NextGenPower

IEA / VGB workshop on USC materials

Vienna, September 19 and 20, 2012

Arthur Stam, DNV KEMA

Setting

- Example of hard coal fired power plant currently under construction: E.ON Maasvlakte 3, should run this year 285bar/600/620C, sea water cooling, has a net efficiency of 46%

- CCS lowers carbon emissions AND efficiency (approx. 9 %points)
  - Efficiency raise
  - Maximize co-firing

NEXTGENPOWER

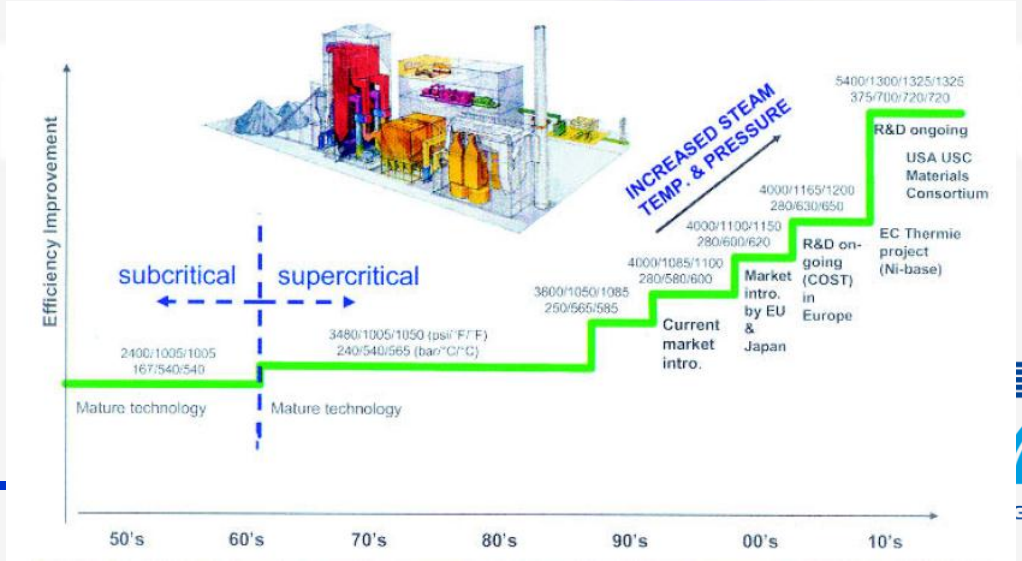
Ongoing developments

Europe:

- AD700 / Thermie700 (material development and plant design for 700 °C)
- Comtes (testing of components at 700 °C)
- EON 50+ Kraftwerk (building of power plant operating at 700 °C) – postponed >5 yrs

Similar projects in US, Japan and China

- Next logical step would be to make real size components
- At the same time looking at even higher steam temperatures (up to 750 C)



NEXTGENPOWER

FRAMEWORK GRAMME

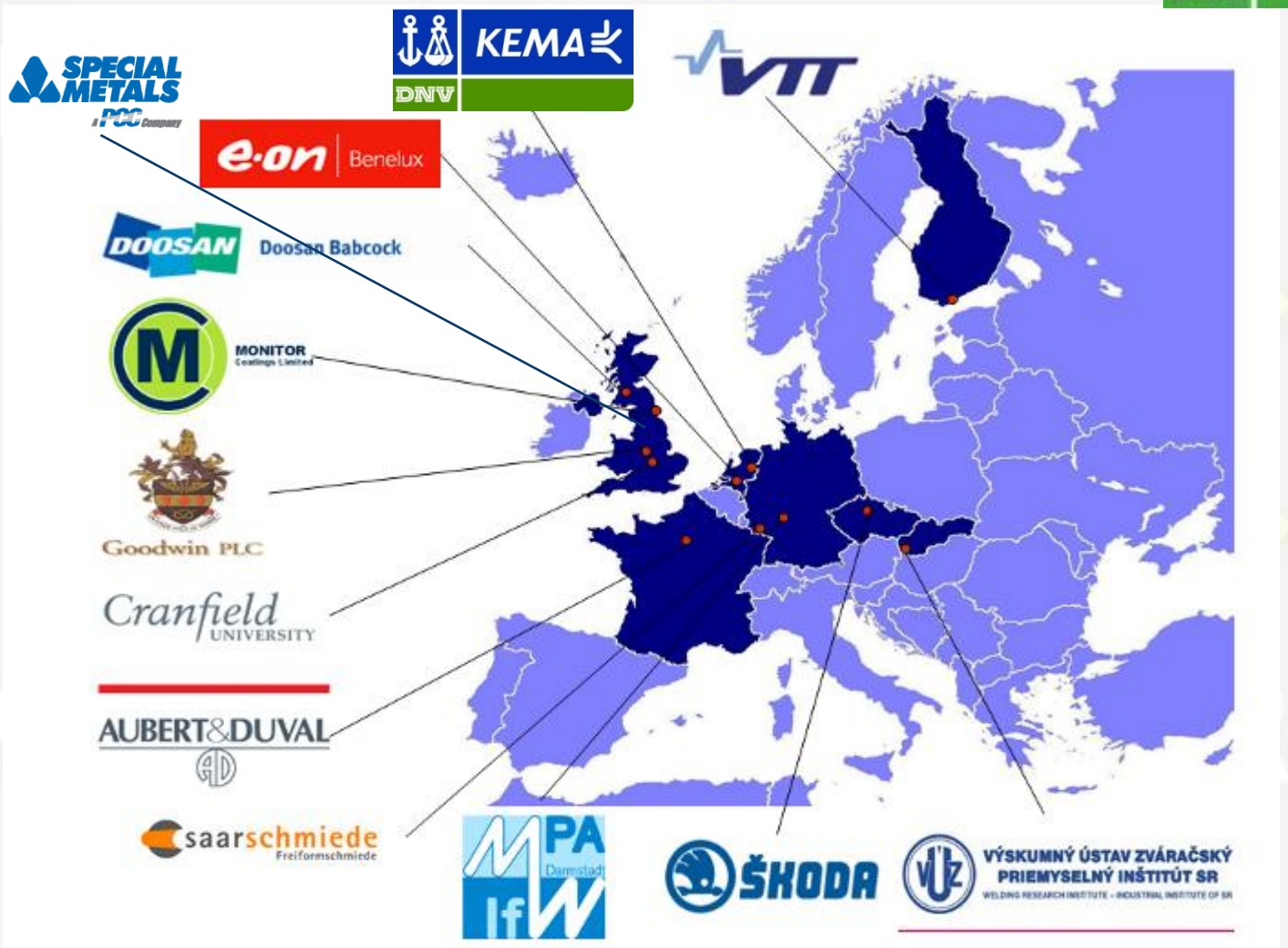
The Goal

- Make it possible to **operate at higher efficiencies** by operating at elevated steam conditions using better materials.
- Make it possible to **maximize co-firing** in combination with raised temperatures using better materials and coatings.

- Demonstration of **fabrication of Ni-based alloys and coatings** in/for coal fired power plants co-firing biomass.

NEXTGENPOWER

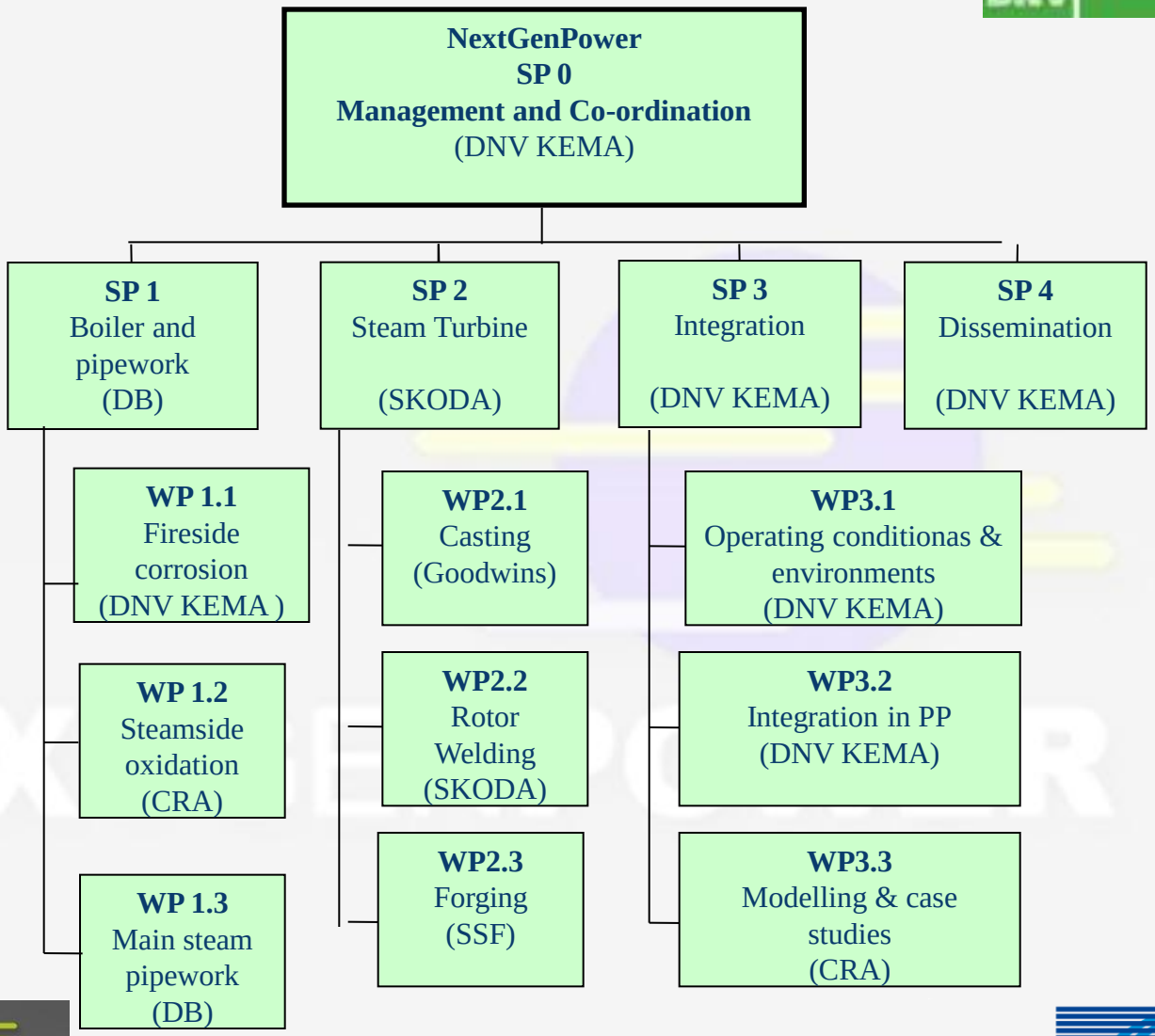
The Partners



NEXTGENPOWER

SEVENTH FRAMEWORK PROGRAMME

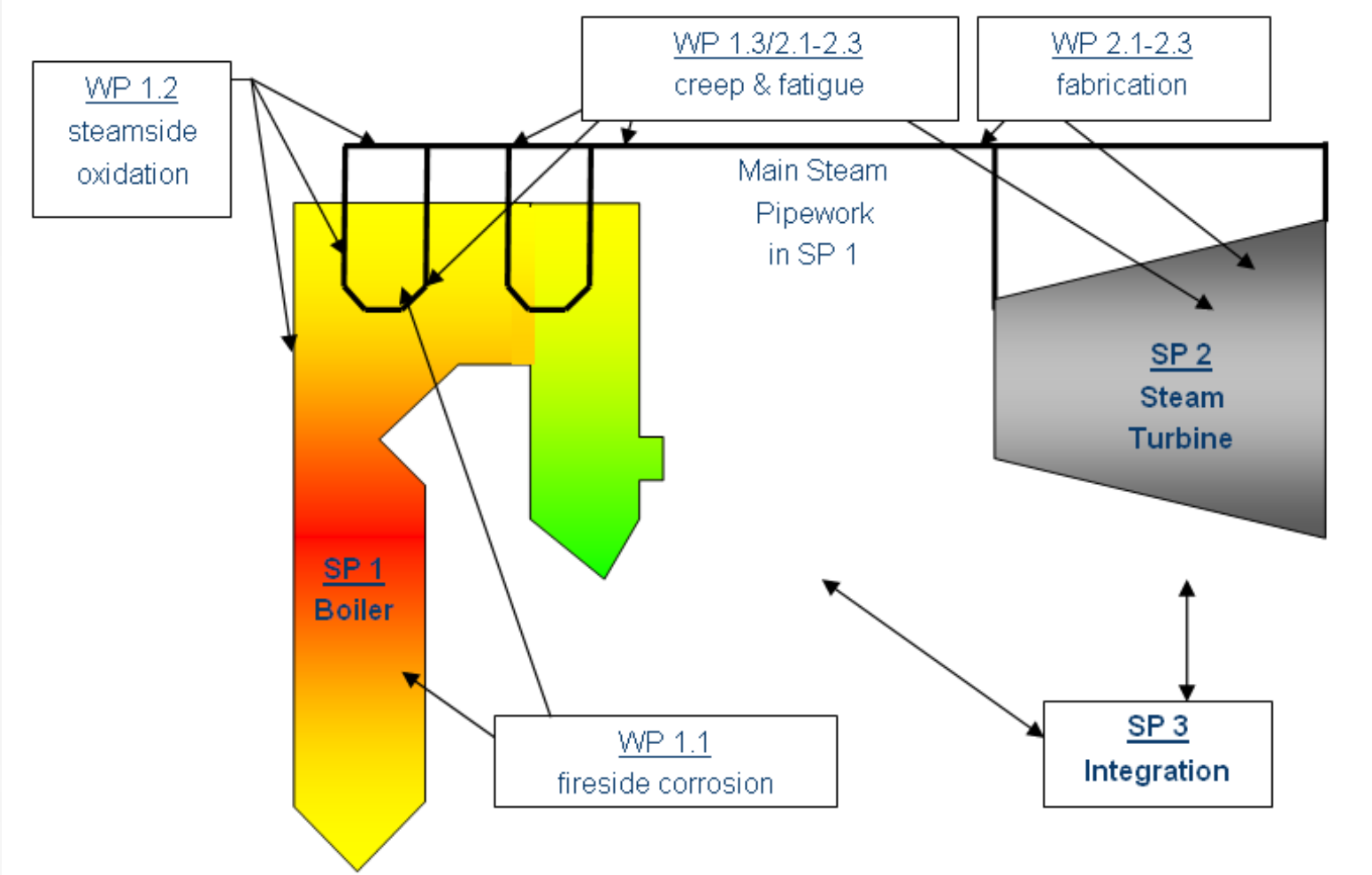
SP/WP structure



NEXTGENPOWER

SEVENTH FRAMEWORK PROGRAMME

Where are the challenges?

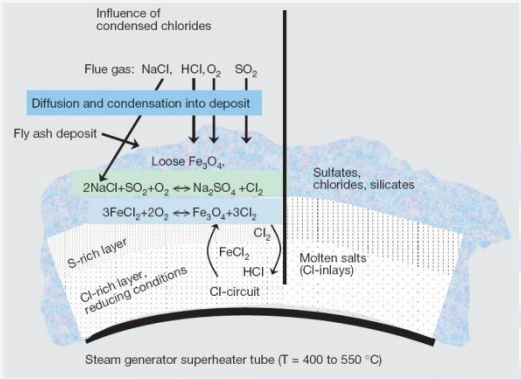


NEXTGENPOWER

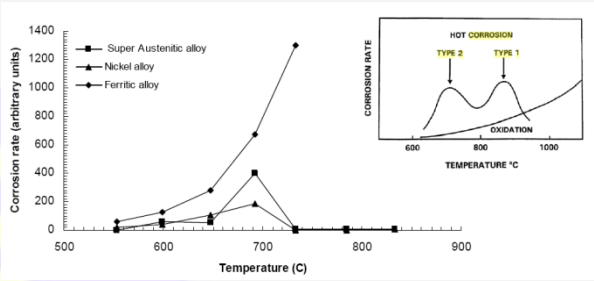
SEVENTH FRAMEWORK PROGRAMME

What are the challenges?

- **Fireside corrosion**

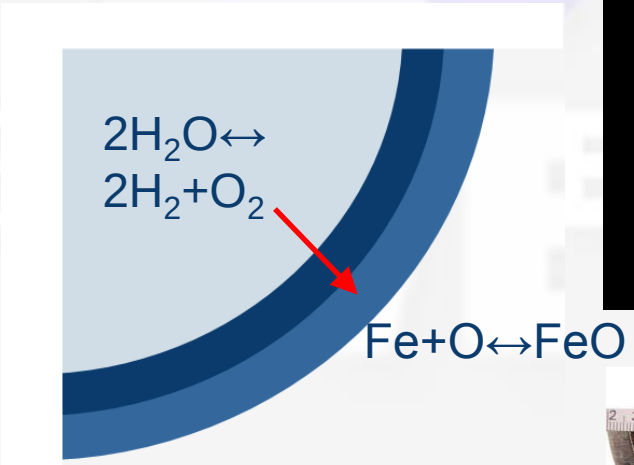


chlorides



sulfates

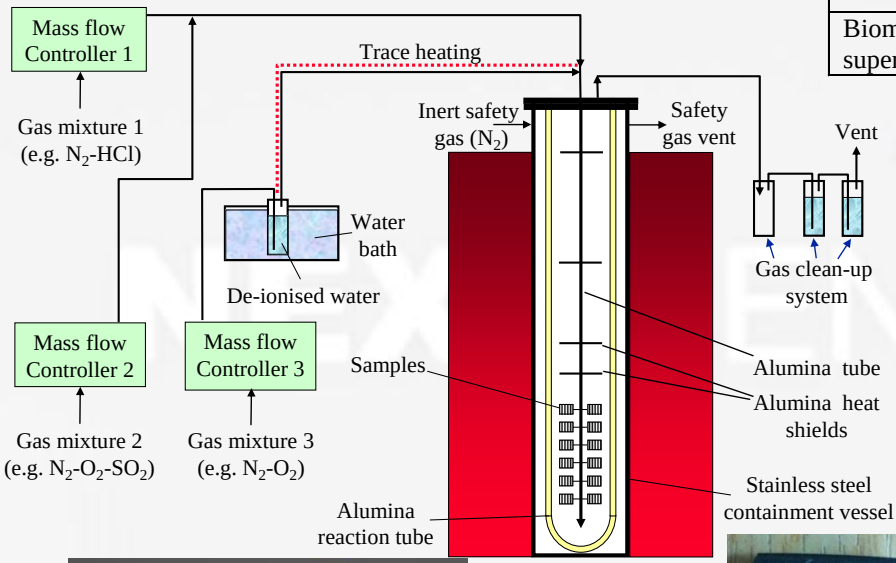
- **Steam side oxidation**



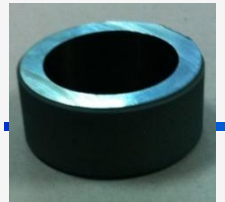
HT corrosion: lab screening (CRA)

- Exposure of rings (T24, T92, A316, Sanicro25, 304H, TP347HFG, A617, A740(H?), A263) in vertical tube furnace:
  - on controlled temperature (600 - 850°C)
  - with or without coating (Ni50Cr, NiCrAlY, HastalloyC276, In625, “ERS”)
  - with suitable ash deposit
  - synthetic gas mixture

Gas description	Simplified gas composition
Coal combustion – platens	N_2 – 13.6% vol CO_2 – 7.1% H_2O – 4% O_2 – 1400 vpm SO_2 – 400 vpm HCl
Coal combustion – wall	N_2 – 10% vol CO_2 – 3.6% CO – 7.1% H_2O – 1.1% O_2 – 1400 vpm SO_2 – 400 vpm HCl
Biomass combustion – superheater/reheater	N_2 – 12.6% vol CO_2 – 13.5% H_2O – 4% O_2 – 240 vpm SO_2 – 90 vpm HCl



Deposit description	Composition
Bare surface (no deposit)	-
Doosan screening mix	37.5 mole % Na_2SO_4 / 37.5 % K_2SO_4 / 25 % Fe_2O_3
Coal - water wall	Kaolinite - FeO - FeS
Coal - superheater/reheater	80% kaolinite - 7.5 mole % Na_2SO_4 / 7.5 % K_2SO_4 / 5 % Fe_2O_3
Biomass – superheater/reheater	5% wt KCl – 93% K_2SO_4 – 2% Na_2SO_4



NEXTGENPOWER

SEVENTH FRAMEWORK PROGRAMME

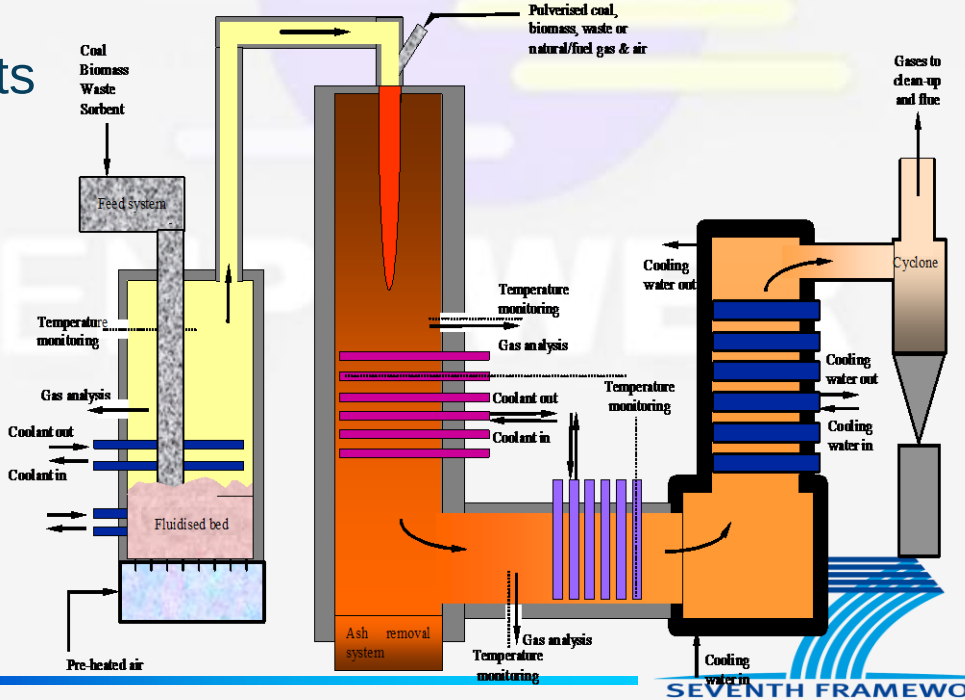
HT corrosion: lab screening (VTT)

- Exposure of rings (10CrMo, T92, Sanicro25, A263, A740H?)
  - on controlled temperature (575 - 750°C)
  - with or without coating (Ni50Cr, FeCr, NanosteelSHS8000 (Fe based 22Cr), In625, A59)
  - with suitable ash deposit (6.5%NaCl, 34.5%KCl, 58%NaSO4)
  - synthetic flue gas mixtures (with 0.1-0.2%HCl, 0.2-1%SO2, 2.5-15%H2O)

NEXTGENPOWER

HT corrosion: rig trials (CRA)

- **Temperature(s):** 600 – 850 °C
- **Material(s):** A down selection of T24, T92, A316, Sanicro25, S304H, TP347HFG, A617, A740, A263 and five types of coatings, depending on the lab screening results and ASPECT results
- 100 kW test rig
- Also includes oxyfuel tests

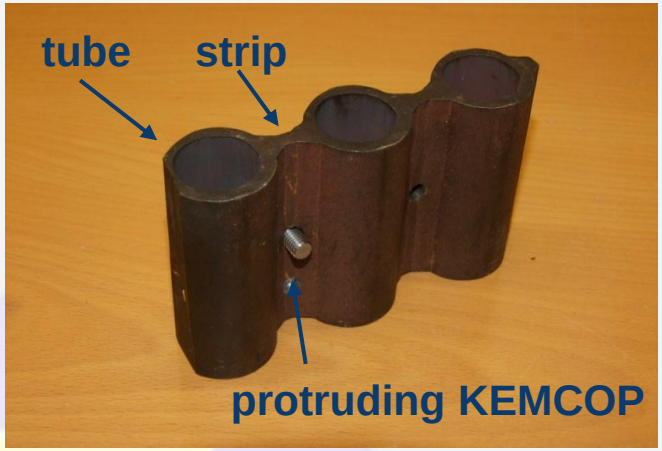


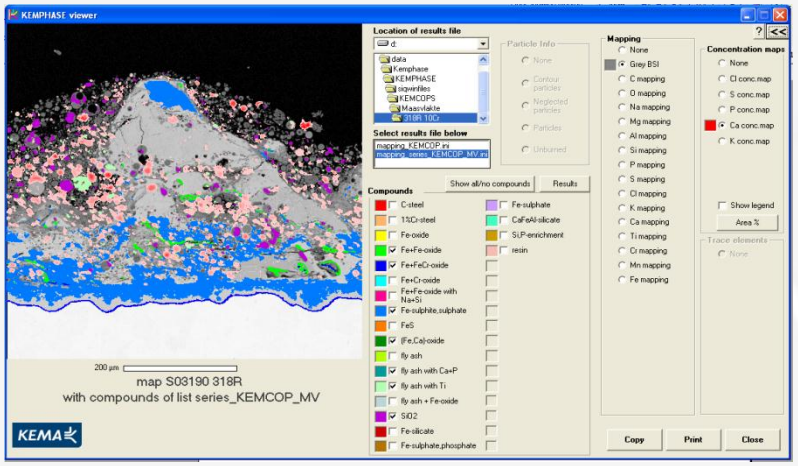
NEXTGENPOWER

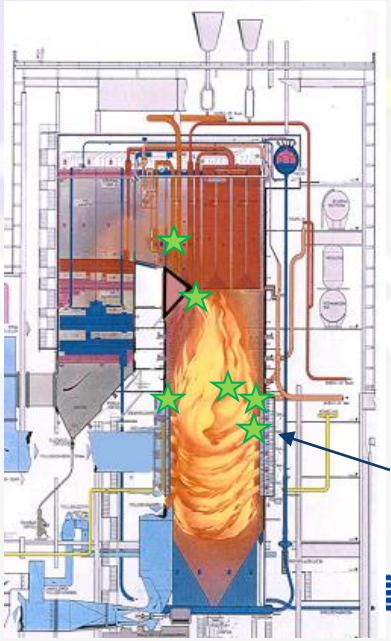
SEVENTH FRAMEWORK PROGRAMME

HT corrosion: plant exposure (DNV KEMA)

- 15Mo3, 10Cr9.10, T24, T92 (uncoated and coated with Ni50Cr), A617, A263, A740H?
- Small corrosion probes, integrated in water wall
- Temperatures 475-650 C
- Seeing actual conditions at water wall

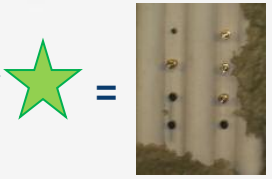






E.ON Benelux Maasvlakte unit 1

6x8 KEMCOPs

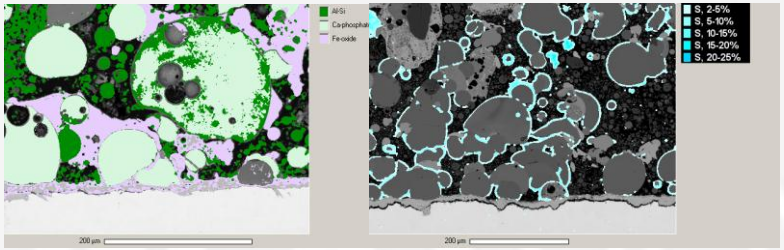


NEXTGENPOWER

SEVENTH FRAMEWORK PROGRAMME

HT corrosion: plant exposure (DNV KEMA)

- At plants E.ON (MV1) and GDF Suez (Gelderland13)
- Coal and co-firing biomass
- Exposure of rings
- Tip controlled at preferred temperature (this case >750C)
- A263 and A740H?
- 15Mo3 ref (540C)



detachable slagging ring **corrosion sensors**

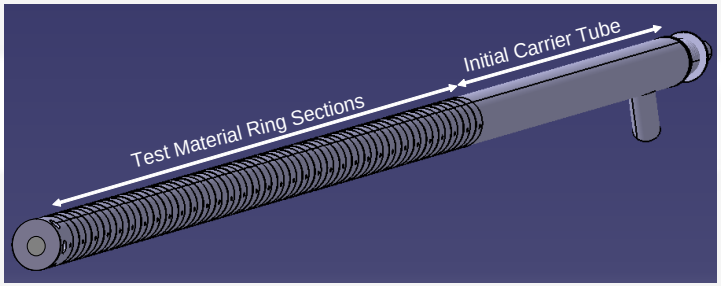
- Detachable ring for deposit characterization
- Additional gas measurements (especially O2) and modelling

NEXTGENPOWER

SEVENTH FRAMEWORK PROGRAMME

HT corrosion: plant exposure (DB)

- At plants E.ON (Ratcliffe) and RWE nPower (Tilbury)
- Coal and (co-)firing biomass
- Exposure of rings
- Different materials exposed simultaneously,
- Super304, TP347HFG, TPAA1, A263 and A740H
- 580-800°C



HT corrosion: plant exposure (VTT)

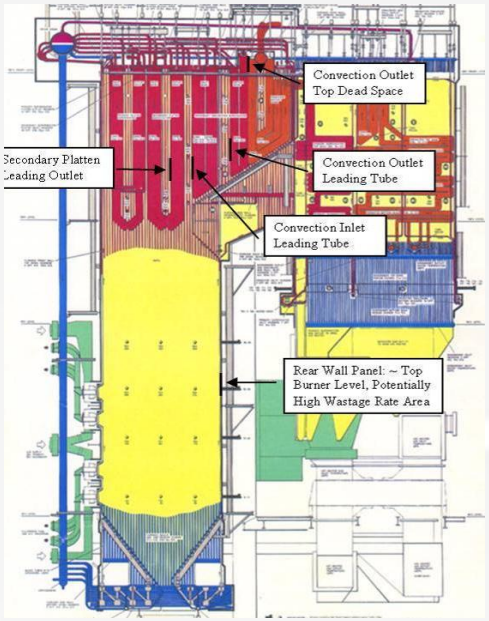
- At Peetersaari power plant (84MWth CFB)
- Firing biomass (and some coal)
- Exposure of rings
- Different materials exposed simultaneously,
- T92, Sanicro25, and A263 with several coatings (depending on the lab tests)
- 475-800 °C

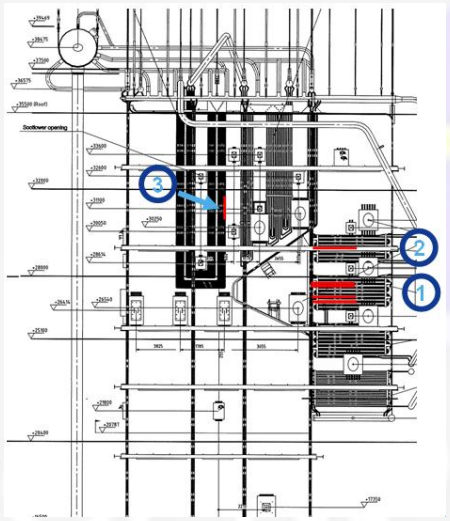
NEXTGENPOWER

SEVENTH FRAMEWORK PROGRAMME

HT corrosion plant panels and tubes (through ASPECT)

- E.ON Ratcliffe and 40 MW CFB Steven's Croft
- Coatings: In625 (Arc Wire), Ni50Cr, FeCrAl, C276, NiCrAlY,





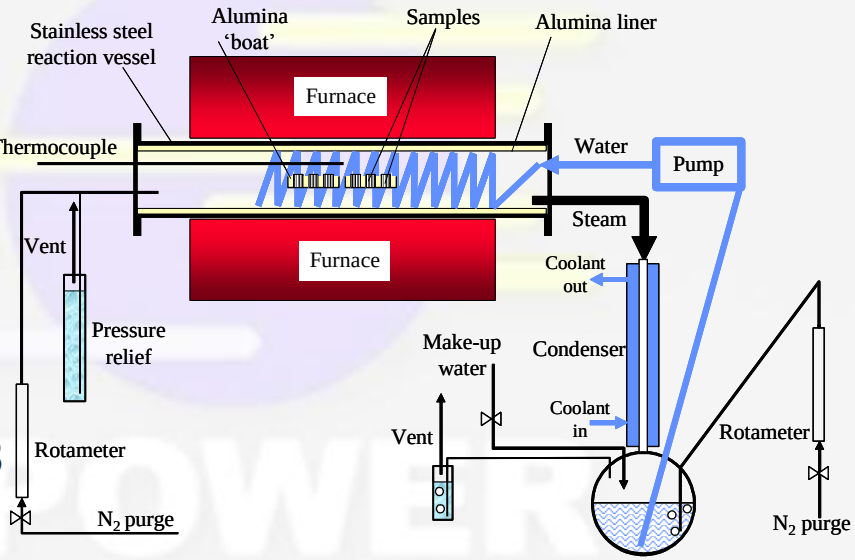
NEXTGENPOWER

SEVENTH FRAMEWORK PROGRAMME

High temperature screening tests (CRA)

- High Cr steels and Ni alloys have been tested and have shown little or no oxidation below 600 °C.
- 600-825C
- Atmospheric pressure

- **Materials**: T24, T/P92, A316, Sanicro25, S304H, TP347HFG, A617, A740H?, A263
- **Coatings**: sealcoat+Al, Al slurry, Al (ionic liquid application)



High temperature and pressure steam pilot plants

- High Cr steels and Ni alloys have been tested and have shown little or no oxidation below 600 °C.
- **Temperatures and pressures**: Cranfield (up to 800°C at 40 bar) and VTT (up to 700°C at 400 bar)
- **Materials** and coatings down selected from screening trials

Mechanical test programme

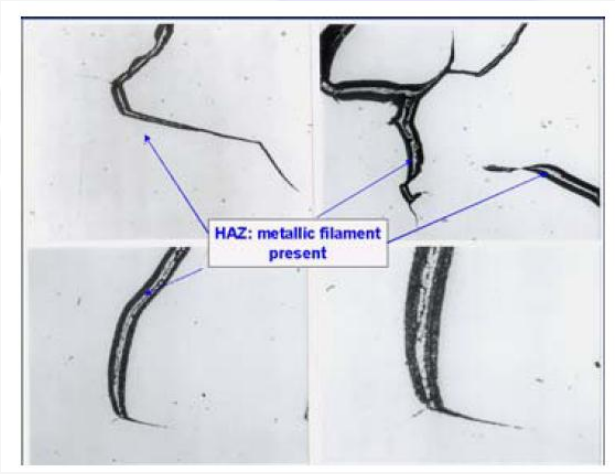
- The mechanical test program is performed on both pre- and post-service material. The material is strain aged to simulate service. In service degradation can reduce material properties, e.g. for some materials the 0.2% proof stresses can drop by 40%.
- Material will be strain aged at temperature to 1% creep strain, over some 3,000hrs.

NEXTGENPOWER

Susceptibility to relaxation cracking

- *At the points where rest tensions are (e.g. at welds) carbides precipitate due to which relaxation is blocked and has to take place in a corridor without precipitates. Therefore relaxation tensions are concentrated which causes cracks.*

- 700, 725, 750 °C (pre-service simulation), 980 °C (pre-service simulation, notched stress relaxation as welded), 725 °C (post-service simulation)
- A 263
- Performed by TU Darmstadt

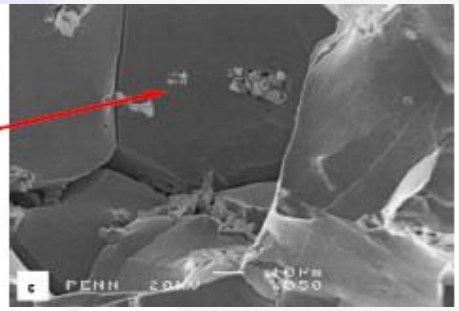


NEXTGENPOWER

SEVENTH FRAMEWORK PROGRAMME

Gas phase embrittlement of A263

- *Oxygen from the gas phase penetrates intergranular and reacts with sulphur, carbon and carbides. There gas bubbles are formed. During time-temperature moving of grain boundaries, tension concentrations move, but can't be accomodated at the bubbles, causing crack propagation.*
- phase embrittlement will be identified with a Slow Strain Rate Test (SSRT). Tensile and strain are controlled while a strain rate of 0.006%/min is applied.



Oxidized carbides on the Surface of In718

NEXTGENPOWER

Negative creep

- *Negative creep describes the time dependent contraction of a material as opposed to the elongation seen for a material experiencing normal creep behaviour. Negative creep is caused by contraction of the material during the creep test.*
- *May be relevant to bolts and fasteners.*
- Gleeble tests performed by SWI
- 500 and 750˚C, 20MPa

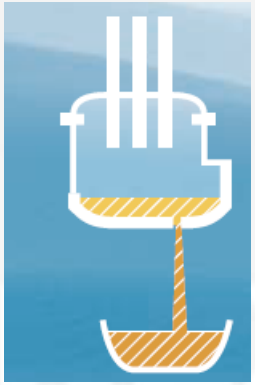
LCF testing programme on A263

pre-service simulation (parent material)		
creep 1000, 3000, 10000, 30000	700, 725, 750	DB
LCF: R=0 & 0.5; 10^1 to 10^4 cycles; 15 cpm trapazoid	700, 725, 750	TUD,VTT
LCF: R=0 & 0.5; 10^1 to 10^3 cycles; 1hr dwell	700, 725, 750	TUD
LCF: R=0 & 0.5; 10^1 to $5x10^2$ cycles; 10hr dwell	700, 750	VTT
LCF: R=0; 101 to $5x10^2$ cycles; 168hr dwell	700, 750	DB
LCF: R=0; 101 to $5x10^1$ cycles; 1000hr dwell	700, 750	DB
pre-service simulation (longitudinal weld)		
creep 3000, 30000	700, 725, 750	DB
LCF: R=0; 10^1 to 10^4 cycles; 15 cpm trapazoid	700, 725, 750	TUD,VTT
LCF: R=0; 10^1 to 10^3 cycles; 1hr dwell	700, 725, 750	TUD
LCF: R=0; 10^1 to $5x10^2$ cycles; 10hr dwell	700, 750	VTT
LCF: R=0; 10^1 to $5x10^2$ cycles; 168hr dwell	700, 750	DB
LCF: R=0; 10^1 to $5x10^1$ cycles; 1000hr dwell	700, 750	DB
post-service simulation (parent material)		
LCF: R=0 & 0.5; 10^1 to 10^4 cycles; 15 cpm trapazoid	725	VTT
LCF: R=0 & 0.5; 10^1 to 10^3 cycles; 1hr dwell	725	VTT
post-service simulation (longitudinal weld)		
LCF: R=0 & 0.5; 10^1 to 10^4 cycles; 15 cpm trapazoid	725	VTT
LCF: R=0 & 0.5; 10^1 to 10^3 cycles; 1hr dwell	725	VTT

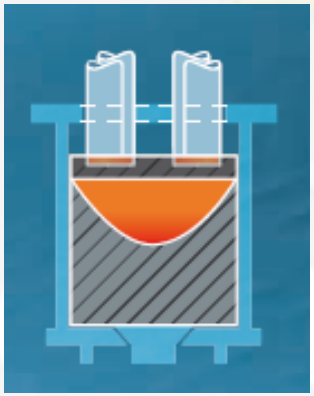
Rotor forging

- **Forging of real scale rotors**
- **Rotor forging of Ni alloys**
  - Homogeneity of ingots
  - Very large forces compared to steel
- Materials
  - Alloy 263 (SSF) and A263H (A&D)

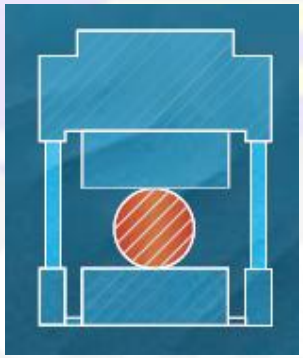
melting



remelting



forging
25-200t



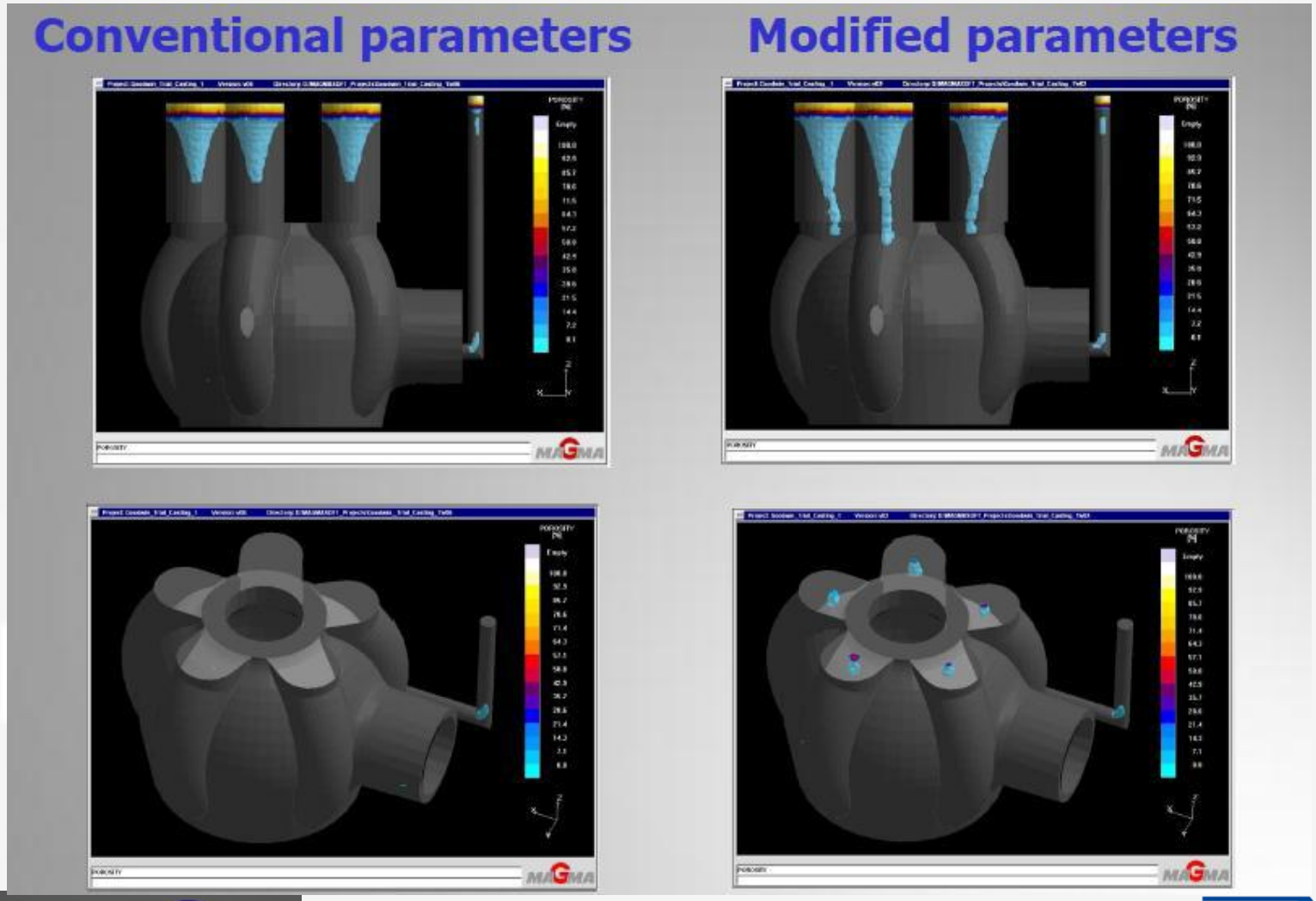
hardening

SEVENTH FRAMEWORK PROGRAMME

Rotor welding

- **Rotor welding**
  - Limited on ultrasonic inspection
  - Different thermal expansion coefficients
  - Welding procedure development
  - Creep and fatigue of welds
- Material
  - Alloy 263

Casting modelling

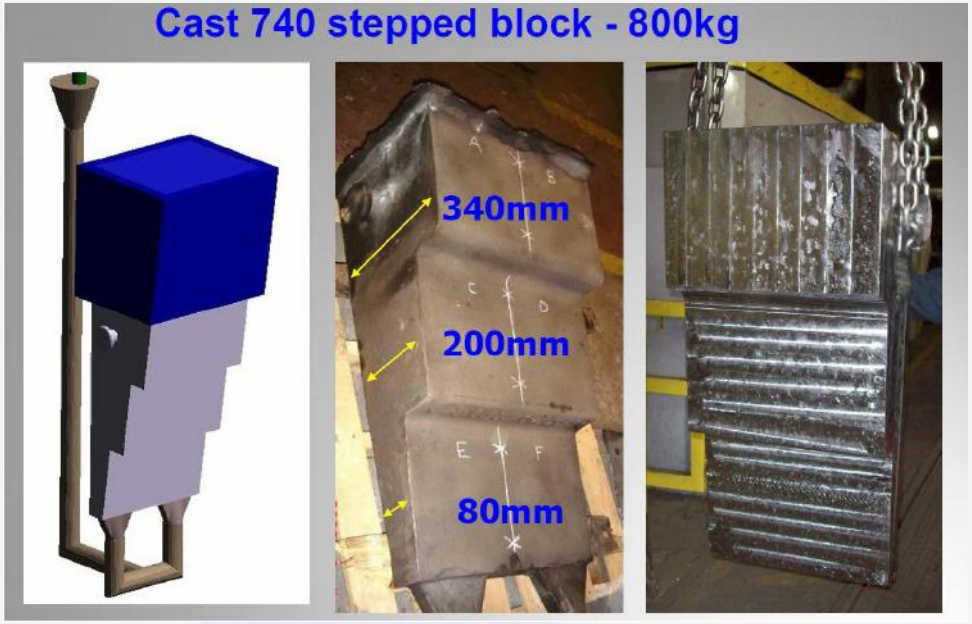


NEXTGENPOWER

SEVENTH FRAMEWORK PROGRAMME

Large scale castings

- **Casting of full scale Ni-alloys**
  - Valve chests
  - Cylinder casings
- Shrinkage
- Intergranular cracking
- Materials
  - Haynes282
  - Alloy 740H
  - Alloy 263

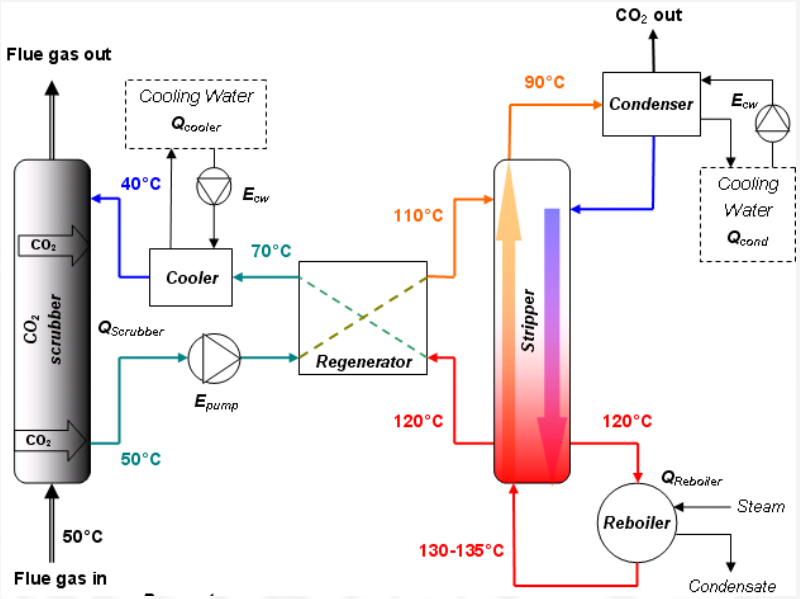


Alloy 625 control valve

Integration modelling

- Design coal plant with
  - 90% CO_2 capture
  - 45% effciency

- Lifing of USC superheaters and reheaters integrated with co-firing and oxyfuel combustion



NEXTGENPOWER

SEVENTH FRAMEWORK PROGRAMME

Thank you very much

for your attention!

NEXTGENPOWER