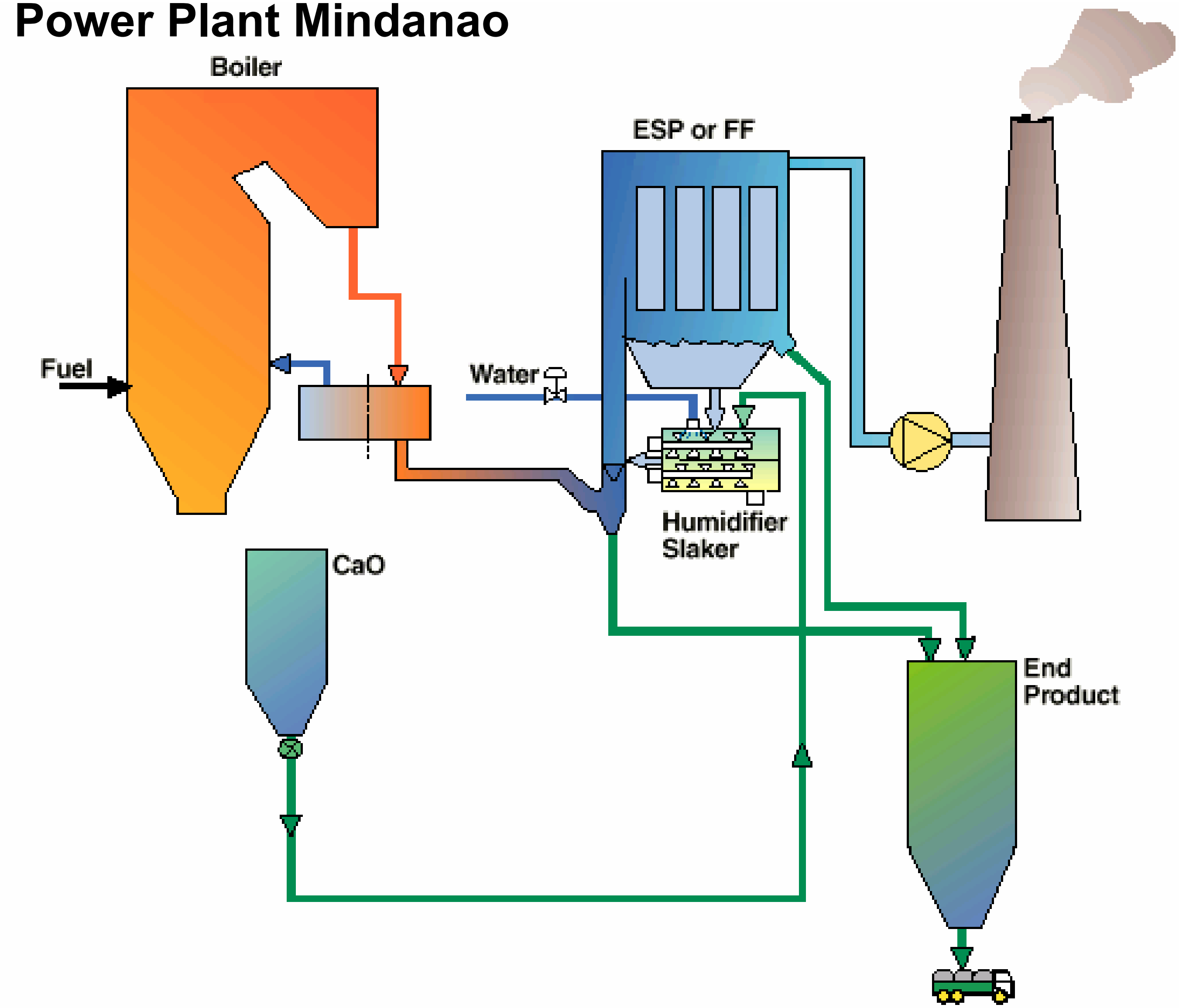
Coal Range		
LCV	MJ/kg	19.5 – 25.7
Ash	%	6 – 35 (45)
Water	%	8 – 12 (14)
Volatiles	%	30 - 40
Sulfur	%	0.5 – 1.7
Grindability	°H	50
Softening point	°C	> 1200

STEAG Power Plant with dry FGD
Power Plant Mindanao, Philippinen

Commissioning	2006
Installed Capacity (gross)	210 MW
Project volume	305 Mio US$
Fuel	Hard coal



Flue Gas Desulphurization
Dry FGD Power Plant Mindanao



steag

encotec

Flue Gas Desulphurization
Dry FGD Power Plant Mindanao

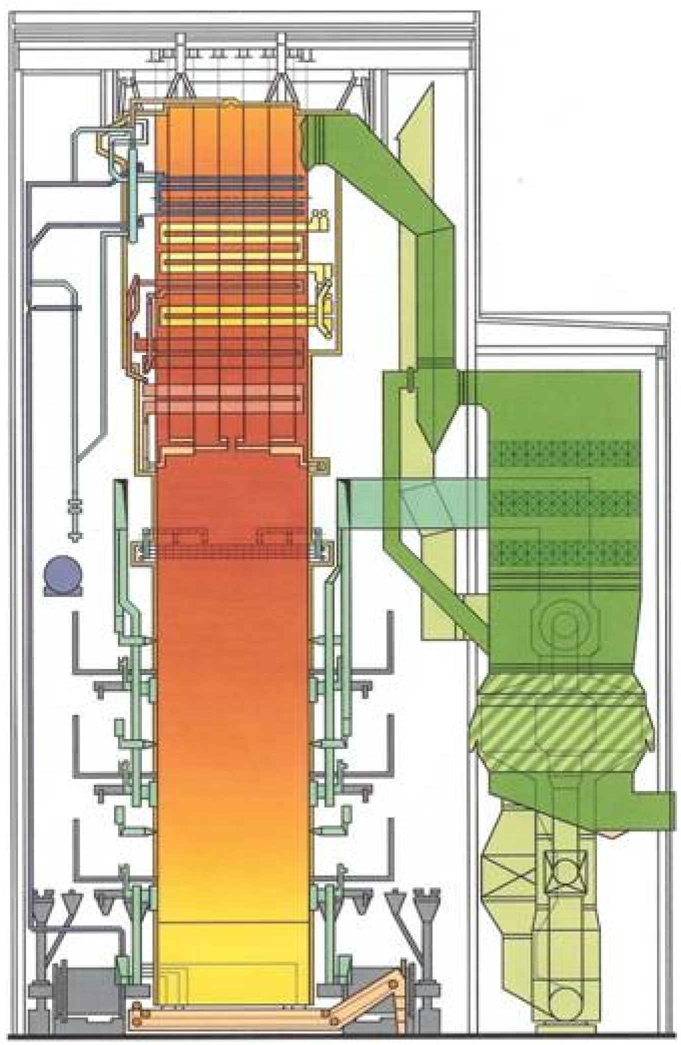
Fabric Filter

Comparison of 4 STEAG Power Plants with wet FGD


Plant No. 1
The 500 MW STEAG Power Plant

The 500 MW STEAG Power Plant

steag encotec



Boiler Height	104 m
Steam Mass Flow	420 kg/s
Power Output gross	500 MW
Steam Pressure	254 bar
Steam Temperature	535°C
Calorific value	19.5 MJ/kg
Sulfur	1.2 %
Ash	35%

$\dot{V}$	:			1,550,000	m^3(i.N.)/h_{wet}
$\dot{V}$	:			1,400,000	m^3(i.N.)/h_{dry}
SO_2 in	:			3,300	mg/m^3 (i.N.)
SO_2 out	:			200 (400)	mg/m^3 (i.N.)
HCl	:	490	→	10	mg/m^3 (i.N.)
HF	:	80	→	1.7	mg/m^3 (i.N.)
Dust	:	50	→	30	mg/m^3 (i.N.)

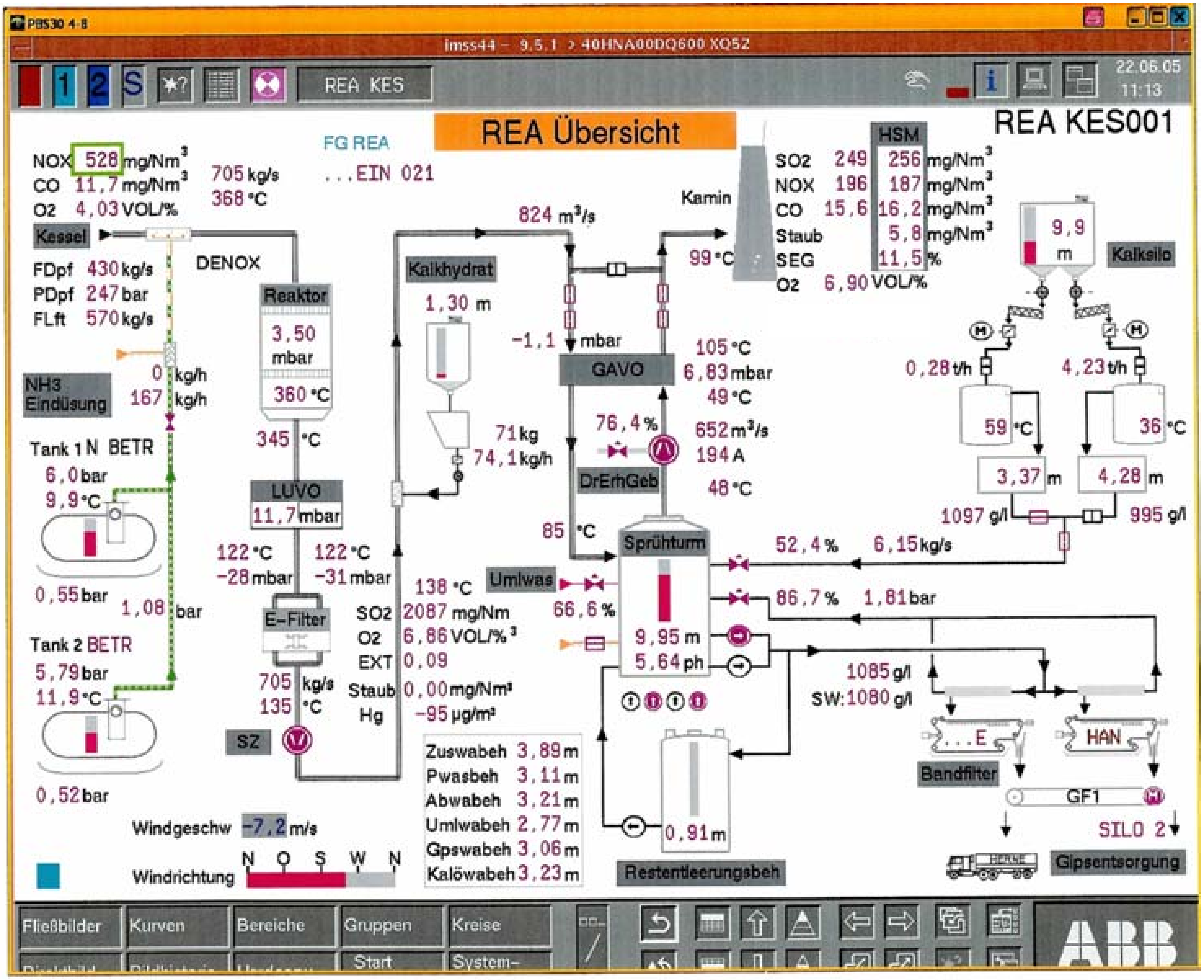
FGD of the 500 MW STEAG Power Plant

FGD

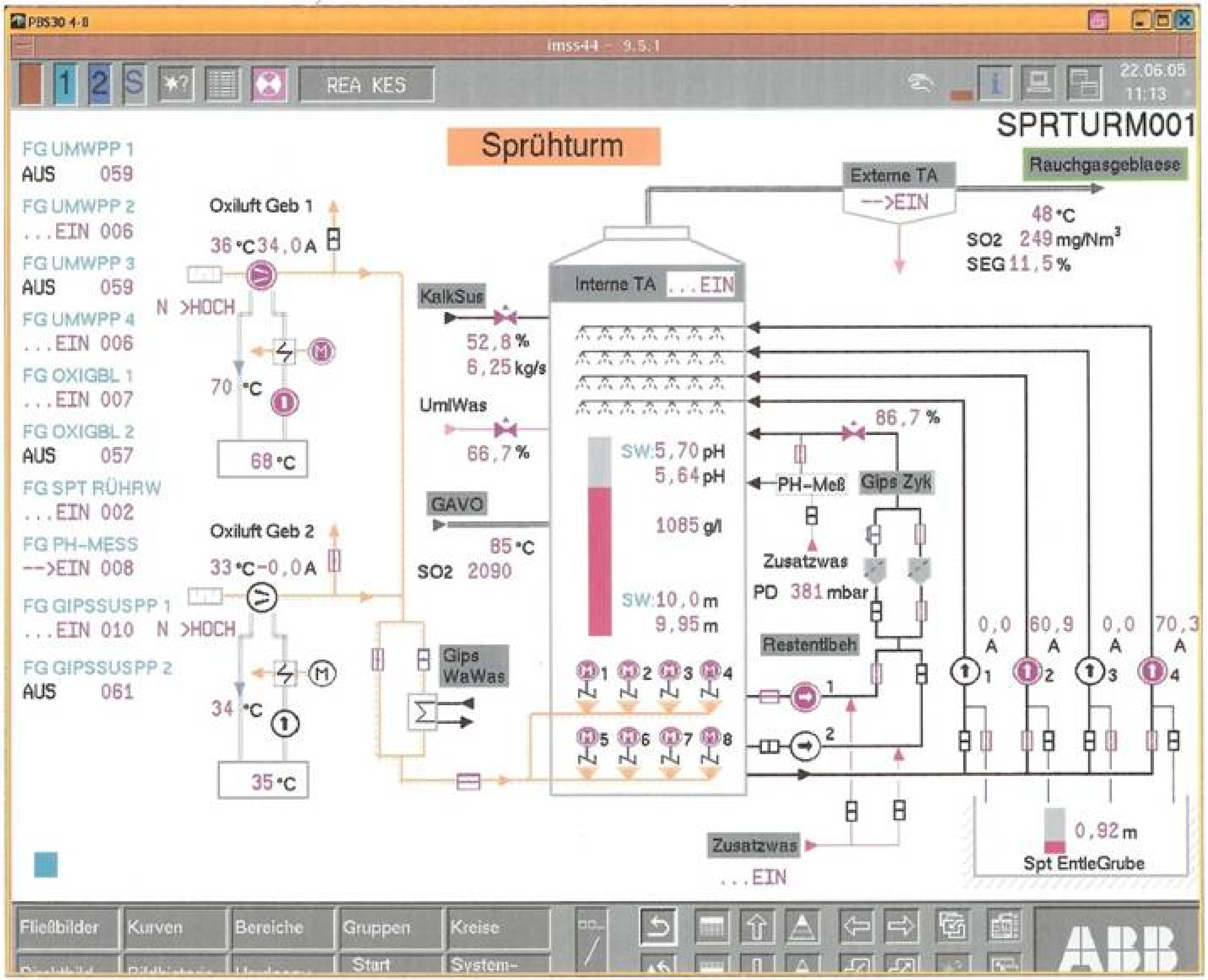
FGD of the 500 MW STEAG Power Plant

Flue gas Preheater

FGD of the 500 MW STEAG Power Plant / Flue Gas Line



FGD of the 500 MW STEAG Power Plant / Absorber



steag
encotec

Plant No. 2
The 660 MW STEAG Power Plant

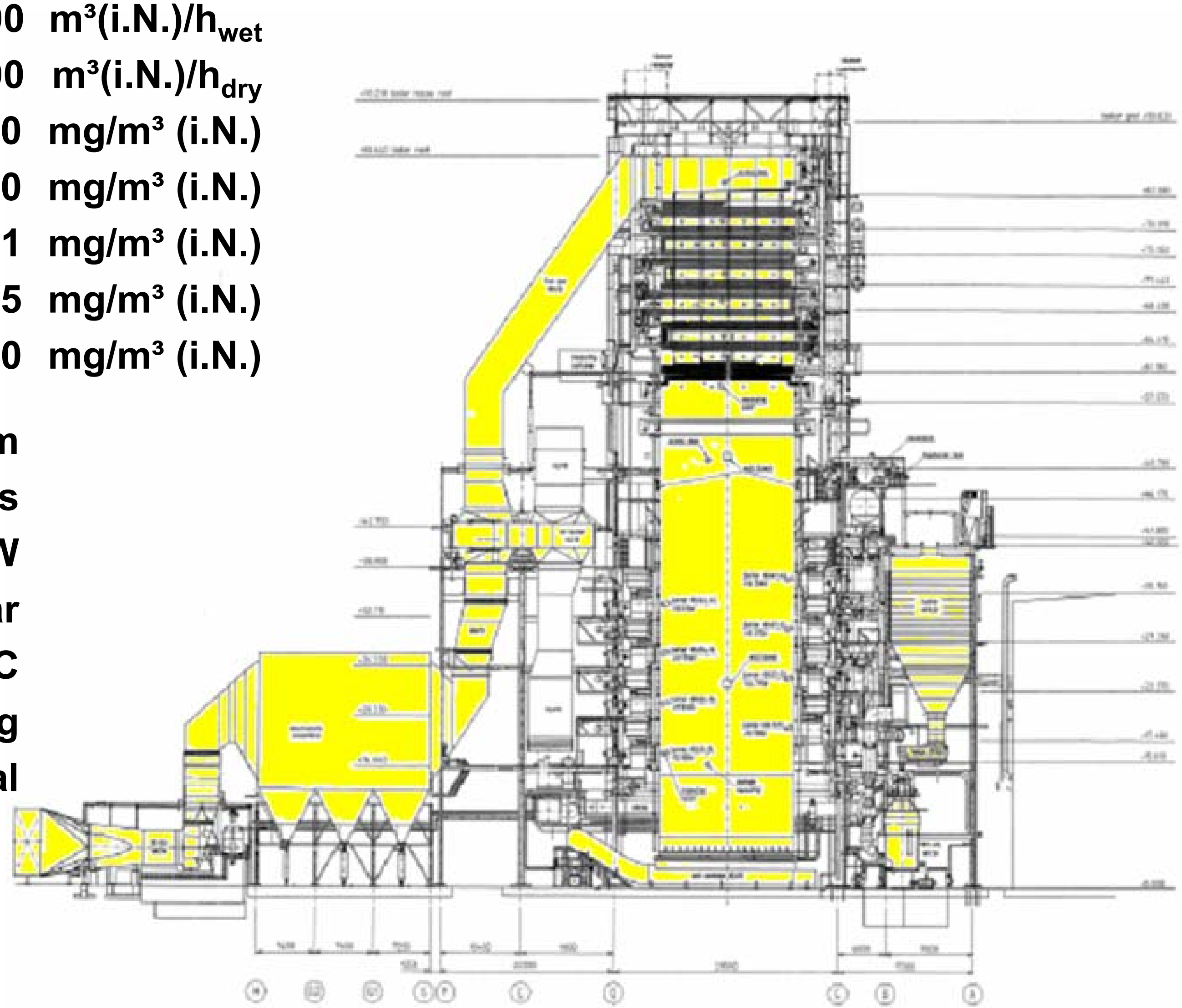
steag

The 660 MW STEAG Power Plant

The 660 MW STEAG Power Plant

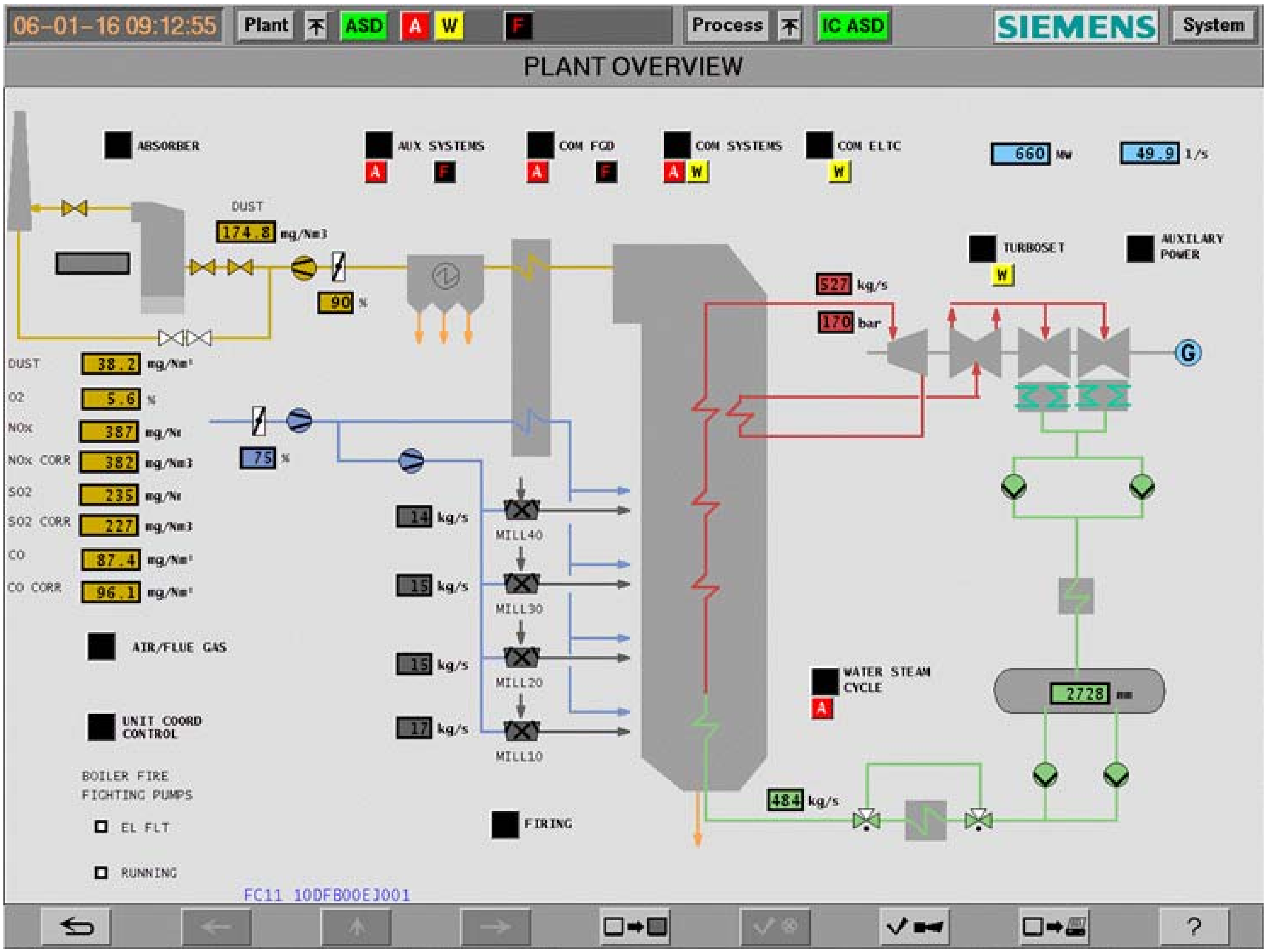
$\dot{V}$	:			2,000,000	m^3(i.N.)/h_{wet}
$\dot{V}$	:			1,850,000	m^3(i.N.)/h_{dry}
SO_2 in	:			1,460	mg/m^3 (i.N.)
SO_2 out	:			350	mg/m^3 (i.N.)
HCl	:	40	→	1	mg/m^3 (i.N.)
HF	:	12	→	<0.5	mg/m^3 (i.N.)
Dust	:	< 142	→	10	mg/m^3 (i.N.)

Boiler Height	93 m
Steam Mass Flow	524 kg/s
Power Output gross	660 MW
Steam Pressure	185 bar
Steam Temperature	541°C
Calorific value	25.8 MJ/kg
Coal	South African Coal

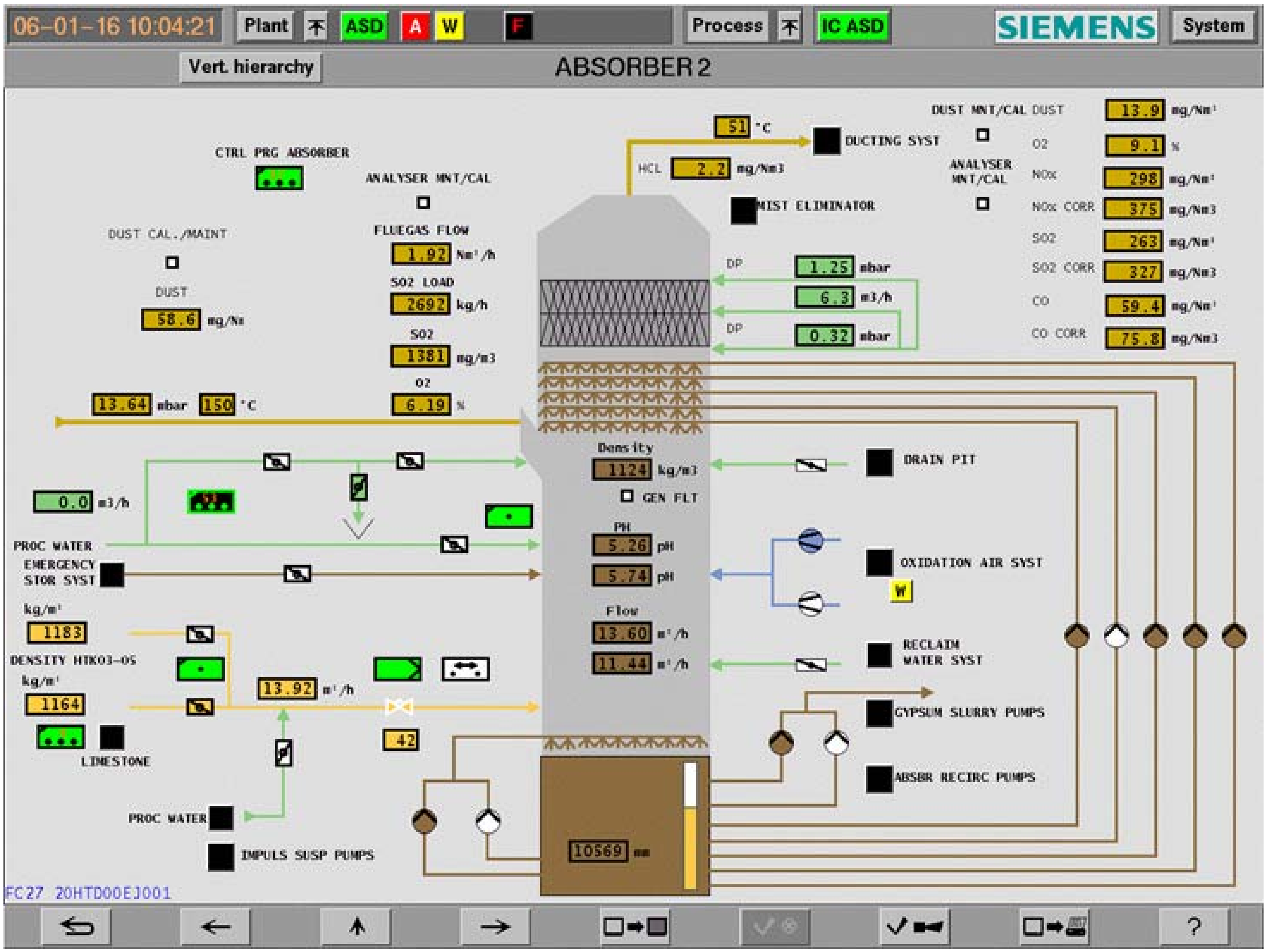


FGD of the 660 MW STEAG Power Plant

FGD of the 660 MW STEAG Power Plant / Plant Overview



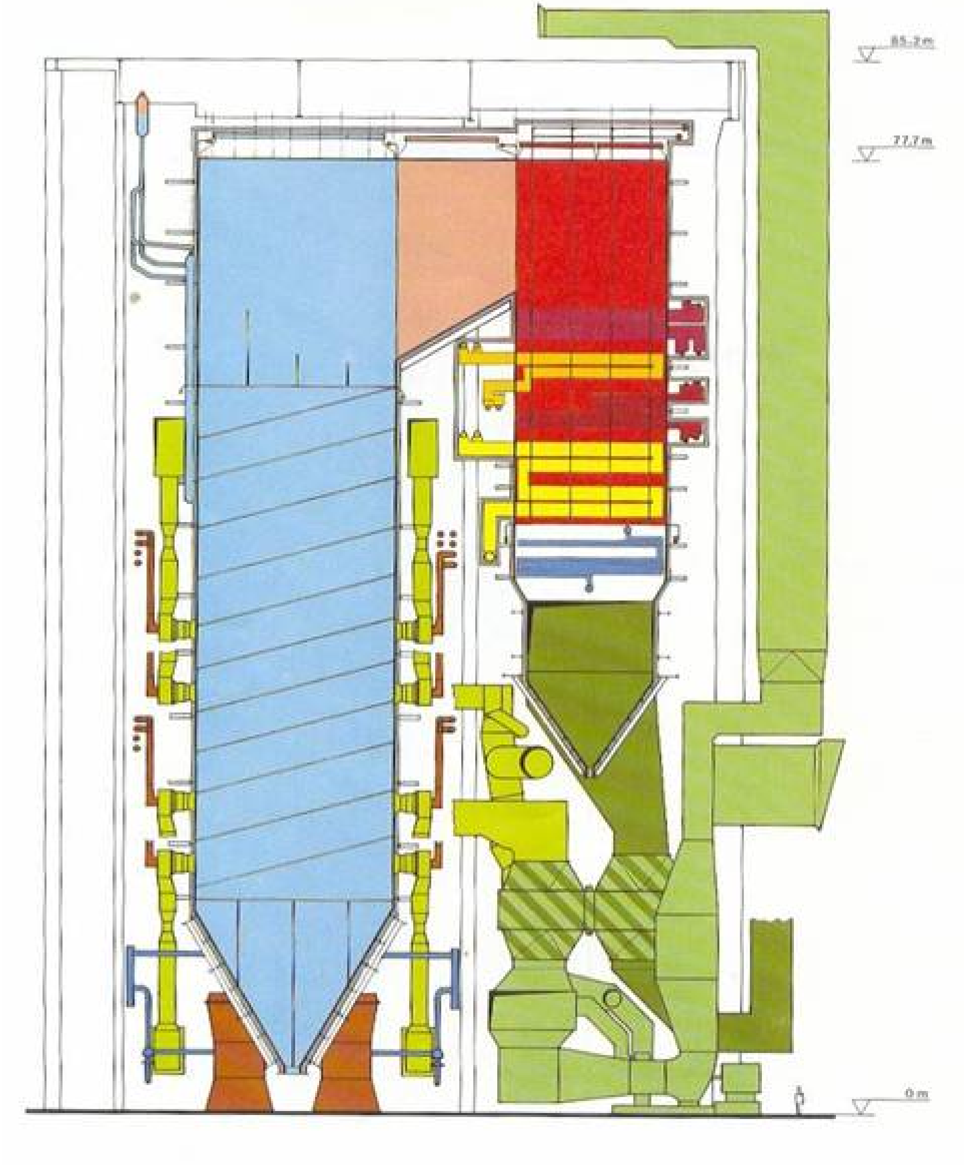
FGD of the 660 MW STEAG Power Plant / Absorber



Plant No. 3
The 760 MW STEAG Power Plant / FGD Retrofit

The 760 MW STEAG Power Plant / FGD Retrofit

steag
encotec

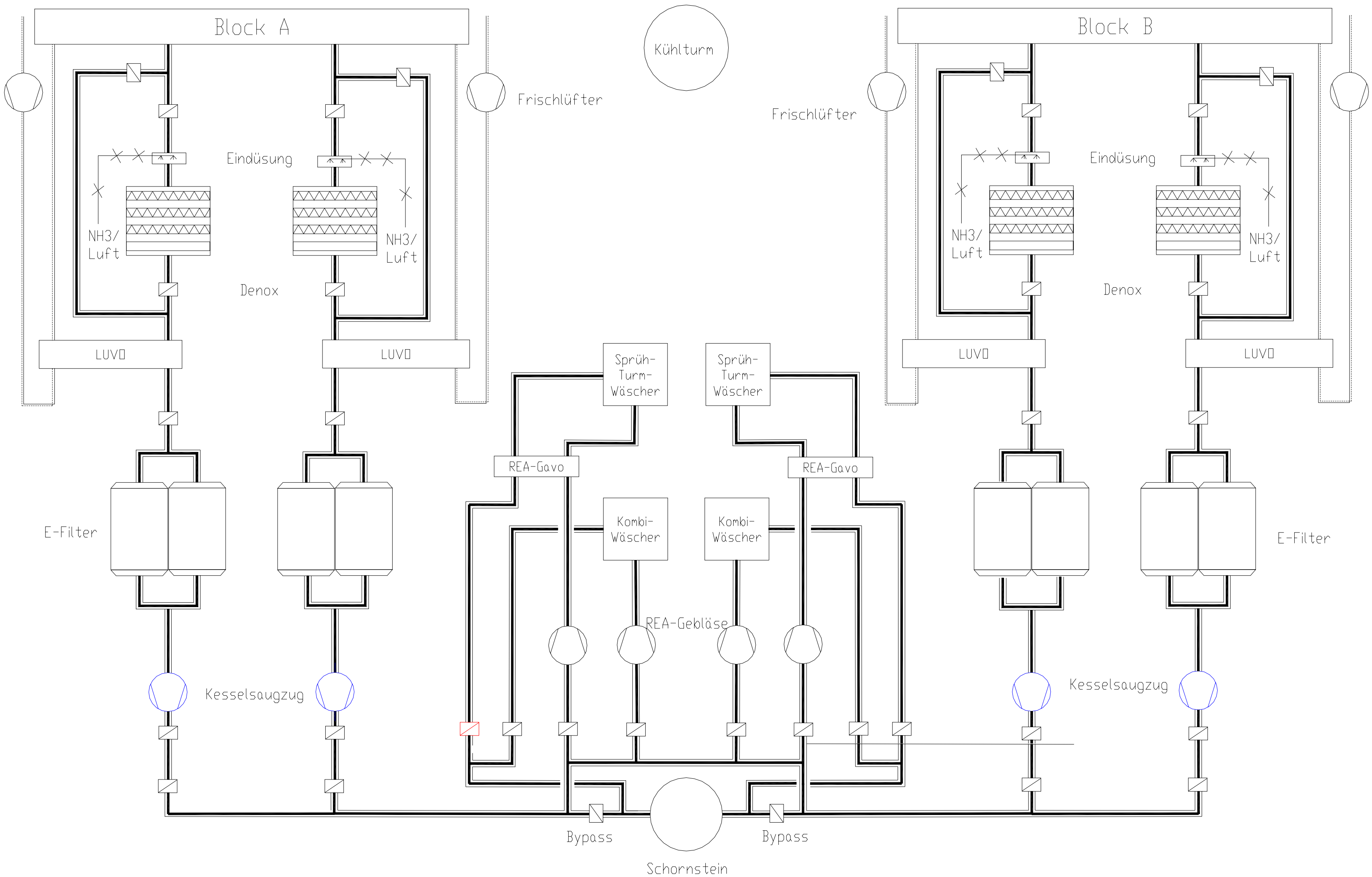


Boiler Height	85 m
Steam Mass Flow	600 kg/s
Power Output gross	760 MW
Steam Pressure	206 bar
Steam Temperature	530°C
Calorific value	27.3 MJ/kg
Coal	Import (South African)

$\dot{V}$	:			2,434,000	m^3(i.N.)/h_{wet}
$\dot{V}$	:			2,242,000	m^3(i.N.)/h_{dry}
SO_2 in	:			2,420	mg/m^3 (i.N.)
SO_2 out	:			<200	mg/m^3 (i.N.)
HCl	:	143	→	1	mg/m^3 (i.N.)
HF	:	16.5	→	<0.5	mg/m^3 (i.N.)
Dust	:	9.5	→	20	mg/m^3 (i.N.)

The 760 MW STEAG Power Plant / FGD Retrofit

Initial situation



The 760 MW STEAG Power Plant / FGD Retrofit
Reasons for the Refurbishment / Project Aims

- Improvement of the environmental situation
  - New FGD retrofit (SO$_2$: 400 ⟶ 200 mg/m³ (i.N.)$_{dr}$)
  - Optimisation ESP (Dust: 50 ⟶ 20 mg/m³ (i.N.)dr)
- Capacity increase (710 MW→760 MW, 2 x 50 MW, utilization of the permitted furnace thermal capacity)
- Efficiency improvement
- Reduction of the costs of maintenance
- Improvement of the profitability
- Improvement in competition

The 760 MW STEAG Power Plant / FGD Retrofit
New FGD without Bypass
Initial Situation

Boiler/ Turbine: Utilization of existing reserve capacity

DeNOx: Utilization of existing reserve capacity

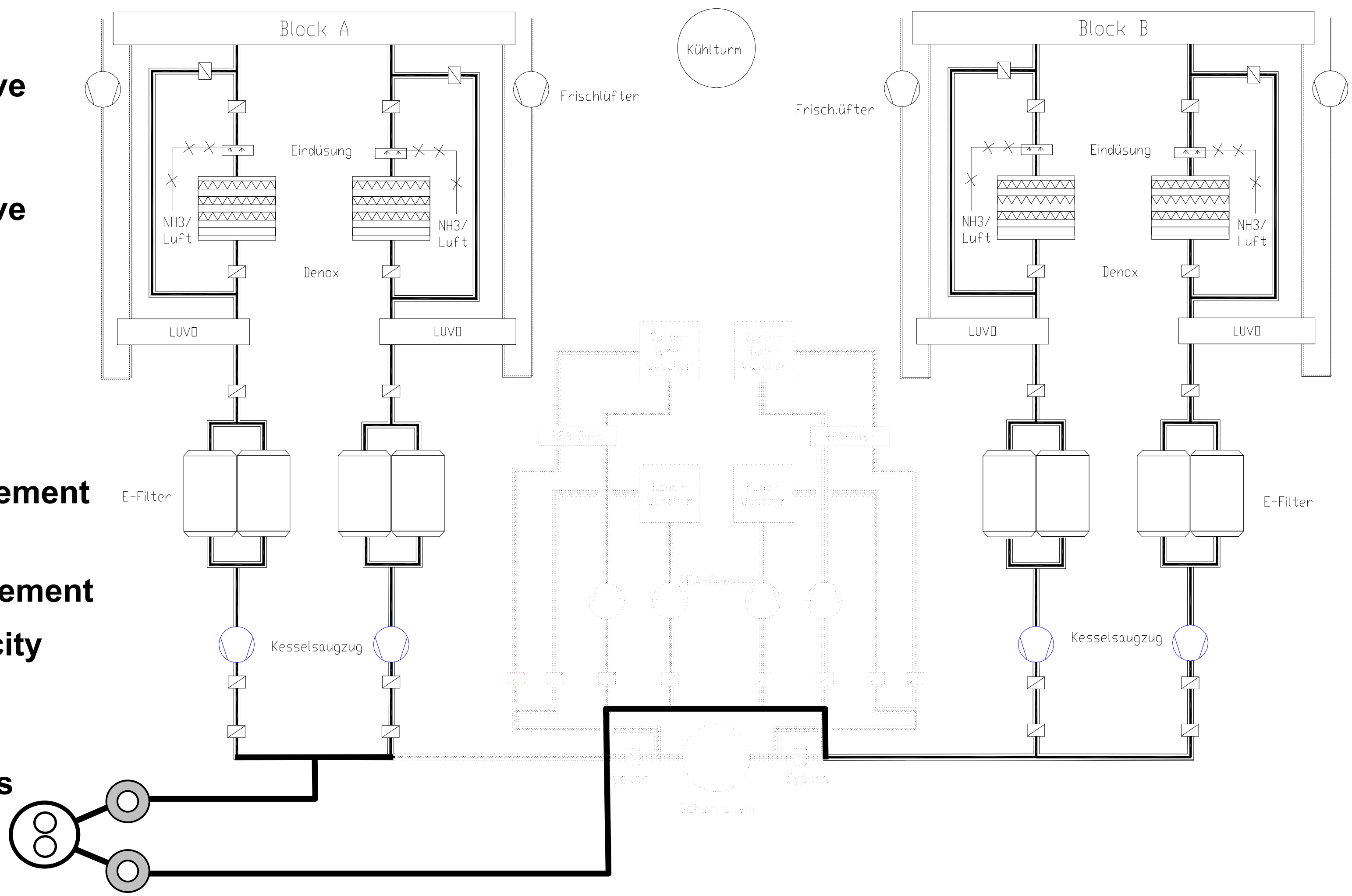
ESP: Optimisation, static reinforcement

Raw gas ducts: Static reinforcement

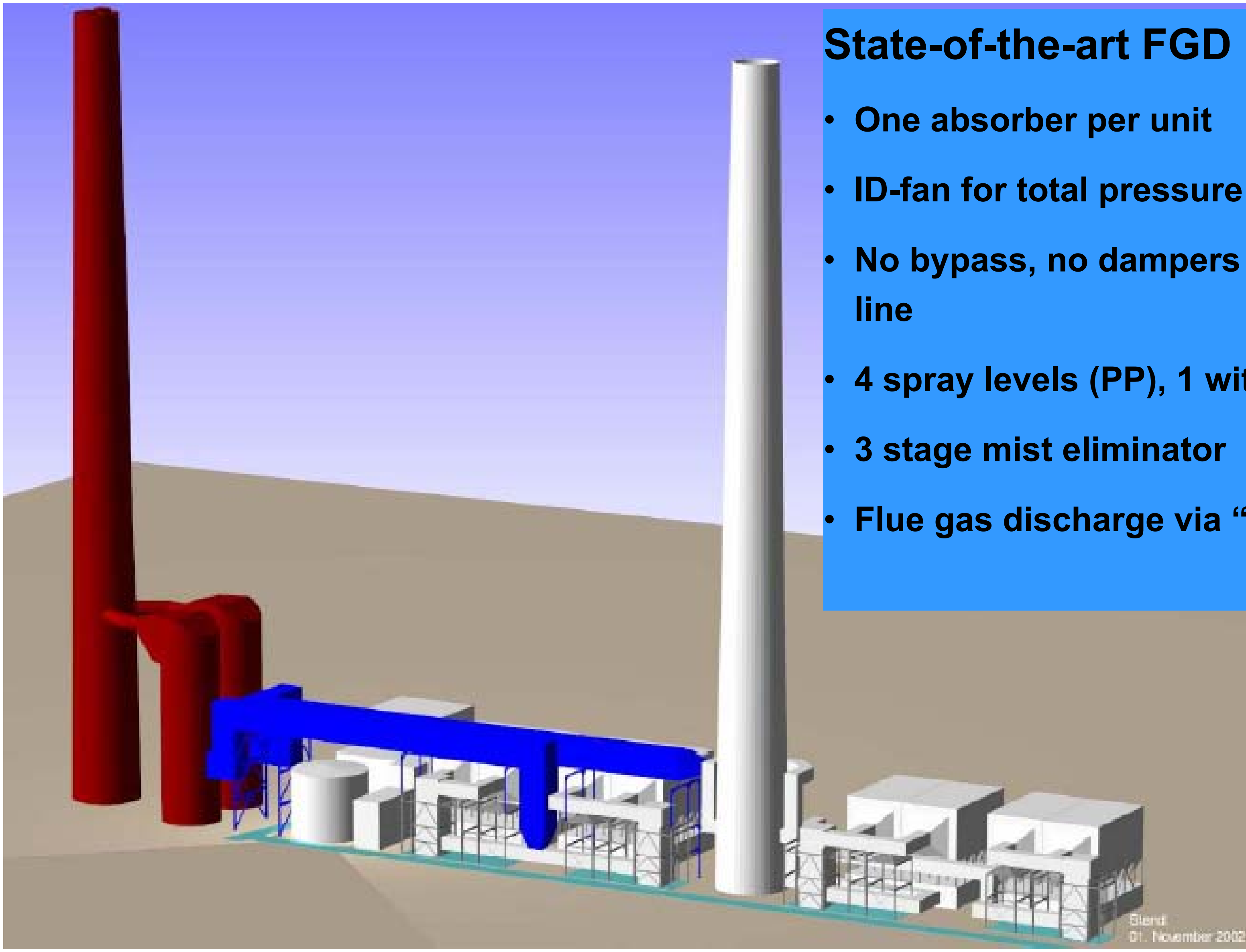
ID-Fans: Retrofit, capacity increase

FGD: New scrubbers

Stack: New wet stack



The 760 MW STEAG Power Plant / FGD Retrofit



State-of-the-art FGD Plant

- One absorber per unit
- ID-fan for total pressure rise
- No bypass, no dampers in the flue gas line
- 4 spray levels (PP), 1 with variable speed
- 3 stage mist eliminator
- Flue gas discharge via “wet stack”

steag

encotec

The 760 MW STEAG Power Plant / FGD Retrofit
New FGD

- One scrubber per unit, without bypass, without dampers
- Existing ID fans for total pressure rise, capacity increase
- Diameter 17 m, height approx. 36 m
- Sump volume approx. 2,400 m³
- Steel rubber lining
- Raw gas inlet Alloy 59
- 4 Spray levels, design in polypropylen (PP)
- Circulation pipe in GRP
- 3 Stage mist eliminator

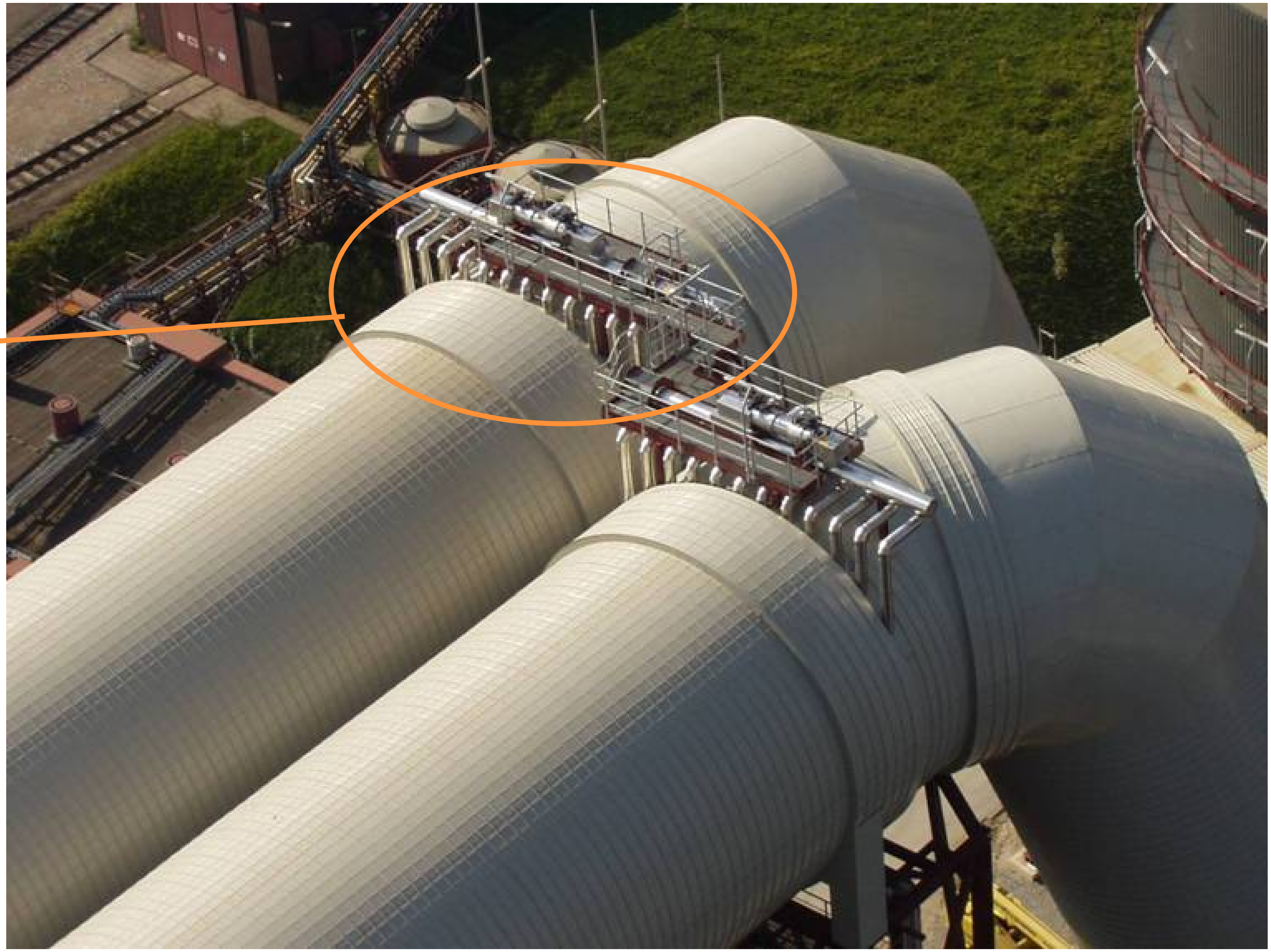
The 760 MW STEAG Power Plant / FGD Retrofit
New Wet Stack

- Flue gas discharge via “wet stack”
- Total height 230 m
- Steel concrete shaft with
  2 flue gas pipe of GRP
- Clean gas velocity < 18 m/s at 110% load
- Selective condensate discharge
- Avoidance of interior installed components

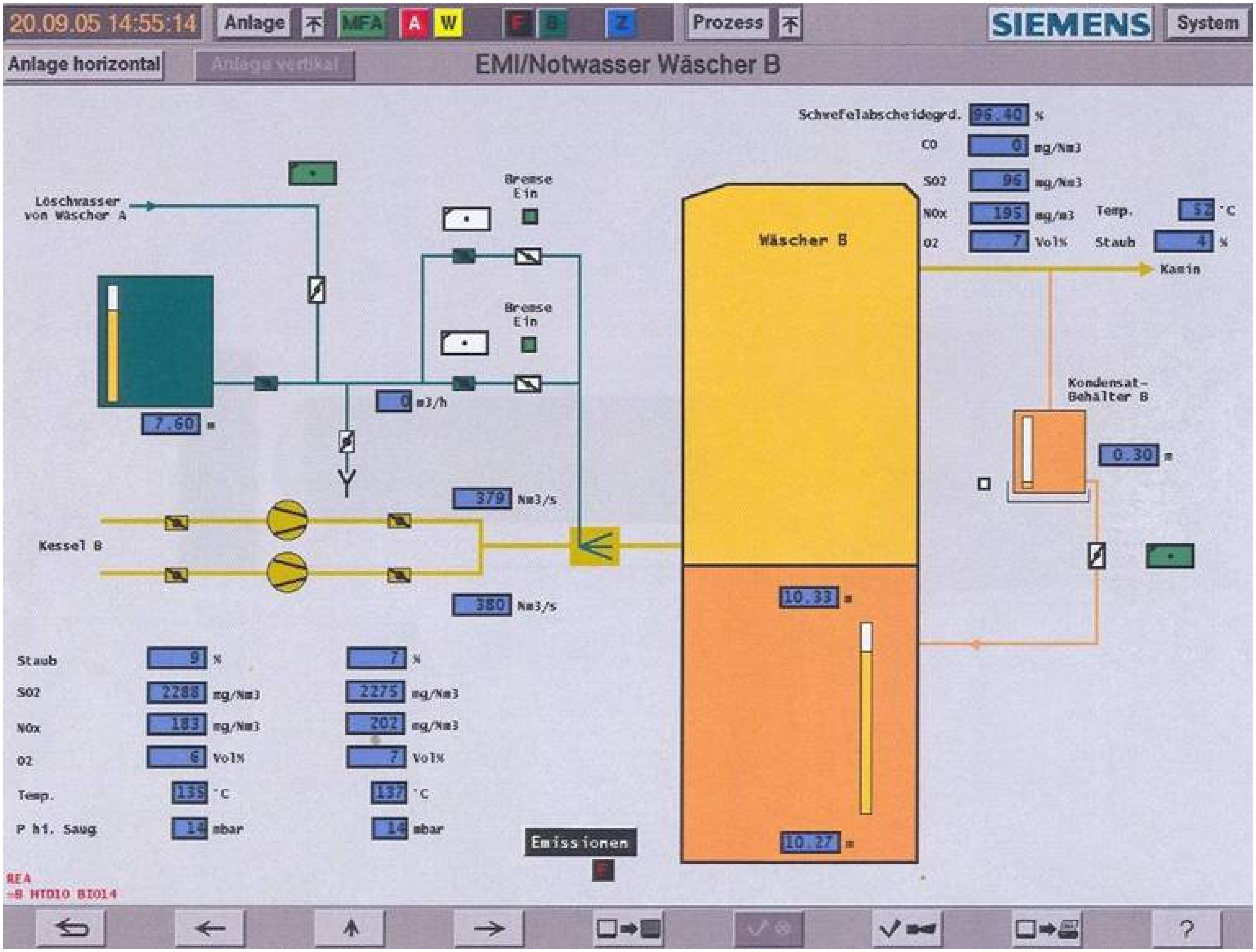
The 760 MW STEAG Power Plant / FGD Retrofit

steag encotec

Emergency water injection

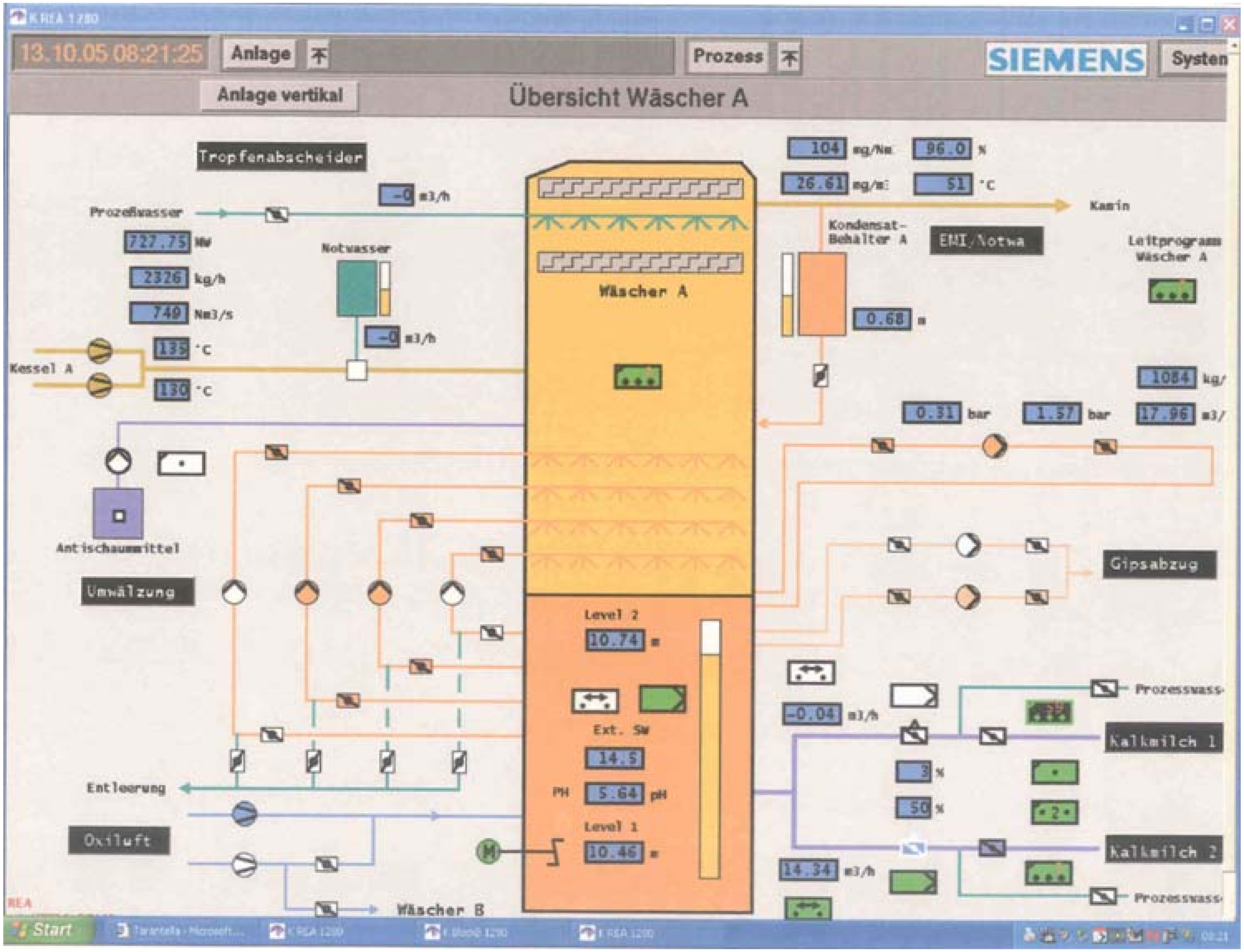


The STEAG 760 MW Power Plant / Flue Gas Line FGD



The STEAG 760 MW Power Plant / Absorber FGD

steag
encotec

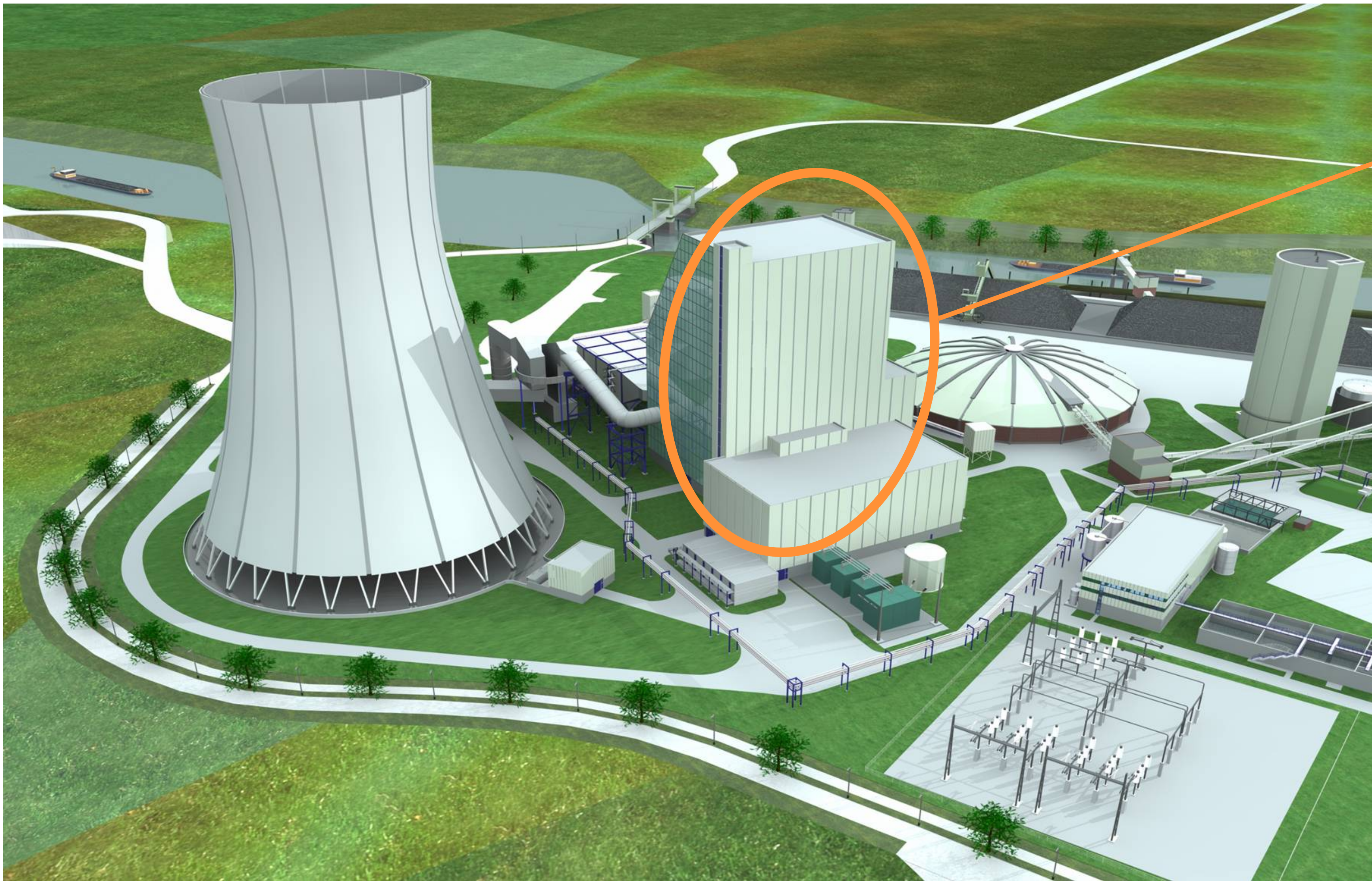


Plant No. 4
The new 750 MW STEAG Power Plant (CCEC)

<u>C</u>lean
<u>C</u>ompetitive
<u>E</u>lectricity from
<u>C</u>oal

The new 750 MW STEAG Power Plant (CCEC)

steag encotec



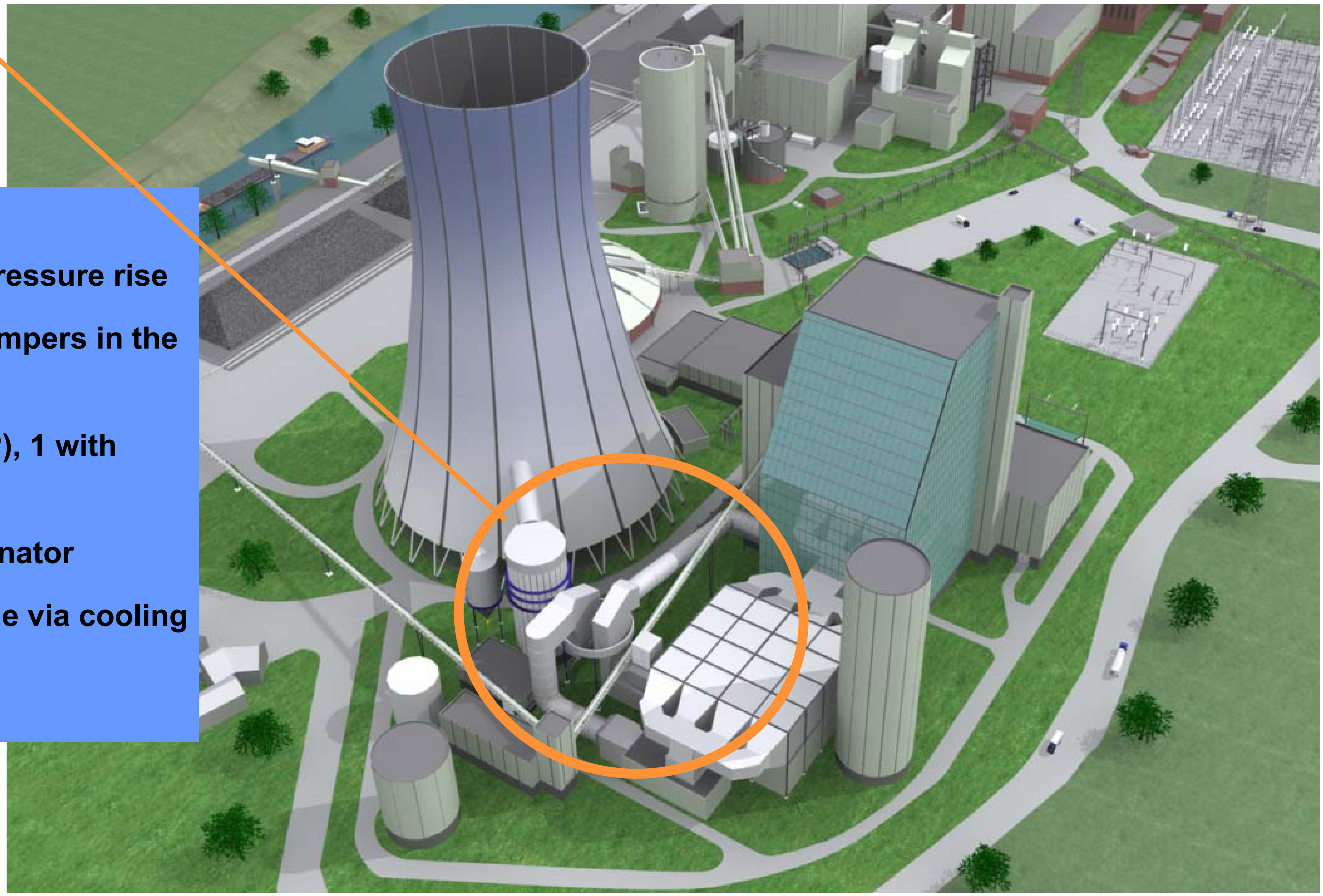
The new 750 MW STEAG Power Plant (CCEC)

steag

encotec

State-of-the-art FGD Plant

- One absorber
- ID –fan for total pressure rise
- No bypass, no dampers in the flue gas line
- 4 spray levels (PP), 1 with variable speed
- 3 stage mist eliminator
- Flue gas discharge via cooling tower

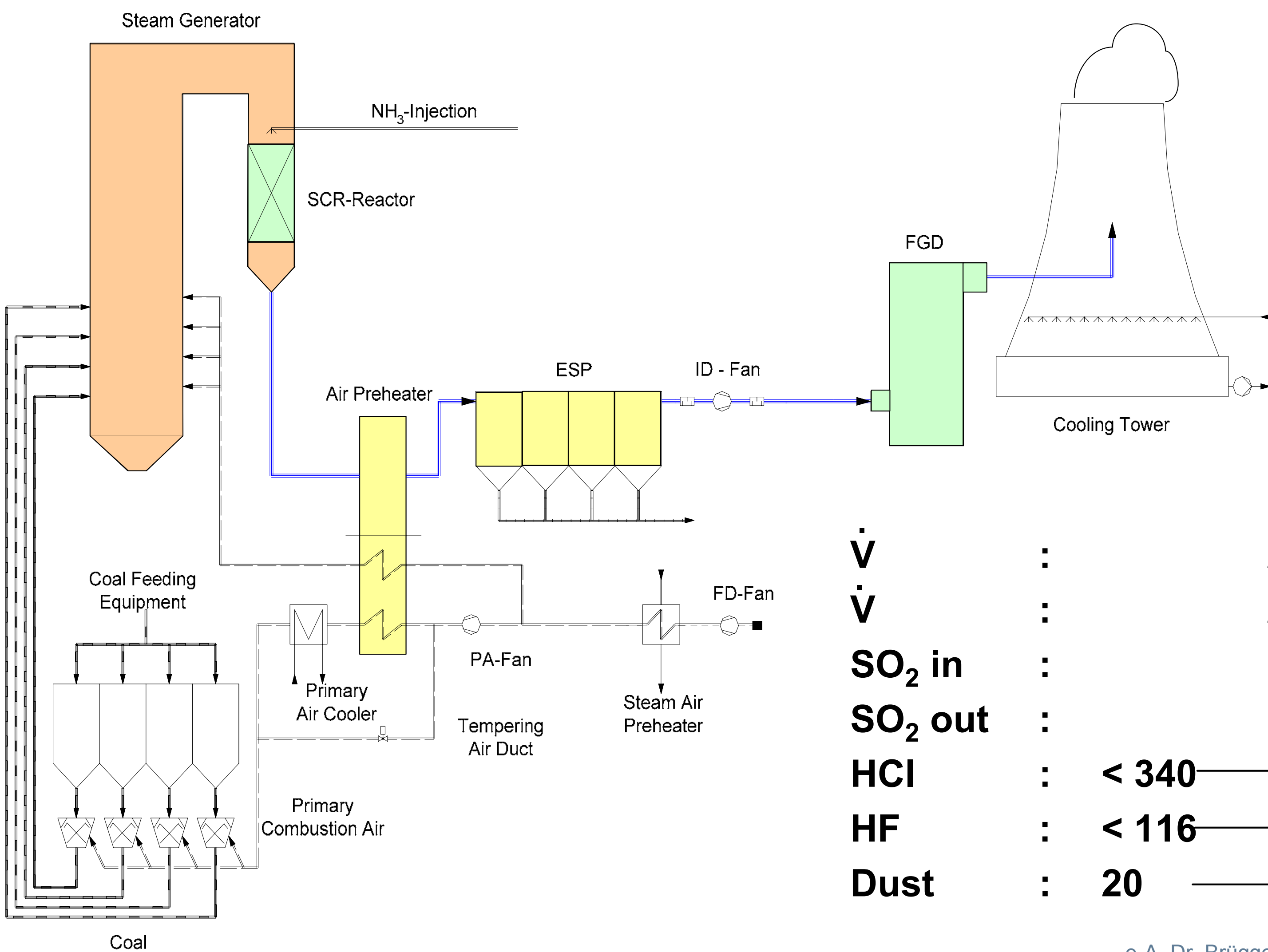


Clean Competitive Electricity from Coal (CCEC)

steag encotec

- **Lowest Investment**
  - standardization / modularization
  - reduction of costs by lessons learned
  - application of proven technology but mono components
- **Shortest Construction Period**
- **High Availability**
- **Low Maintenance Costs**
  - quick repair and overhauls, long intervals
  - spare parts on stock or on call at supplier
  - maintenance friendly design
  - skilled and trained team
- **Optimal Logistics (plant sites)**

The new 750 MW STEAG Power Plant (CCEC)
Air / Flue Gas Schematic Drawing



$\dot{V}$	:			2,200,000	m³(i.N.)/h_{wet}
$\dot{V}$	:			2,000,000	m³(i.N.)/h_{dry}
SO_2 in	:			2,200	mg/m³ (i.N.)
SO_2 out	:			200	mg/m³ (i.N.)
HCl	:	< 340	→	<10	mg/m³ (i.N.)
HF	:	< 116	→	<1	mg/m³ (i.N.)
Dust	:	20	→	<20	mg/m³ (i.N.)

Comparison of different FGD Plants

Benchmarking Figures	Dim MW	No. 1 Reheat/Stack 500	No. 3 Wet stack 2 x 760	No. 2 Wet stack 2 x 660	No. 4 Cooling tower 750
Comm.		1989	1982 / 85	2003	2009
Refurbishment/ Retrofit		—	2005	—	—
Plant Efficiency net	%	38.9	38,6	40,23	45,1
Boiler Efficiency net	%	93.2	93,2	93,4	94,5
Sulfur Range	%	< 1.55	1,22	< 1,5	0,5 - 1,5
Spec. Steam Flow	$kg/s/MW_{net}$	0.93	0.86	0.87	0.81
Spec. Fuel Flow	kg_{Fuel}/s / kg_{Steam}/s	0.141	0.110	0.107	0.114
Spec. Fluegas Mass Flow	$kg/s/MW_{net}$	1.22	1.29	1.03	1.04
Scrubber Design					
1. Absorbens	—	Quicklime	Quicklime	Limestone	Quicklime
2. L/G Ratio	l/m^3	12.6	11.5	12.4	11.9
3. Velocity gas zone	m/s	2.6	3.8	4.0	< 4
4. Pressure drop	mbar	45	16.5	13	14
5. Gas Temp. beh. Scrubber	°C	46	52	54	50-52
6. Internal Power Consumption	MW	7.0	6.3	5.0	3.5
Equivalent hours of full load Operation	h/a	6,800	approx. 7,000	6,600	approx. 7,000

steag
encotec

Water resources

Main data Power Plant	DIM	Mindanao	Flue gas reheat No. 1	Wet Stack No. 2	Wet Stack No. 3	Cooling Tower No. 4
Power Output gross	MW	210	500	2 x 660	2 x 760	750
Water resources						
Quicklime / Limestone	t/h	QL	QL 6,5	LS 5,9	QL 5,9	QL 4,5
Additional Water	m³/h	30	90	350	330	150
	l/MWh	143	180	265	217	200
Waste water	m³/h	No	40	80	75	40
	l/MWh	No	80	61	49	53
Liquid/fluegas ratio (L/G-Ratio)	l/m³	No	12.6	12.4	11.5	11.9

Selection of Desulphurization Processes

- General question: Recovery of byproduct ⇒ gypsum

  or landfill

- Semi dry system: ⇒ Product has to be landfilled

  ⇒ Problems with S > 2 % in coal

  ⇒ Operating experience up to 350.000 m³/h flue gas for one line

  ⇒ Offers up to 750.000 m³/h flue gas for one line

  ⇒ For 1000 MW min 4 lines necessary

  ⇒ Water 20 – 40 l / 1000 m³/h Flue gas (~ 0.14 l/kWh)

- Wet system: ⇒ Produced gypsum marketable

  ⇒ High operating experience with high throughput per line

  ⇒ Water 60 – 80 l / 1000 m³7h Flue gas (~ 0.2 l/kWh)

  ⇒ Waste Water 40 – 80 m³/h (~0,06 l/kWh)

Comparison of FGD-Processes

System	Efficiency	Ca/S	Investment (West European basis)
Dry	80 - 90 %	$<$ 2	65 - 78 US$/KW$_{el}$ (50 – 60 €/KW$_{el}$)
Semi-Dry	90 - 97 %	1.2 -1.5	65 - 78 US$/KW$_{el}$ (50 – 60 €/KW$_{el}$)
Wet	90 - 99 %	1.05	85 - 115 US$/KW$_{el}$ (75 – 90 €/KW$_{el}$)

- Wet-system if:
  - High S-content in coal
  - Gypsum can be sold
  - Landfill cost for product of semi dry process
  - Cost benefit for high flue gas throughput
  - Water resources are sufficient
- Semi dry-system if:
  - Lower desulphurization efficiency is asked for
  - Product has to be landfilled
  - Water resources are insufficient

STEAG International Reference FGD Plants as Owner's Engineer

steag encotec

• Ratcliffe Power Station	UK	4 x 500	MW
• Chemnitz	Germany	120	MW
• Orhaneli Power Plant	Turkey	210	MW
• Mae Moh Power Plant	Thailand	4 x 150	MW
• Yatagan Power Plant	Turkey	3 x 210	MW
• Beijing Power Plant	China	330	MW
• Banshan Power Plant	China	250	MW
• Chongqing Power Plant	China	400	MW
• West Burton Power Station	UK	4 x 500	MW
• Maritza	Bulgaria	4 x 210	MW
• Cottam Power Station	UK	4 x 500	MW
• Pego	Portugal	2 x 300	MW

STEAG Power Stations Services

steag encotec

STEAG can provide unique services as the „Owner's Engineer" transferring extensive long-term FDG- and SCR-operating experience to our customers:

- **Optimal process, arrangement and equipment design**
- **Design review**
- **Material and equipment selection**
- **Material handling**
- **Maintenance assistance**
- **Measuring services**
- **SCR catalyst management**
- **Operator training in our plants**

STEAG Experience with different FGD - Solution

steag encotec

STEAG has experience with several FGD Technologies:

- Lurgi Lentjes
- Noell / KRC
- Marubeni/ABB
- FISIA Babcock, Steinmüller
- FLS/MHI
- John Brown
- Hitachi
- AE Austrian Energy
- RWE Solutions
- Alstom
- Ebara