

# **REINHOLD ENVIRONMENTAL Ltd.**



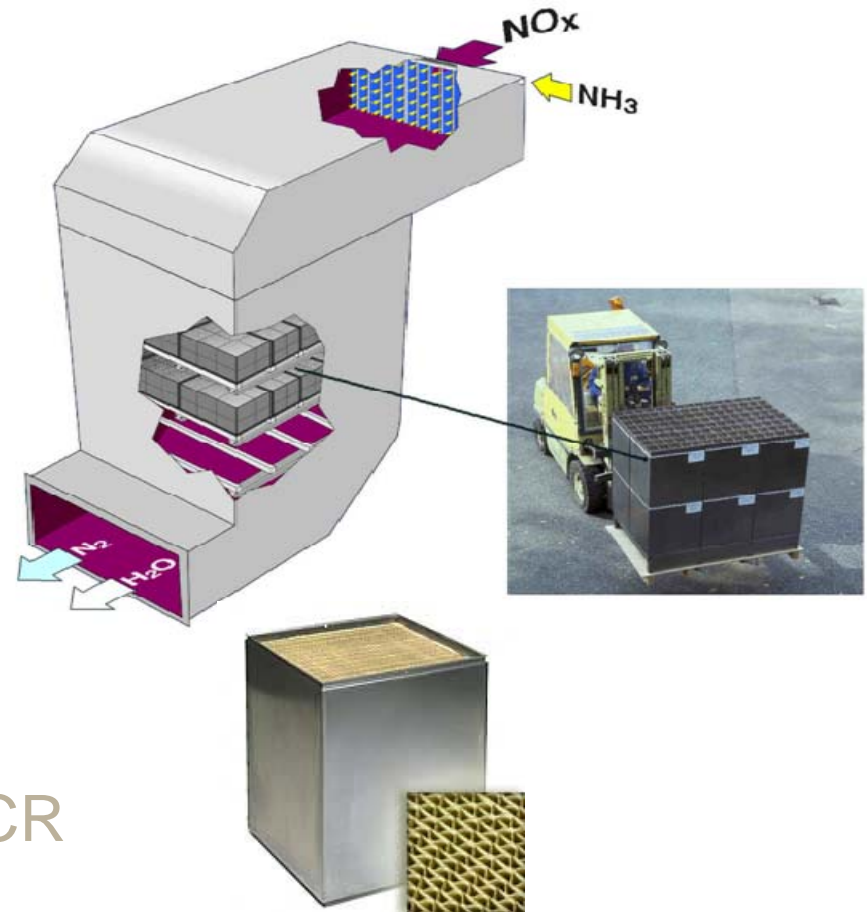
## **2011 NO<sub>x</sub>-Combustion Round Table & Expo Presentation**

February 7-8, 2011, in Birmingham, AL / Hosted by Southern Company

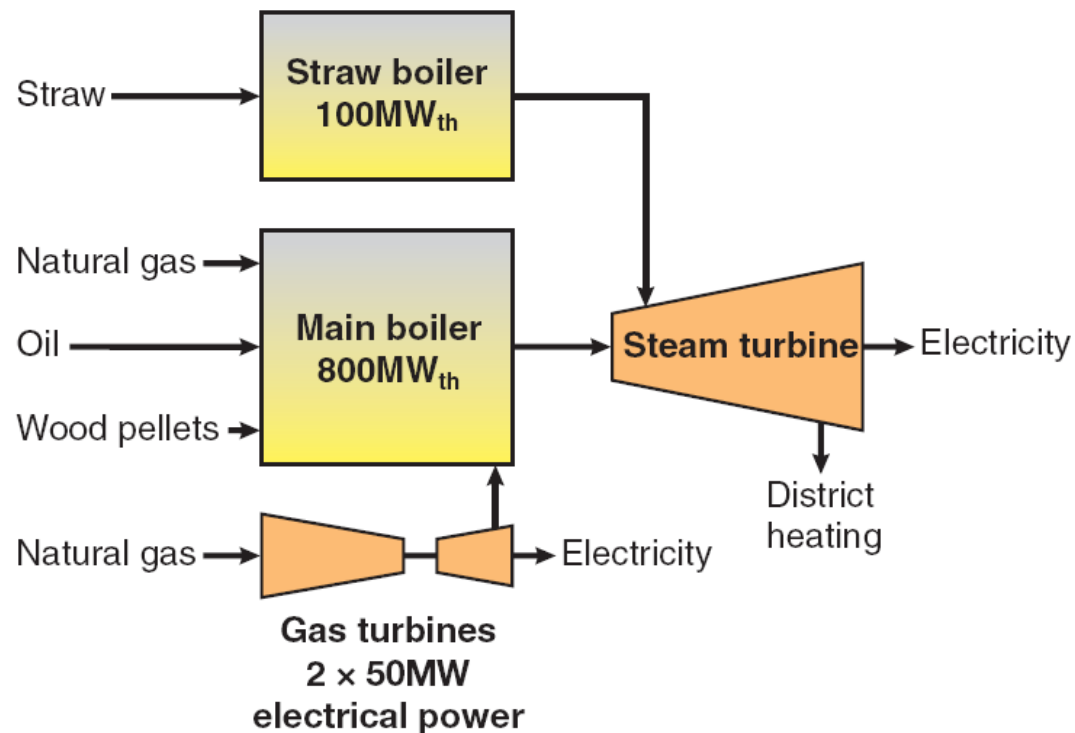
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# Contents

- Biomass sources
- Catalyst deactivation
  - What deactivates the catalyst?
- Biomass in power production
  - High-dust co-combustion
  - High-dust 100% biomass
  - Low-dust 100 % biomass
- Low-dust versus high-dust SCR

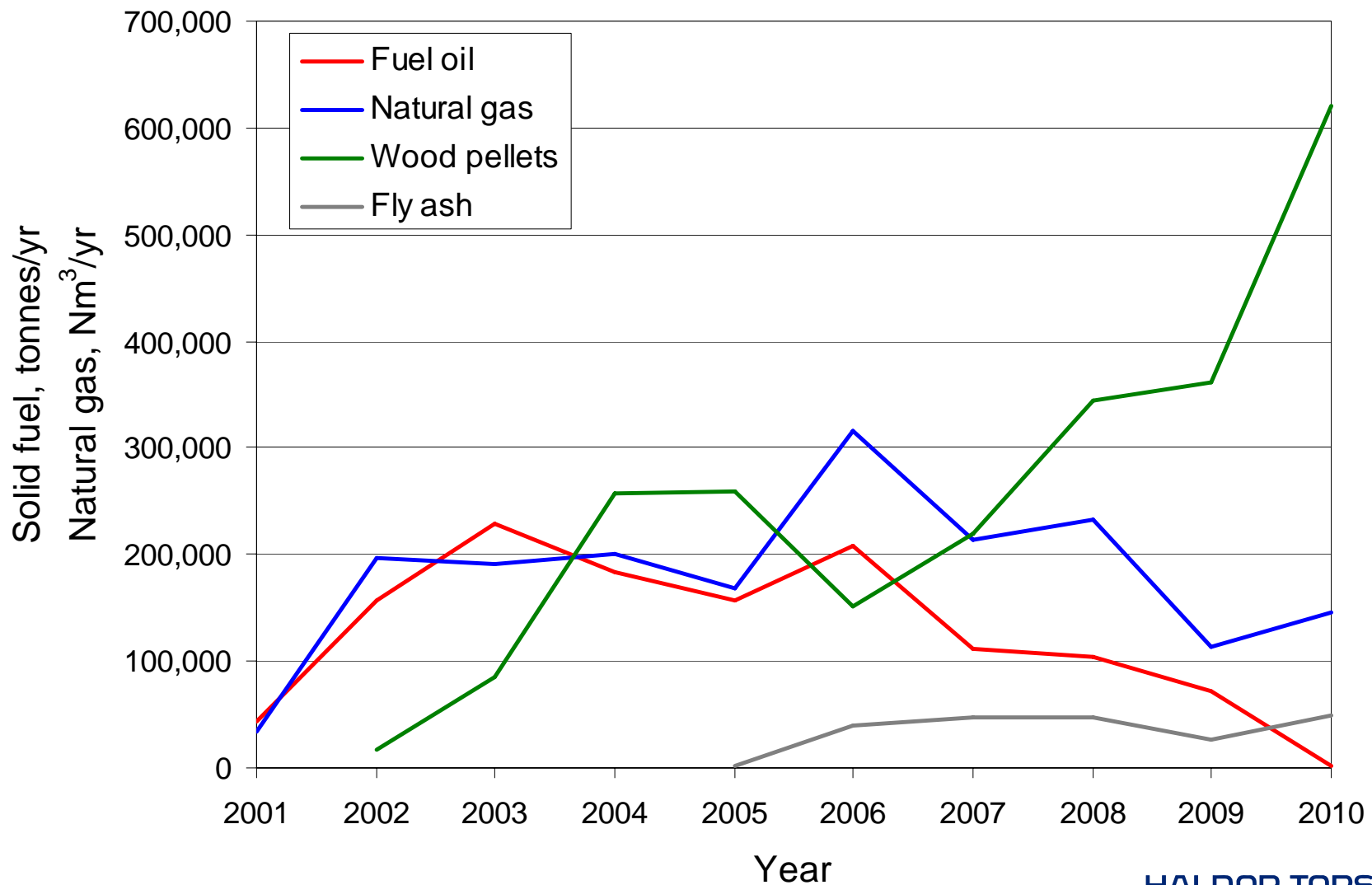


# DONG Energy Avedøre Unit 2, Denmark



- 570 MW<sub>e</sub>, CHP
- Commissioned in 2000
- SCR DeNO<sub>x</sub> in 2001
- Fuel boiler 1
  - Natural gas
  - Fuel oil
  - Wood pellets
- Fuel boiler 2
  - Straw
- 2 Gas turbines

# Avedøre 2 – main boiler fuel history

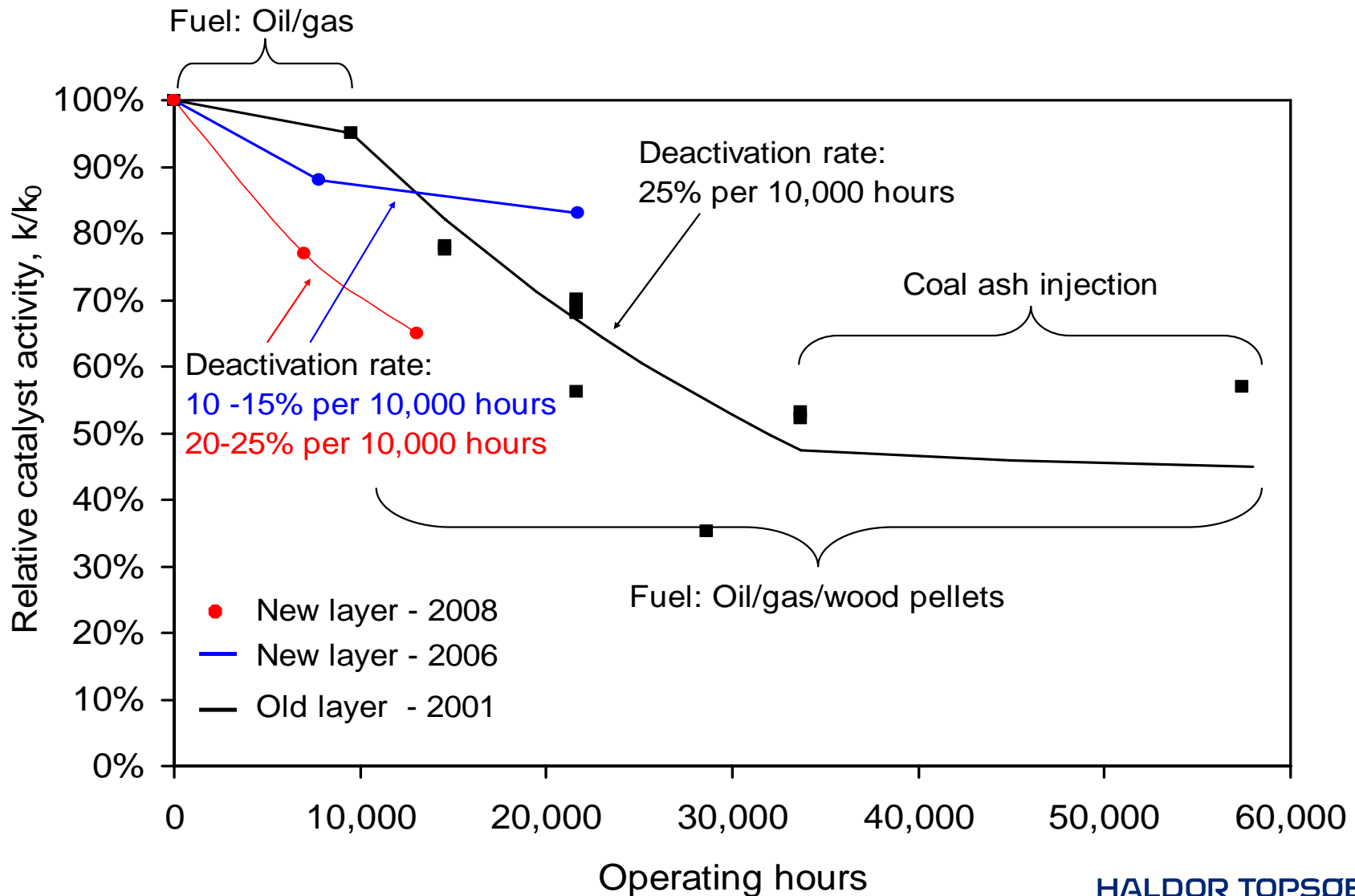


# Catalyst washing at Avedøre 2

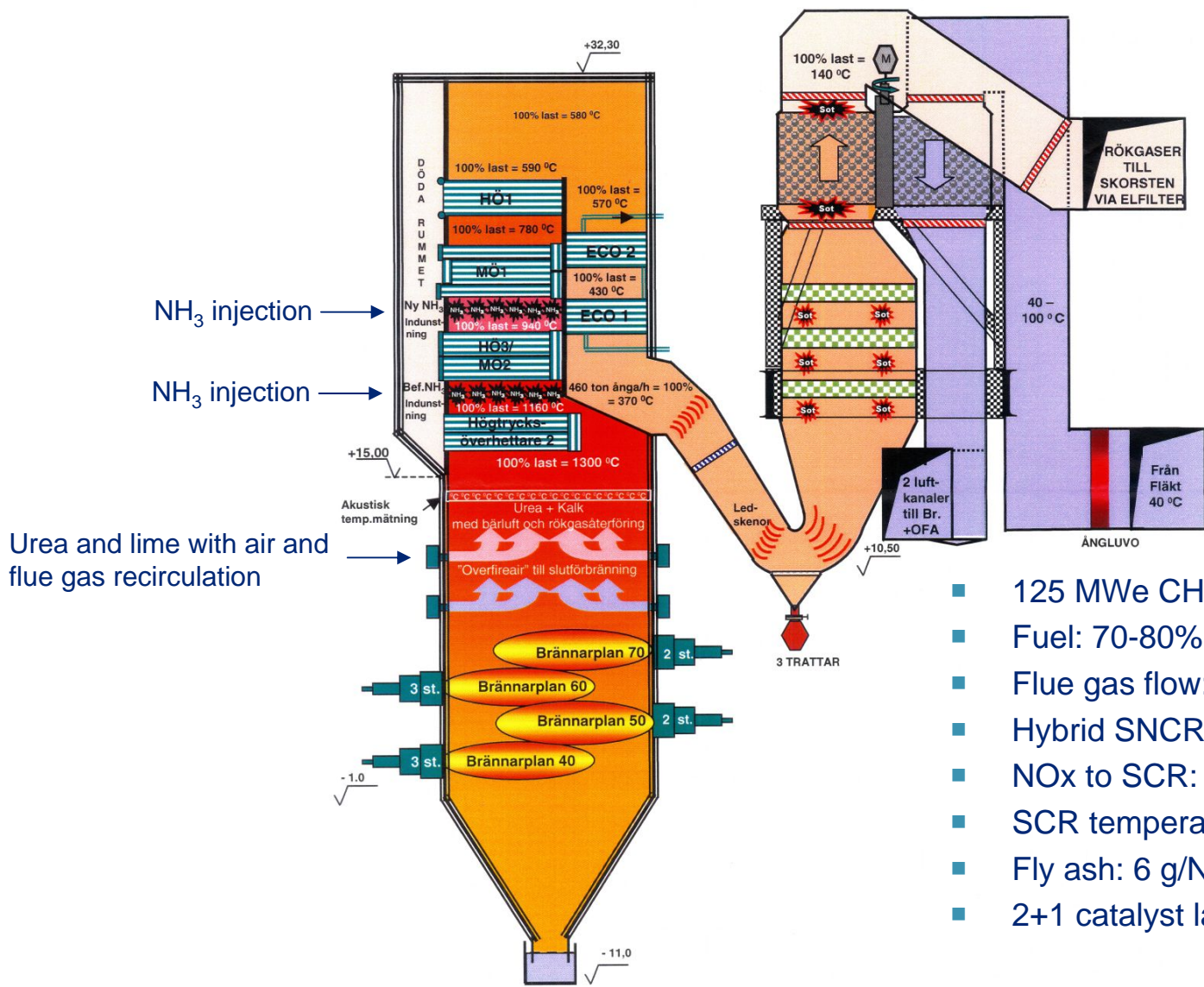


Washing of catalyst, several times per year, was applied in the period 2002-2005

# Avedøre 2 - catalyst deactivation



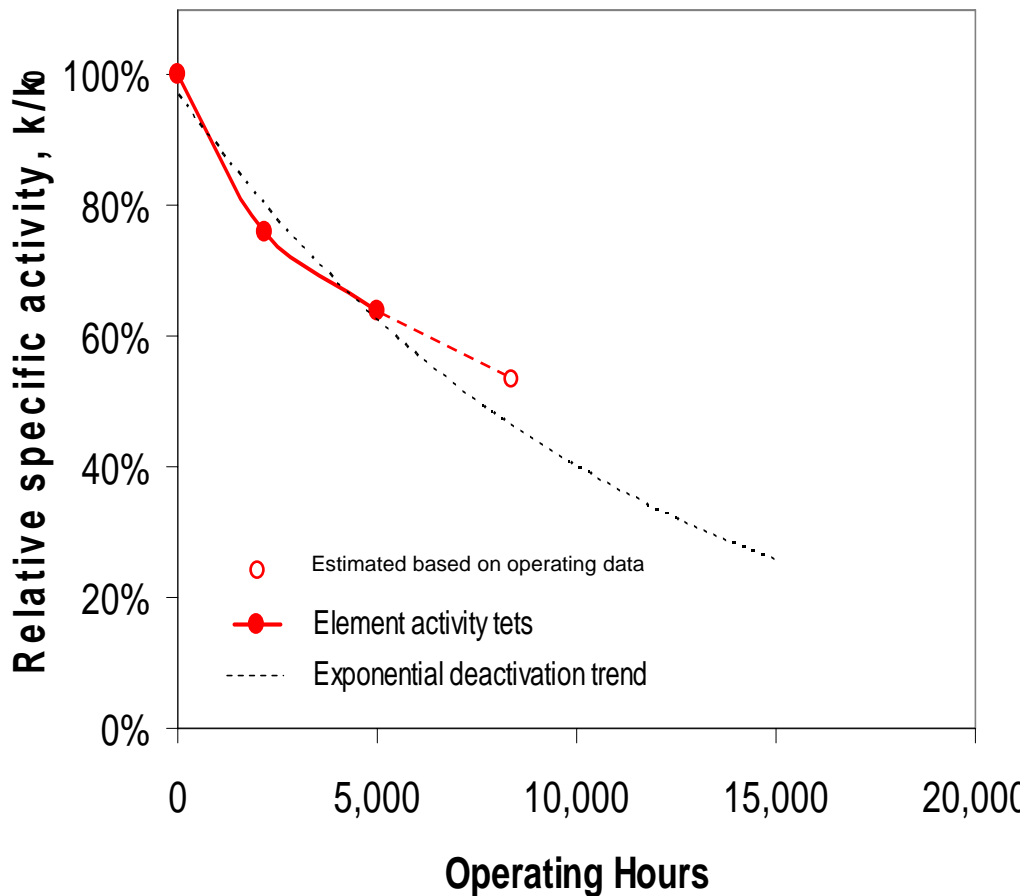
# Vattenfall – Uppsala CHP, Sweden



- 125 MWe CHP
- Fuel: 70-80% peat, 20-30% wood
- Flue gas flow: 670,000 m<sup>3</sup>/h
- Hybrid SNCR/SCR
- NO<sub>x</sub> to SCR: ~125 ppm
- SCR temperature: up to 750°F
- Fly ash: 6 g/Nm<sup>3</sup>
- 2+1 catalyst layers

# Vattenfall – Uppsala CHP

- Accelerated deactivation due to P accumulation
- The phosphorous is predominantly found at the surface

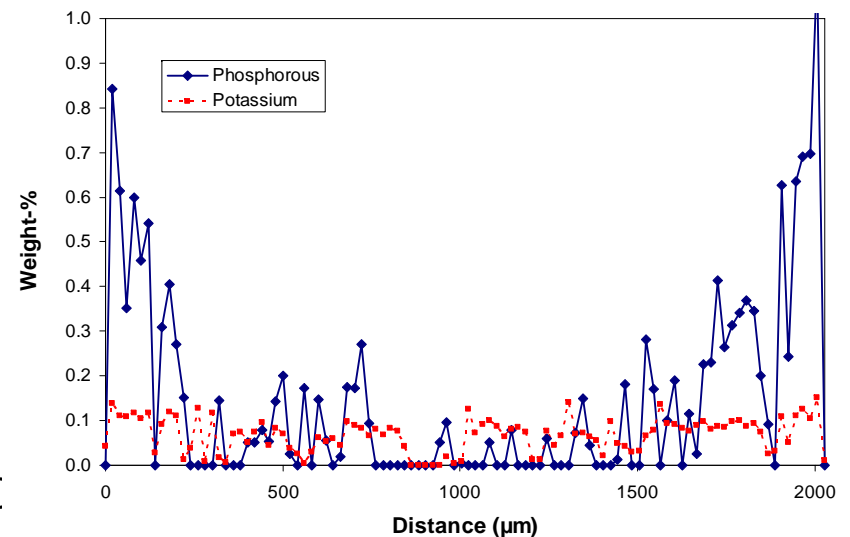


## Ash analyses, wt%

K <sub>2</sub> O	0.5-0.7
Na <sub>2</sub> O	0.3
P <sub>2</sub> O <sub>5</sub>	0.8-1.2
CaO	35-40
SiO <sub>2</sub>	20-30

## Catalyst analysis

~0.1% potassium
0.5-0.8 % iron
0.2-0.4 % magnesium
0.66 % phosphorous



# Sierra Power 7 MW CHP, CA, USA

- Grate-fired boiler at a saw mill, Terra Bella, California, USA
- Fuel: Wood, demolition wood
- Plant history
  - Start up in 1986
  - Shut down in 1995 due to low natural-gas prices
  - Restarted in 2001
  - SCR installed in 2008
- SCR is semi-high dust, downstream a multicyclone separator
- SCR temperature 520°F, <10 ppm SO<sub>2</sub>
- Soot blowers and sonic horns
- Mechanical shaking of structural beams



# Sierra Power – catalyst deactivation

Service hours	0	3,000	
		Air cleaned	Water washed
Catalyst activity % relative to fresh	100	93	79
Potassium, mg/kg	200	12,720	4,820
Sodium, mg/kg	500	1,760	500
Phosphorous, wt %		0.33	0.25

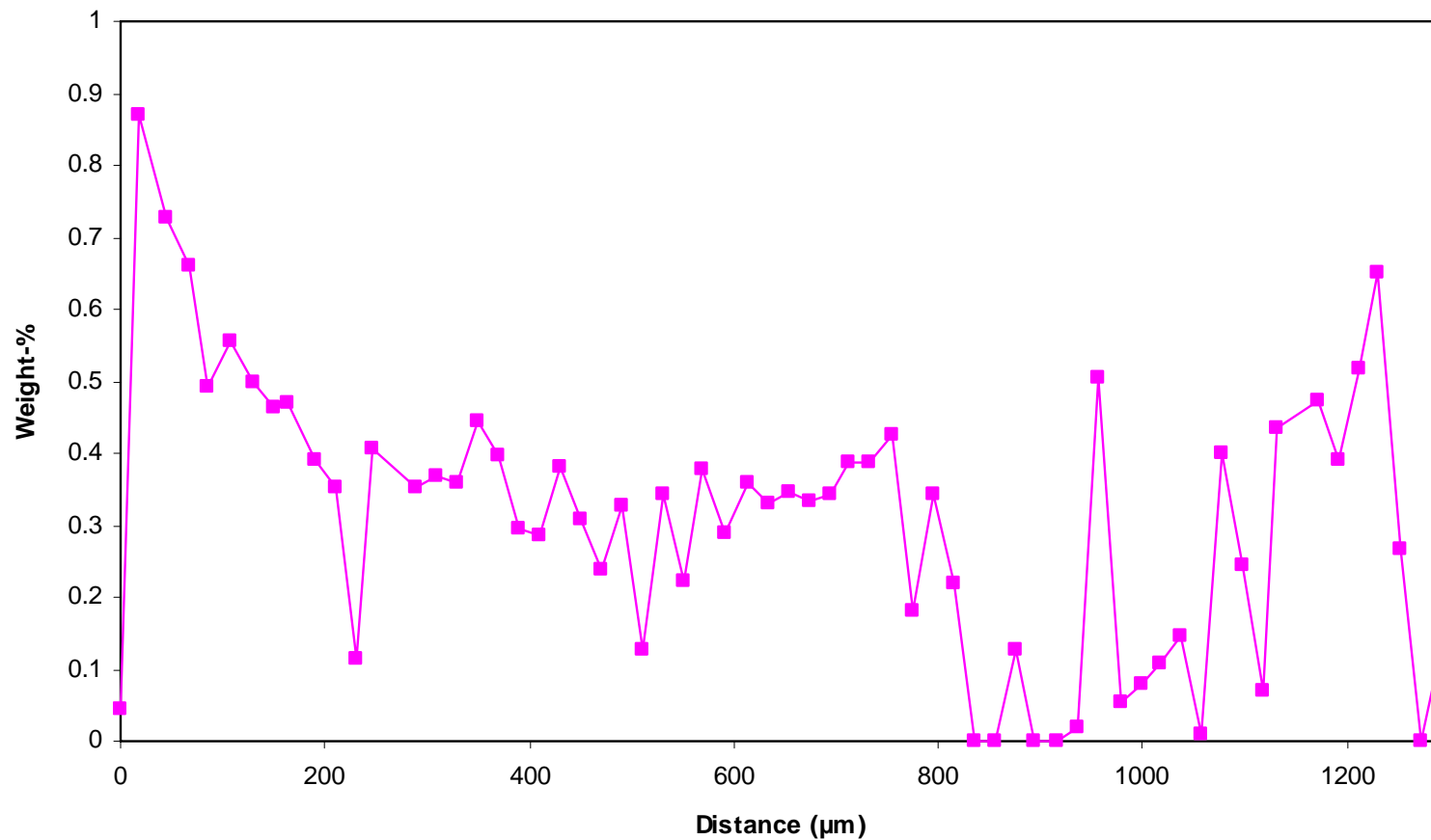
60 – 70% of the alkali metals and ~25% of the phosphorous removed by washing

## ■ Conclusions

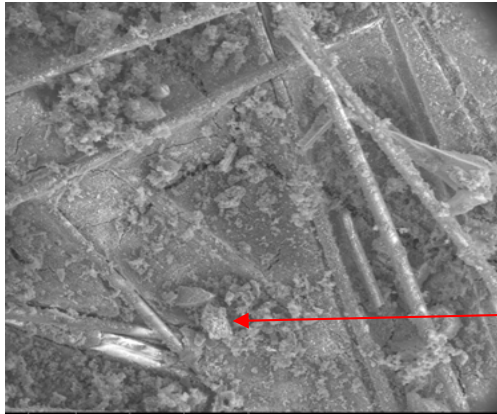
- Low deactivation in spite of high K content:
- Aerosol formation lower than observed in PF and CFB boilers
- Catalyst wash increases deactivation

# Sierra Power - impact of catalyst washing

Potassium profile through the catalyst wall after water washing

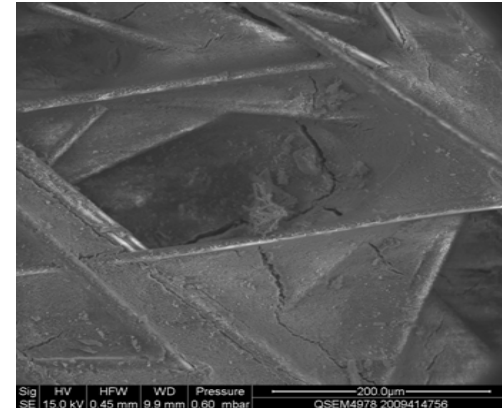


# Sierra Power - impact of catalyst washing



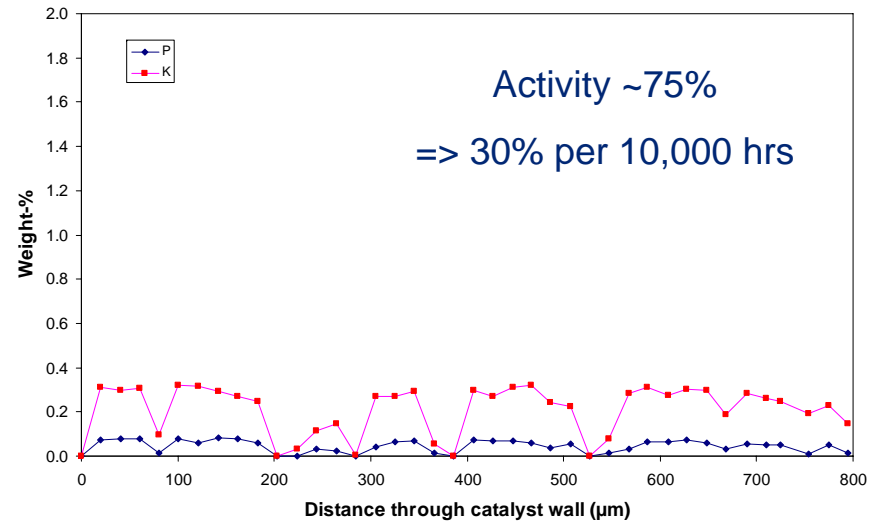
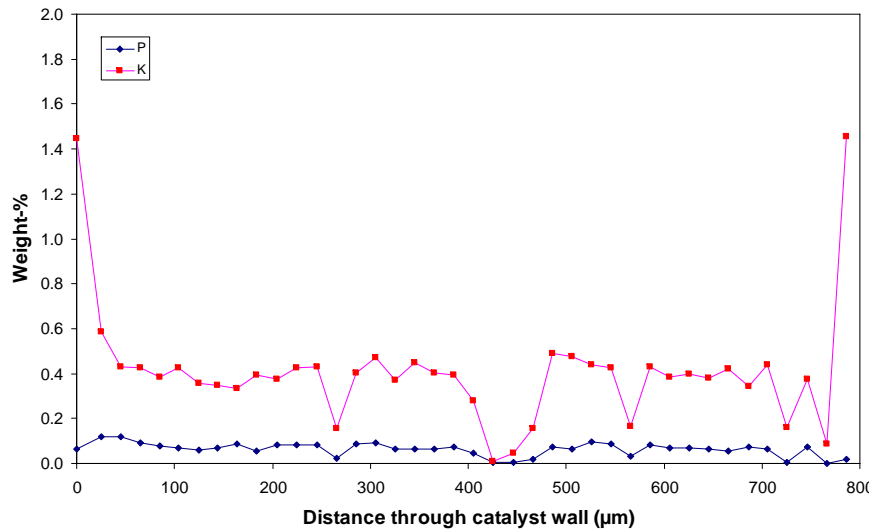
Sample after  
~8,000 hrs

S, K and Ca-rich  
agglomerates



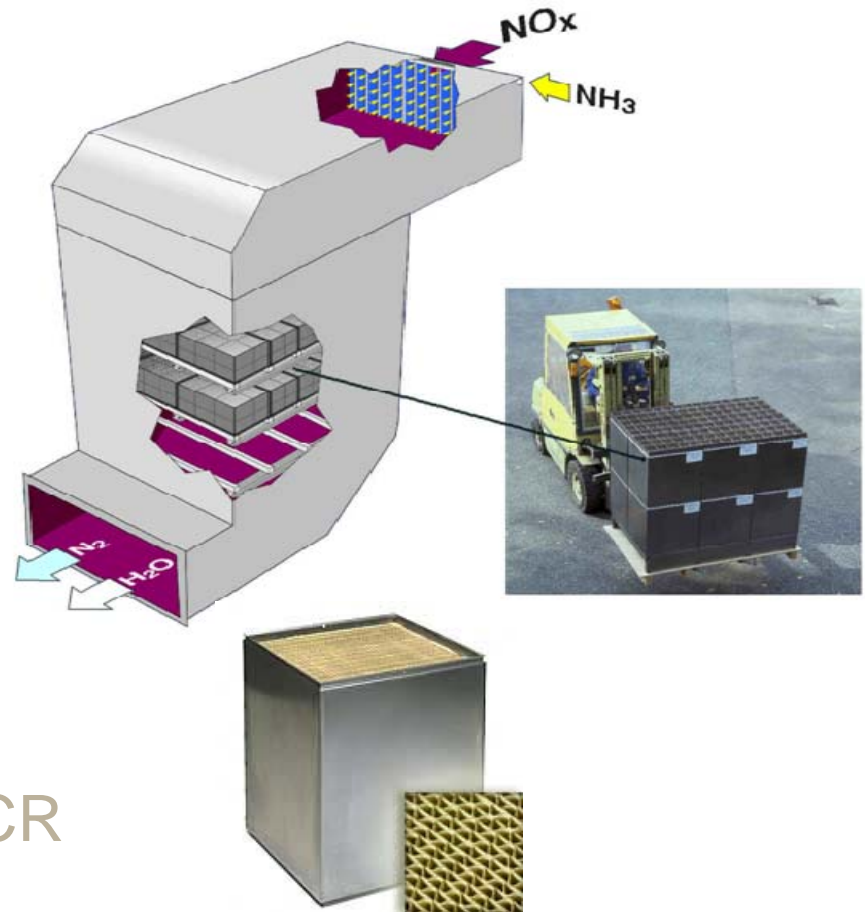
Dirty catalyst

Washed catalyst



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- Low-dust versus high-dust SCR



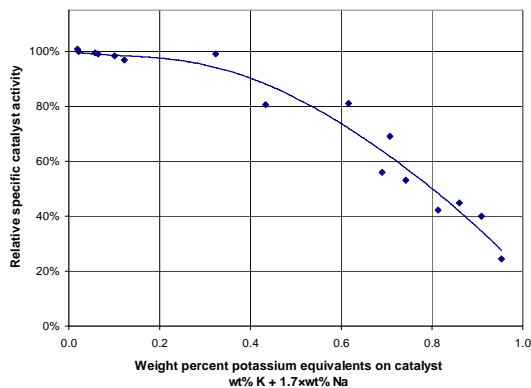
# Pinetree Power, USA

<b>Tamworth Station, NH</b>	<b>Bethlehem Station, NH</b>
22 MW grate-fired boiler	16 MW grate-fired boiler
Fuel: Wood chips (local pine and fir)	
In-service date: 1987	In-service date: 1986
SCR installed in 2008	
<b>LD after ESP, vertical down flow</b>	<b>LD after ESP, horizontal flow</b>
0.12 lbs/mmBtu NOx (~100 ppm)	
NOx reduction: 46%	
SCR temperature: 216 °C/420 °F	
< 0.5 ppm SO <sub>3</sub>	
On-line catalyst cleaning - reverse flow	

# Pinetree Power, Tamworth Station, NH

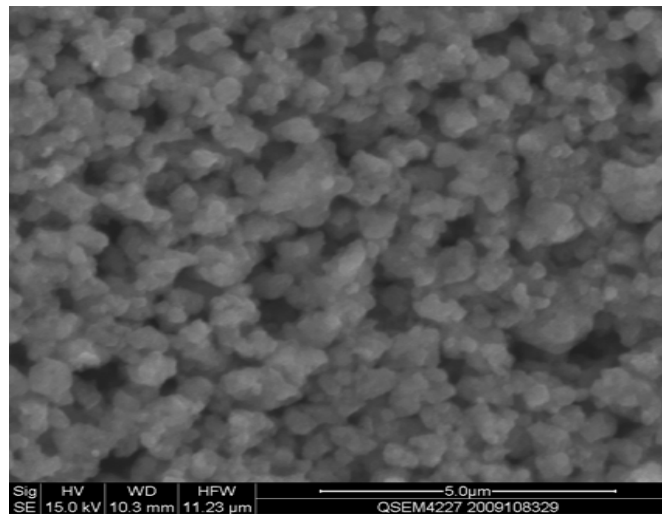
## Test of sample after 6,500 hrs:

- Activity (k/k0): 97% at 482 °F
- Bulk chemical analysis:
  - Potassium:  
0.43% – 1.14% by weight



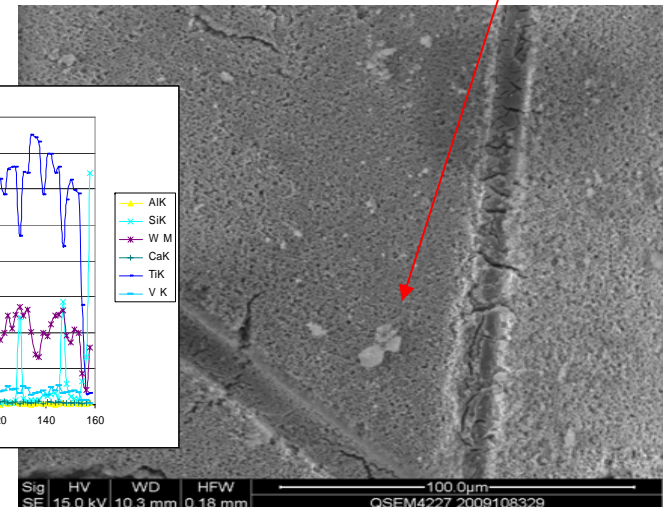
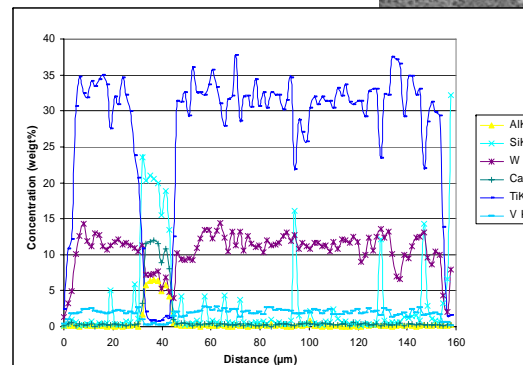
- Phosphorous:  
0.21% - 0.28% by weight

- No potassium in QSEM profile
- Conclusion: Potassium are loose surface deposits



Surface appears clean

SEM:  
K-rich particles



# Pinetree Power, Bethlehem Station, NH

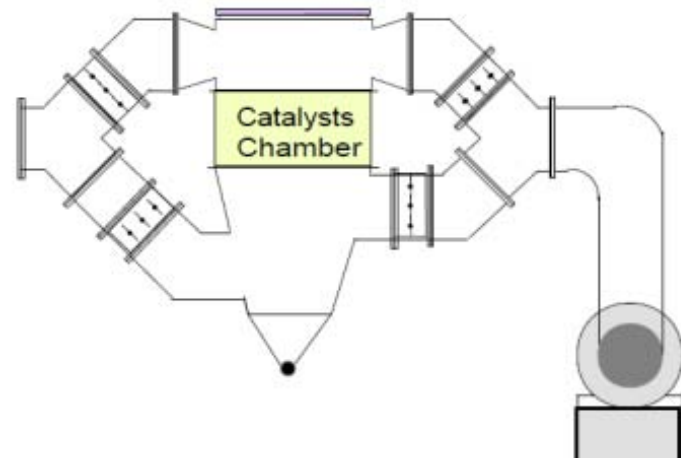
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## Catalyst tests

- 10,000 hrs
  - Activity: ~65%
  - 0.40% - 1.06% by weight potassium
  - ~0.2% by weight phosphorous
- 12,000 hrs
  - Activity ~68% at 482°F
  - 1.5% by weight potassium (bulk), ~0.4% in profile
  - ~0.2% by weight phosphorous (bulk)
- Deactivation rate: ~28% per 10,000 hrs

# Springfield Power, NH, USA

- 16 MW **grate-fired** boiler
- Fuel: **Wood chips**
- SCR installed in 2008
- **Low dust after ESP**
- SCR temperature: **~340 °F**
- ~100 ppm NO<sub>x</sub>
- < 0.5 ppm SO<sub>3</sub>
- Catalyst cleaning
  - reverse flow, no soot blowers



# Springfield Power, NH, USA

## Catalyst tests

	<b>Fresh</b>	<b>~8,000 hrs</b>	<b>~12,000 hrs</b>
Activity, %	100	84	75
Potassium, wt%	~0.02	0.76	0.61
Phosphorous, wt%	~0.15	0.24	0.25
Deactivation rate % per 10,000 hours		20	22

No ABS was found on the samples

# Deactivation in SCRs on grate-fired boilers

Plant	SCR temp. °F	K, wt% Bulk	Deactivation % per 10,000 hrs
Sierra Power, Terra Bella	520	~1.3	~30
Pinetree, Tamworth	420	0.4-1.1	25-30
Pinetree Bethlehem	420	0.4-1.5	25-30
Springfield Power	340	0.6-0.7	20-22

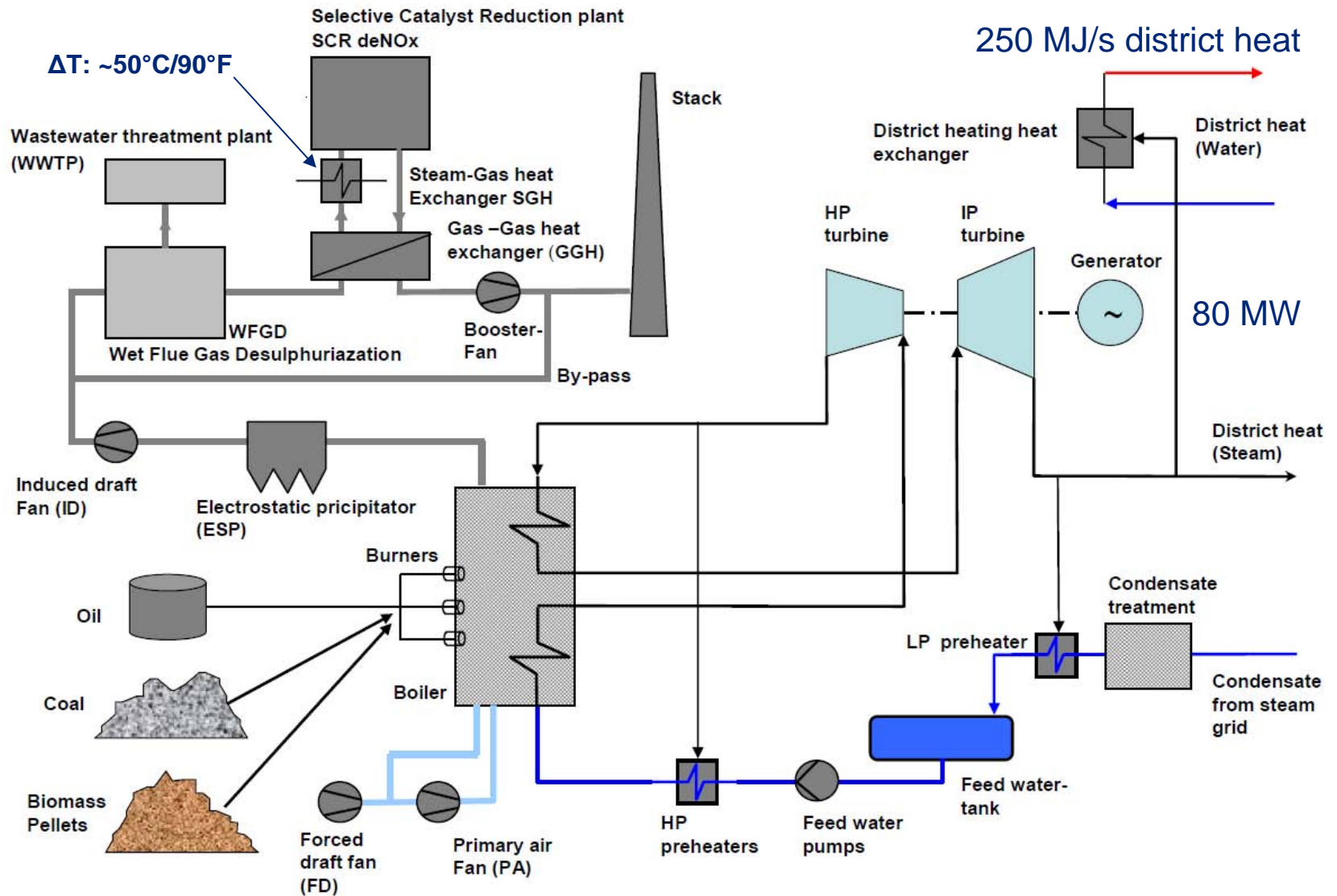
- Lower deactivation rates compared to PF boilers
  - Lower combustion temperature: **low alkali release** in the gas phase
  - K found in **loose deposits** on the outer catalyst surface
  - Low SCR temperature: **slow alkali distribution** in the catalyst

# Vattenfall, Amager 1, Denmark

- Originally coal-fired
- Taken out of service in 2004 for renovation:
  - new boiler with capability for burning biomass
  - SO<sub>x</sub> and NO<sub>x</sub> removal (WFGD and SCR)
- Resumed operation end 2009
- 80 MW electricity capacity  
250 MJ/s district heat
- Fuel consumption at full load:
  - Coal: 50 t/h *or*
  - Oil: 30 t/h *or*
  - Straw/wood pellets: 75 t/h



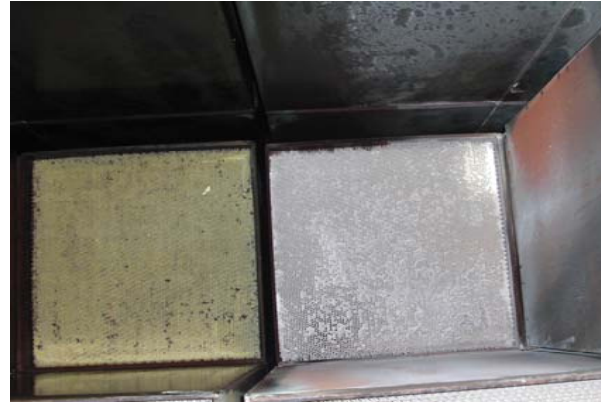
# Vattenfall, Amager Unit 1, Denmark



Source: Vattenfall

# Vattenfall, Amager Unit 1, Denmark

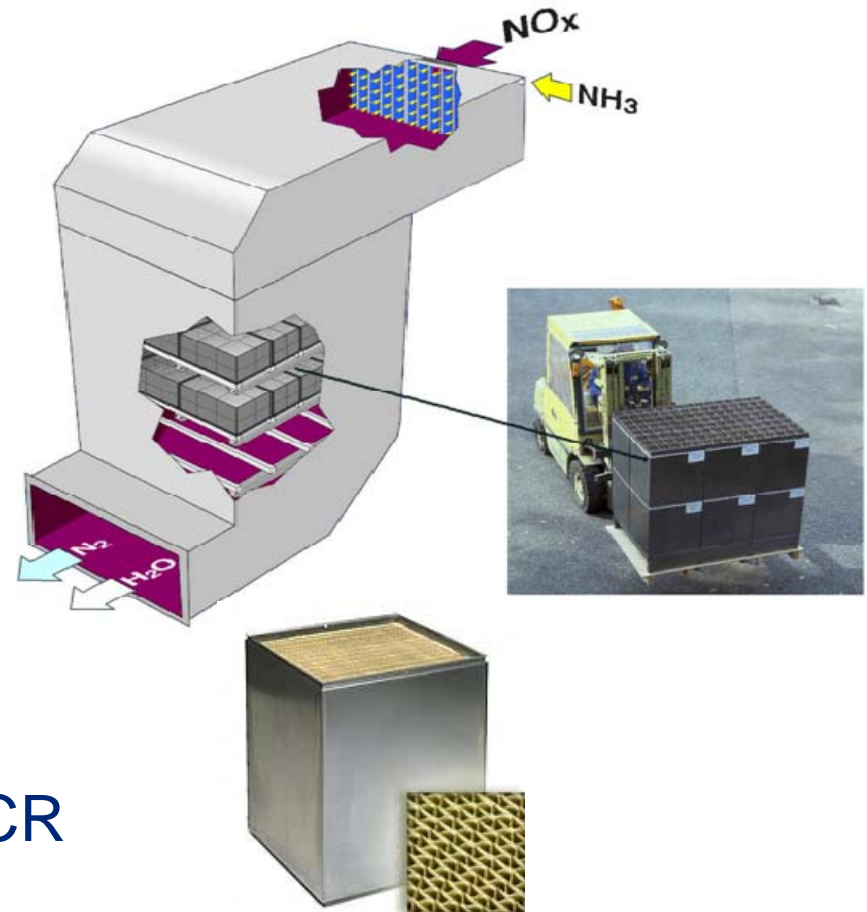
- Inspection 2010: Deposits of sub-micrometer dust



Florian Huber: Presentation tomorrow 2:15 pm: Dealing with fly ash in SCR's

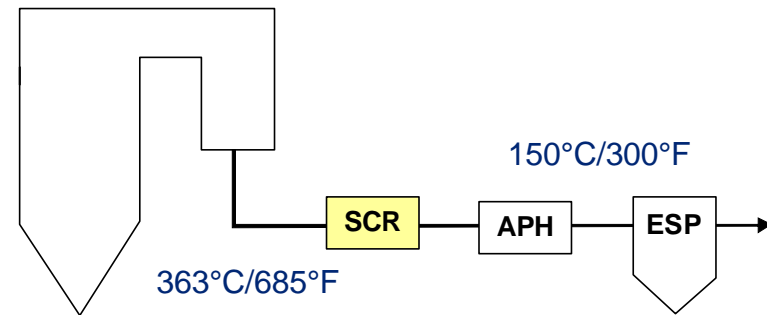
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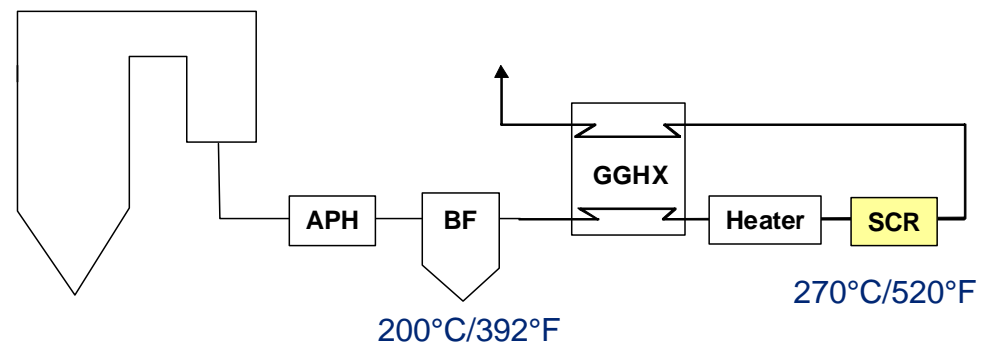


# Three alternative positions of the SCR

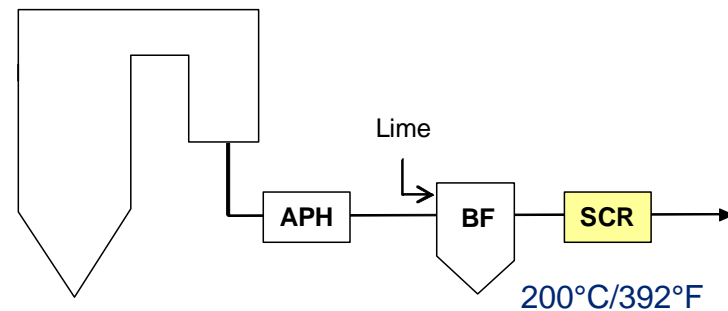
1. High dust after the economizer



2. Tail-end with reheat of the flue gas to >520°F (270°C) after a bag filter



3. Tail-end at 390°F (200°C) without reheat of the flue gas and with lime injection in the bag filter to remove SO<sub>3</sub>

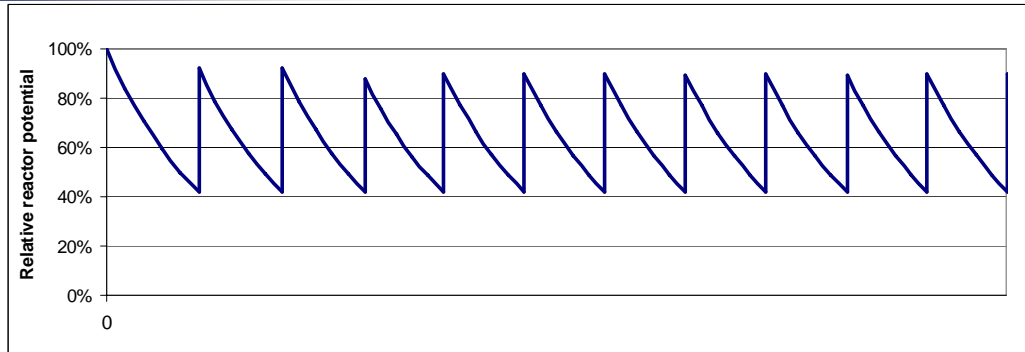


# Study example – 100% wood-fired boiler

Basis: ~1,000,000 Nm<sup>3</sup>/hr flue gas, 780 MW<sub>th</sub>

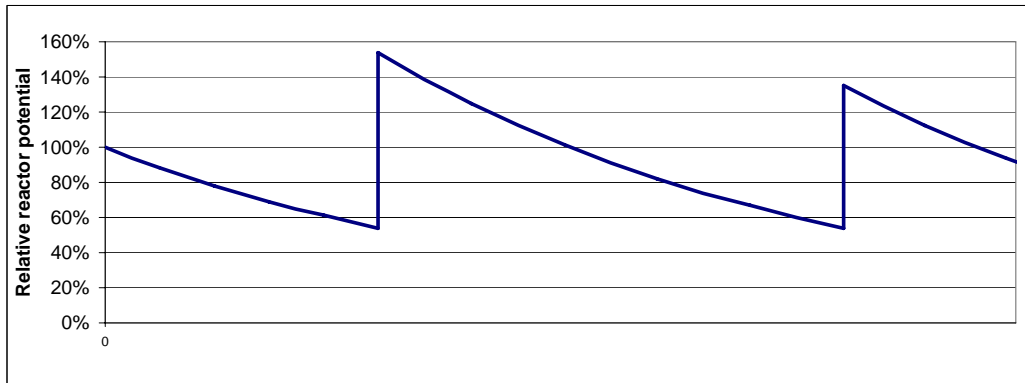
	100% wood			Coal
	High dust 685°F	Tail end 520°F	Tail end 390°F	High dust
SCR lay-out, initial + spare	2 + 2	1 + 1	2 + 1	2 + 1
Catalyst pitch, mm	8	4	4	8
Initial catalyst volume, relative to coal-fired unit	150	52	113	100
Catalyst volume incl. spare	300	104	170	150

# Replacement schedules - 10 years



High dust SCR at 685 °F

2 + 2 layers



Tail-end SCR after bag filter with reheat to 520 °F

1 + 1 layers





Tail-end SCR after bag filter at 390 °F without reheat

2 + 1 layers

# Study example – 100% wood-fired boiler

	100% wood			Coal
	High dust 685°F	Tail end 520°F	Tail end 390°F	High dust
SCR lay-out, initial + spare	2 + 2	1 + 1	2 + 1	2 + 1
Catalyst pitch, mm	8	4	4	8
Initial catalyst volume	150	52	113	100
Catalyst volume incl. spare	300	105	170	150
Average time between catalyst replacements	~ 1 year	~ 3 years	~ 2 year	3-4 years
Average yearly catalyst consumption	90	17	30	10

# Summary – high dust versus low dust

SCR position		
High dust 685°F	The simplest for retrofit SCR on e.g. existing coal-fired boiler	High catalyst deactivation rate => <ul style="list-style-type: none"> <li>■ Large SCR reactor, 4 layers</li> <li>■ Frequent catalyst replacements (1/yr)</li> <li>■ High catalyst consumption</li> </ul>
Tail-end position with reheat to 520°F	Low catalyst deactivation rate => Only two layers required (incl. spare) ~3 years between catalyst replacements Lowest catalyst consumption (~20% of HD)	Large gas-gas HEX and support heater required
Tail-end position at 390°F without reheat	~2 years between catalyst replacements Low catalyst consumption (~1/3 of HD)	SOx may have to be removed upstream SCR



# SCR experience with combustion of biomass

## Summary and conclusion

RESEARCH | TECHNOLOGY | CATALYSTS

# Summary

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- Main poisons from biomass are potassium, phosphorous and calcium
- Potassium is “chemical” poison. It deactivates the catalyst by reacting with the Brønsted acid (ammonia-adsorbing) sites
- Calcium is a “physical” poison. It fouls the catalyst surface by creating a dense layer of calcium salts
- Phosphorous is both a physical and a chemical poison. It fouls the catalyst surface but also penetrates into the catalyst and reacts with the redox (ammonia activation) sites

# Summary – deactivation on 100% biomass

	Boiler type	Fuel	Temp. °F	Deactivation % per 10,000 h
Nässjö CHP	CFB High dust	Wood chips	738	45-50
Masnedø CHP	Grate High dust	Straw	715	50% / 1,000 hrs
Vattenfall Uppsala CHP	PF High dust	70% peat 30% wood	750	60
DONG AVV2	PF High dust	Wood pellets + fly ash	720	15-25
Sierra Power	Grate SCR after cyclone	Wood Demol. wood	520	30
Pinetree & Springfield	Grate SCR after ESP	Pine + fir chips	420 340	25-30 20-25

# Summary

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- Co-firing with biomass is possible without increase in the rate of deactivation compared to 100% coal firing
  - DONG, Studstrup: 7% / 11% on energy / weight basis
  - EON, Langerlo: up to 20% wood, olive residue, sludge
- The coal fly ash
  1. Binds poisonous constituents
  2. Creates a “passivating” layer on the catalysts surface
  3. Continuously “cleans” the catalyst surface
- High-dust SCR’s on 100% biomass
  - Vattenfall, Uppsala CHP: Rapid deactivation, 50-60% per 10,000 hrs, mainly by phosphorous
  - DONG Energy, Avedøre 2: Fly ash injection reduces deactivation by resembling co-firing
  - Sierra Power: Grate firing and low SCR temperature reduces deactivation

# Summary

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- Low dust SCR's on 100% biomass

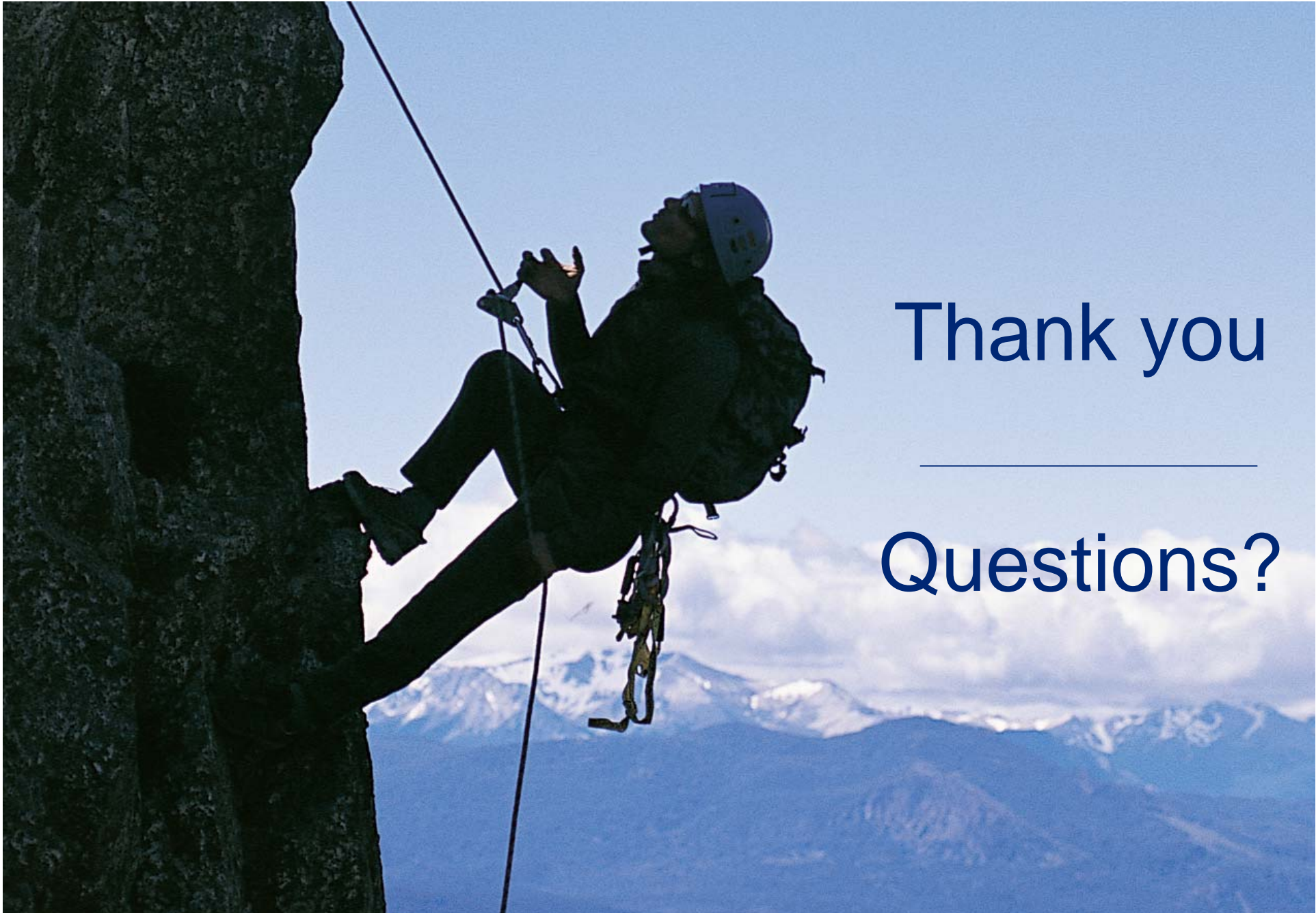
USA grate-fired boilers with SCR located after ESP at 340-420 °F:

- Little formation of aerosols: Potassium is found mainly as loosely deposited particles on the catalyst surface
- Low SCR temperature reduces potassium redistribution
- No poisoning with phosphorous and calcium observed
- Deactivation rate is modest, 20-30% per 10,000 hours
- Provisions for catalyst cleaning are necessary; reverse flow operation seems to work

# Conclusions

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- Biomass firing can rapidly deactivate SCR catalyst
- Deactivation is seen by alkali metals (potassium), phosphorous and calcium
- Co-firing with up to 20% biomass is possible without noticeable impact on catalyst life
- LPA issues may have to be considered
- It is possible to design high-dust SCRs for 100% biomass firing but catalyst consumption will be high
- Injection of coal fly ash can reduce catalyst deactivation
- Deactivation rates at 100% biomass depend on
  - Type of biomass
  - Boiler type / combustion temperature: Grate firing < CFB < PF
  - SCR position and temperature
- Provisions for catalyst cleaning is necessary also for low dust installations



Thank you

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Questions?

Taking SCR performance to new heights...