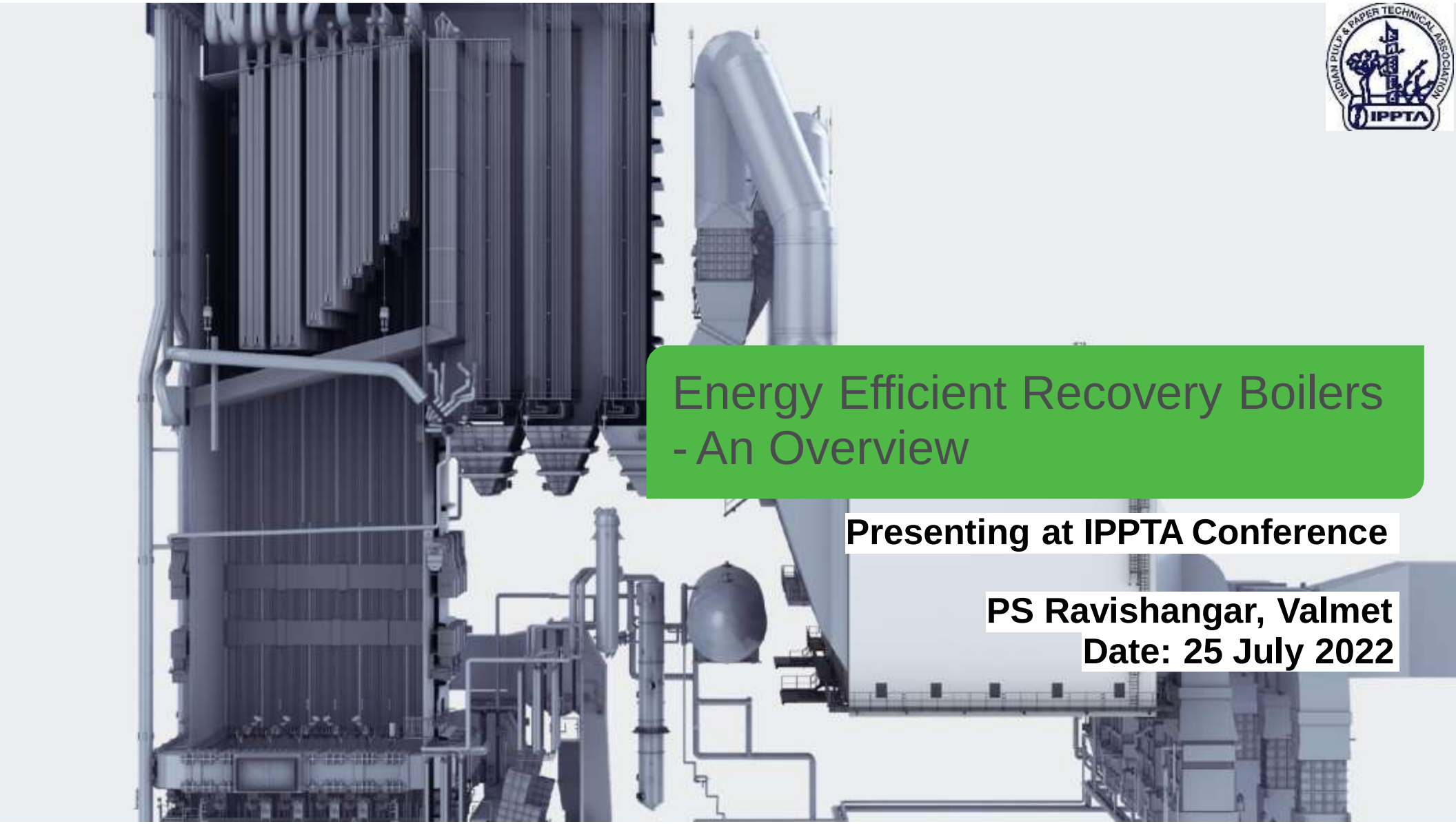

Energy Efficient Recovery Boilers - An Overview

Presenting at IPPTA Conference

PS Ravishangar, Valmet

Date: 25 July 2022

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2 Energy optimization – High Power features

3 High Power configuration

4 Limiting Factors for High Power Generation

5 Case study 1 – High Power Recovery Boiler

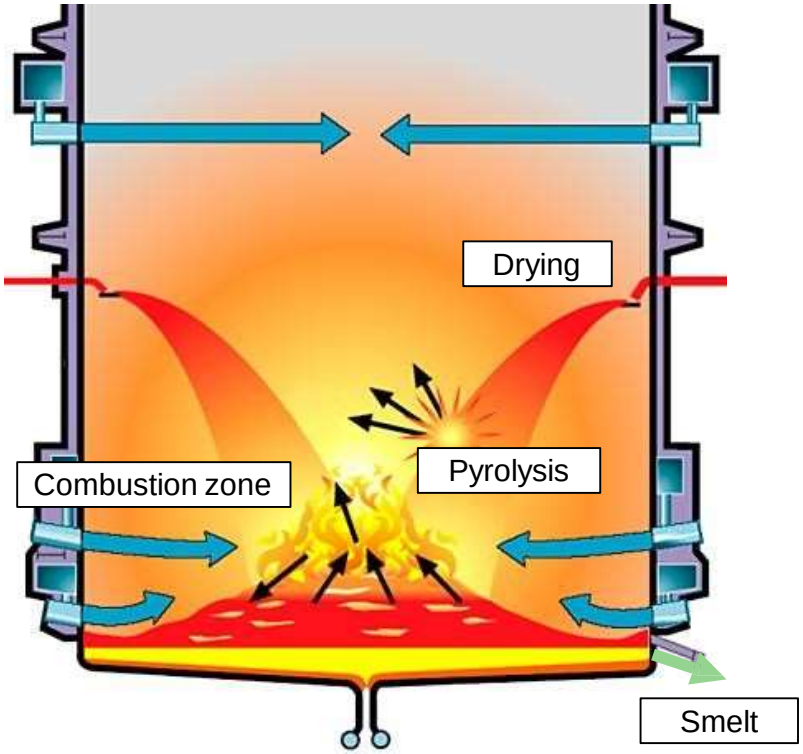
6 Case study 2 – High Power Recovery Boiler

7 Summary

Recovery Boiler Process

Recovery Boiler

Introduction



Chemical recovery

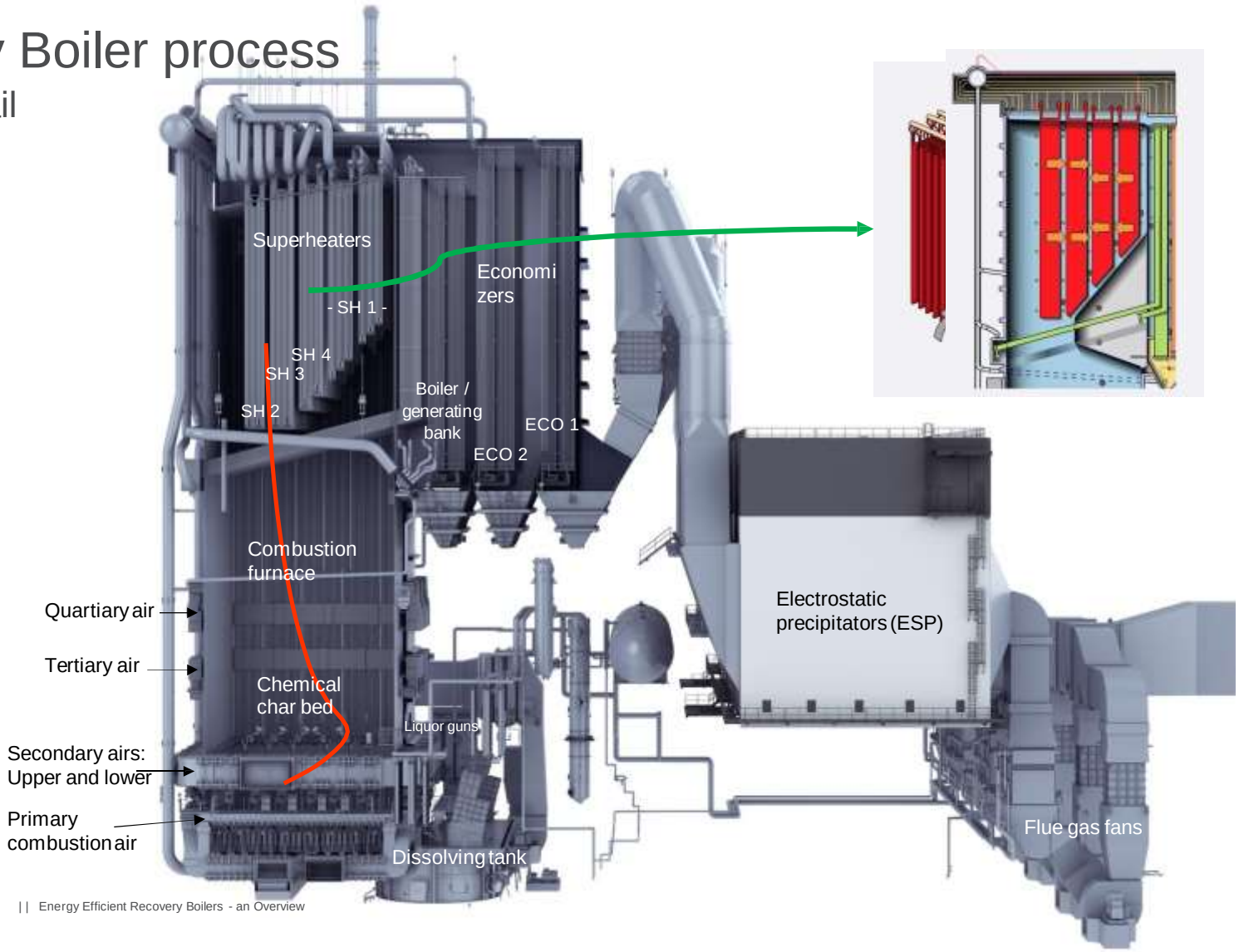
- All sulphur in black liquor and side streams recovered as sodium sulfide (Na_2S)
- Excess sodium recovered as sodium carbonate (Na_2CO_3)

Heat recovery

- Organic compounds burned and high pressure steam generated

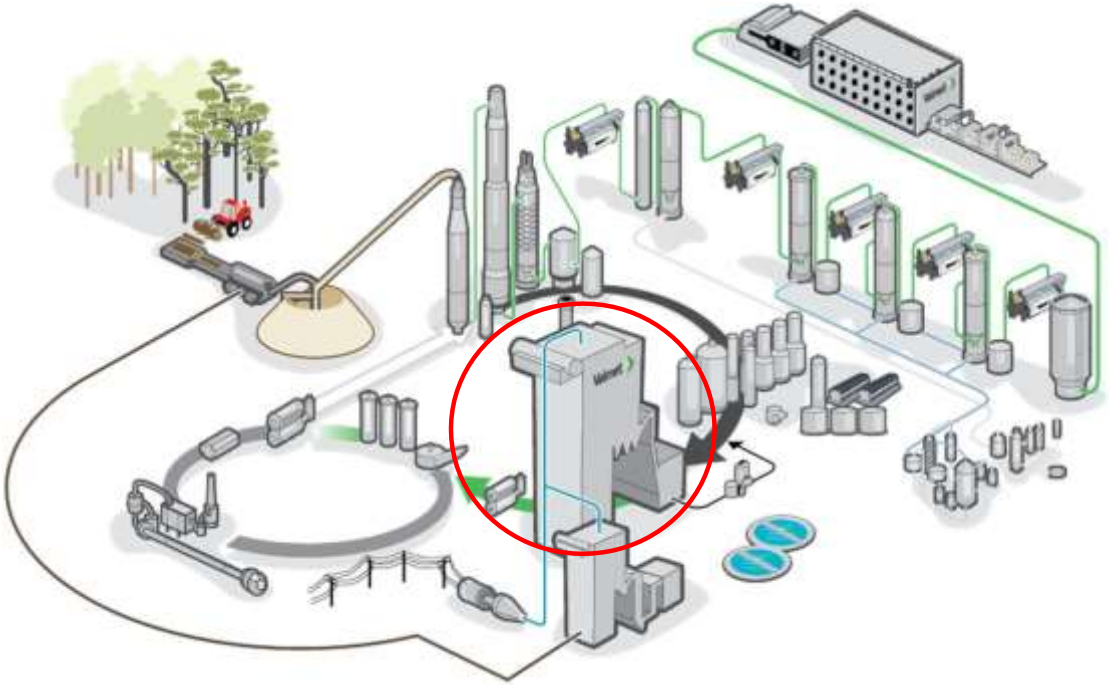
Recovery Boiler process

Boiler in detail



Energy optimization – High Power features

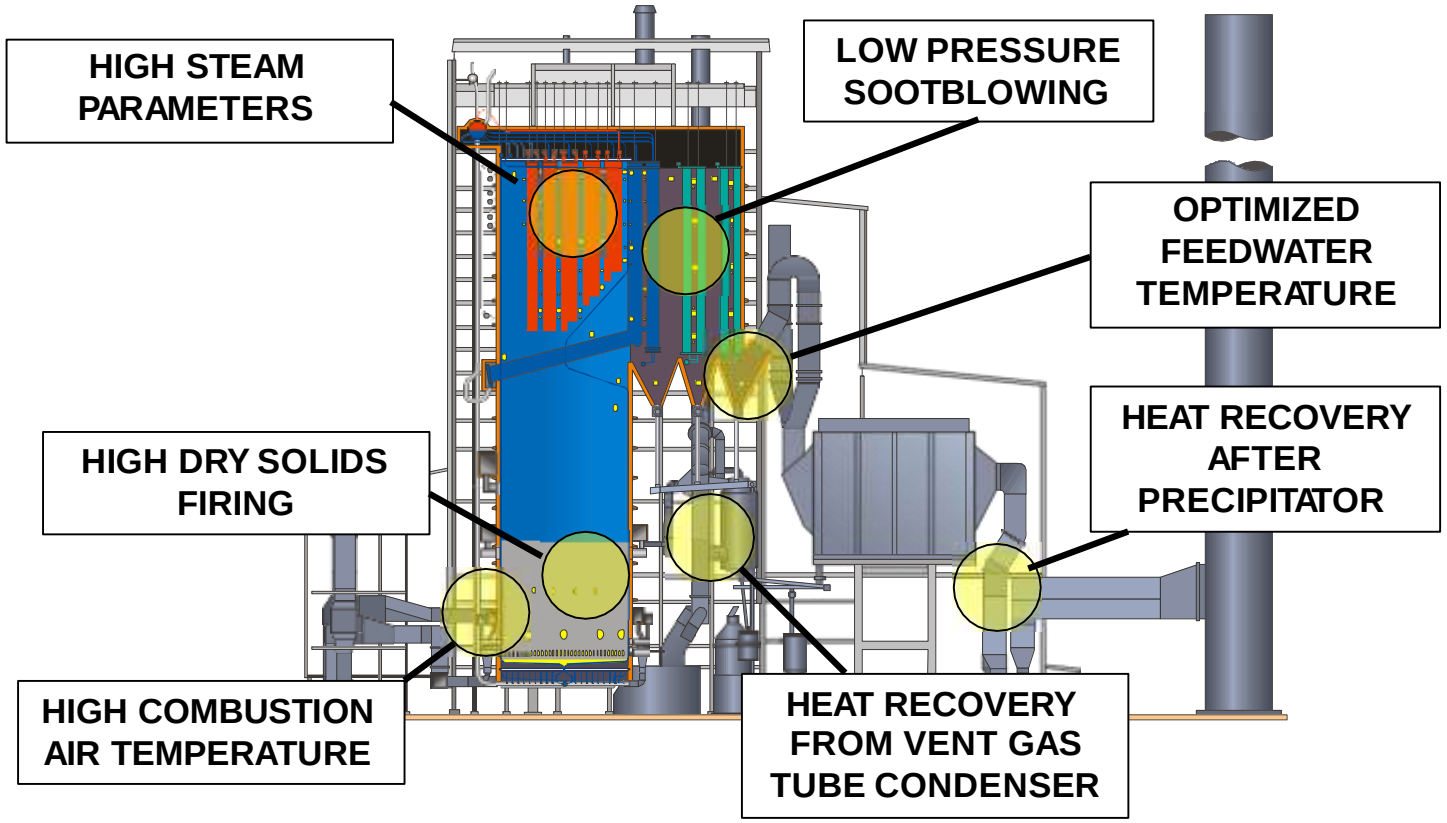
Improving Energy Efficiency of Recovery boiler



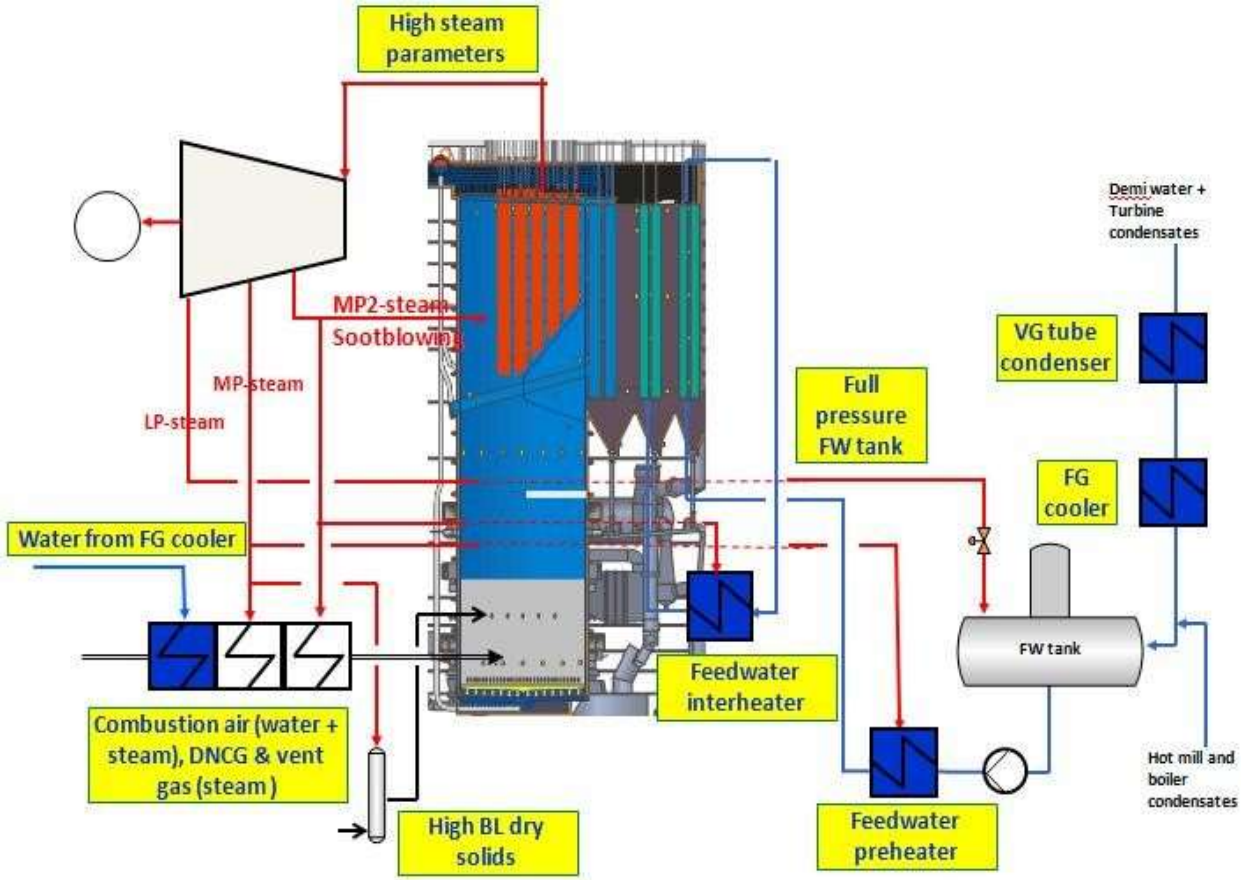
- Maximizing electricity output from Recovery Boiler

Energy Optimization

RB High Power Features



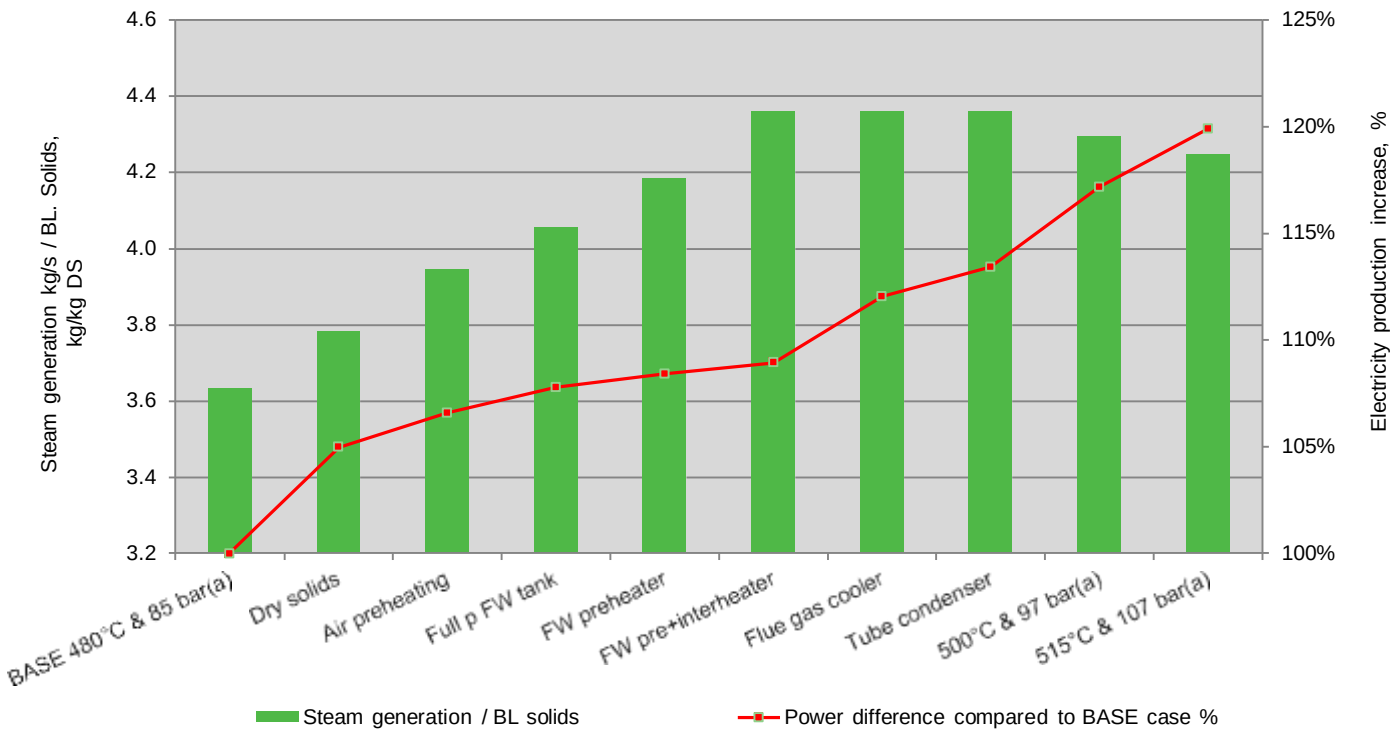
High Power Features



High Power features for higher electricity production

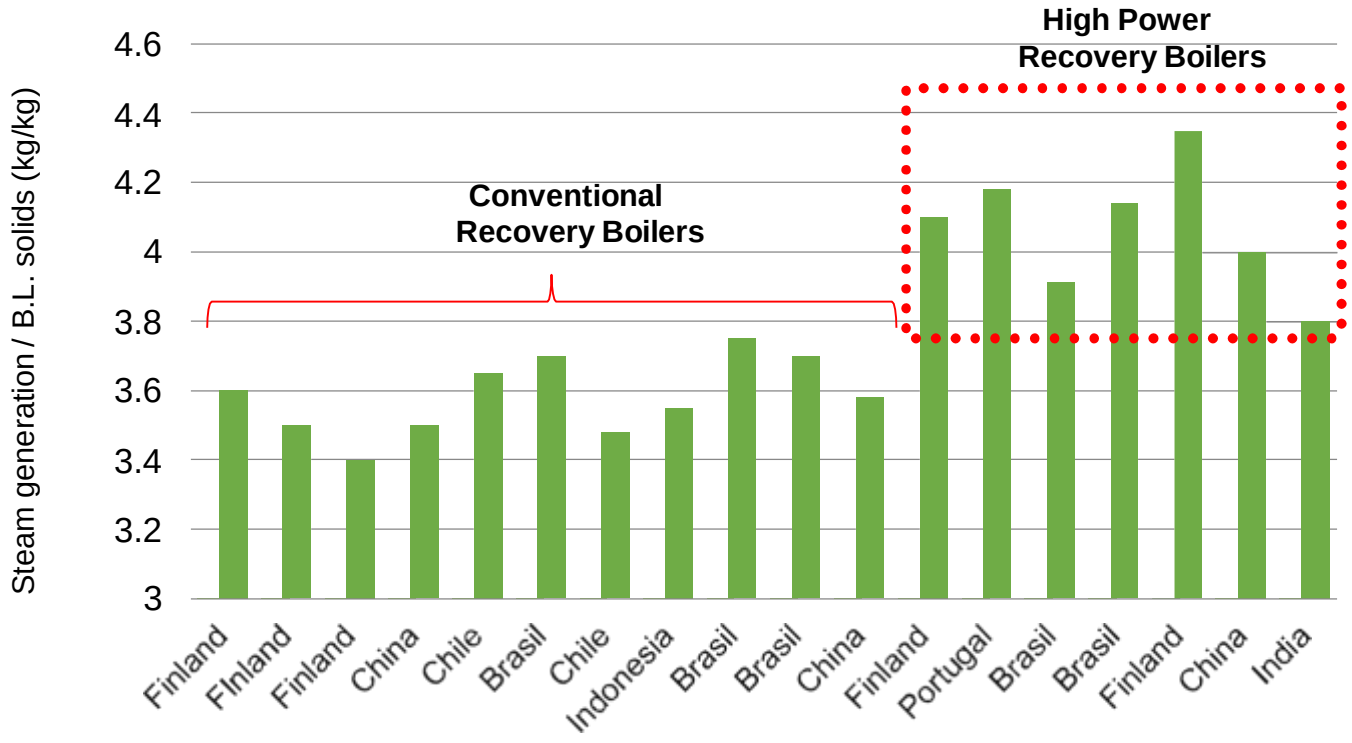
Case example with a condensing turbine

- Black liquor concentration up to ~84% (depends on raw material!)
- Sulfur reduction up to ~96% in smelt Na_2S / (Na_2S + Na_2SO_4) %-mol.
- Main steam parameters up to ~110 bar, 515 °C
- Combustion air up to ~210 °C
- Flue gas outlet temperature optimized together with a feedwater preheating concept; after flue gas cleaning further cooling to ~130 °C
- Heat recovery from dissolving tank vent gas
- Feedwater preheat
  - full LP pressure feedwater tank (~140...150 °C)
  - preheater before economizer (MP1 steam)
  - interheater between economizers (MP2 steam)



High Power Recovery Boilers

Key parameter



High Power Configuration

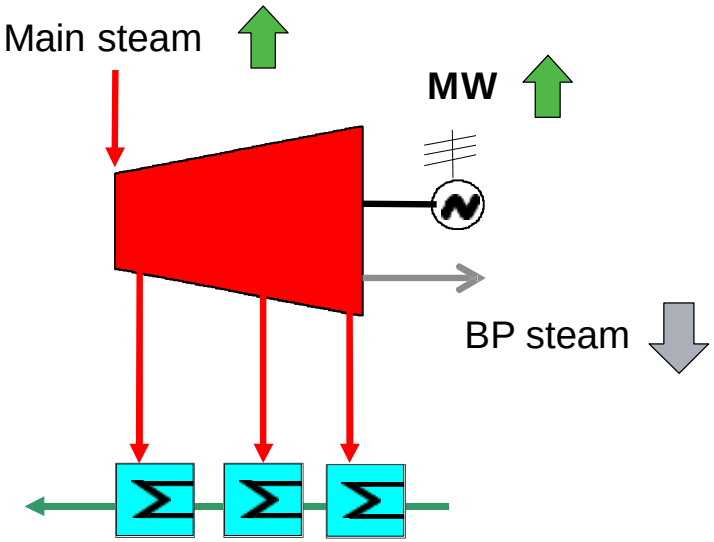
High Power Features

- Higher black liquor dry solids
- Air Preheating
- Feed water preheating
  - Fully pressurised feedwater tank
  - Preheater
  - Interheater
  - Preheater + Interheater
- Heat recovery from dissolving tank vent gases
- Heat recovery from flue gases
- Low Pressure sootblowing
- High Steam parameters

High BL dry solids content

- By increasing dry solids content less water needs to be evaporated in the furnace
- More live steam is generated
- Higher dry solids content increases extraction steam consumption in evaporation

Air preheating



- Heat input to boiler increases
- Main steam flow increases
- Extraction steam flows increase
- Back-pressure steam flow decreases

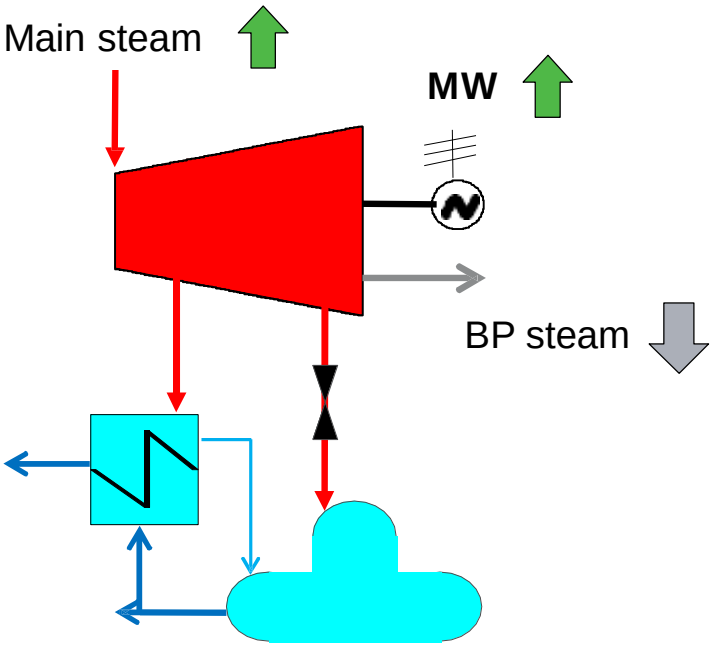
Profitability depends on the ratio of electricity and back-pressure steam prices

Air preheating has proven to be very profitable!

Air preheating

- Heating with back-pressure steam and medium / high pressure extraction steams (also hot water can be used in first stage)
- Temperatures up to >200°C
- Exception is Sec or high sec. air including DNCG and vent gases
  - DNCG max. 190°C
  - Vents max. 120°C
  - Max. mixing T 200°C
- Profitable to heat air as much as possible in low pressure and medium pressure stages

Feedwater preheating



- Enthalpy difference between main steam and feedwater is decreased

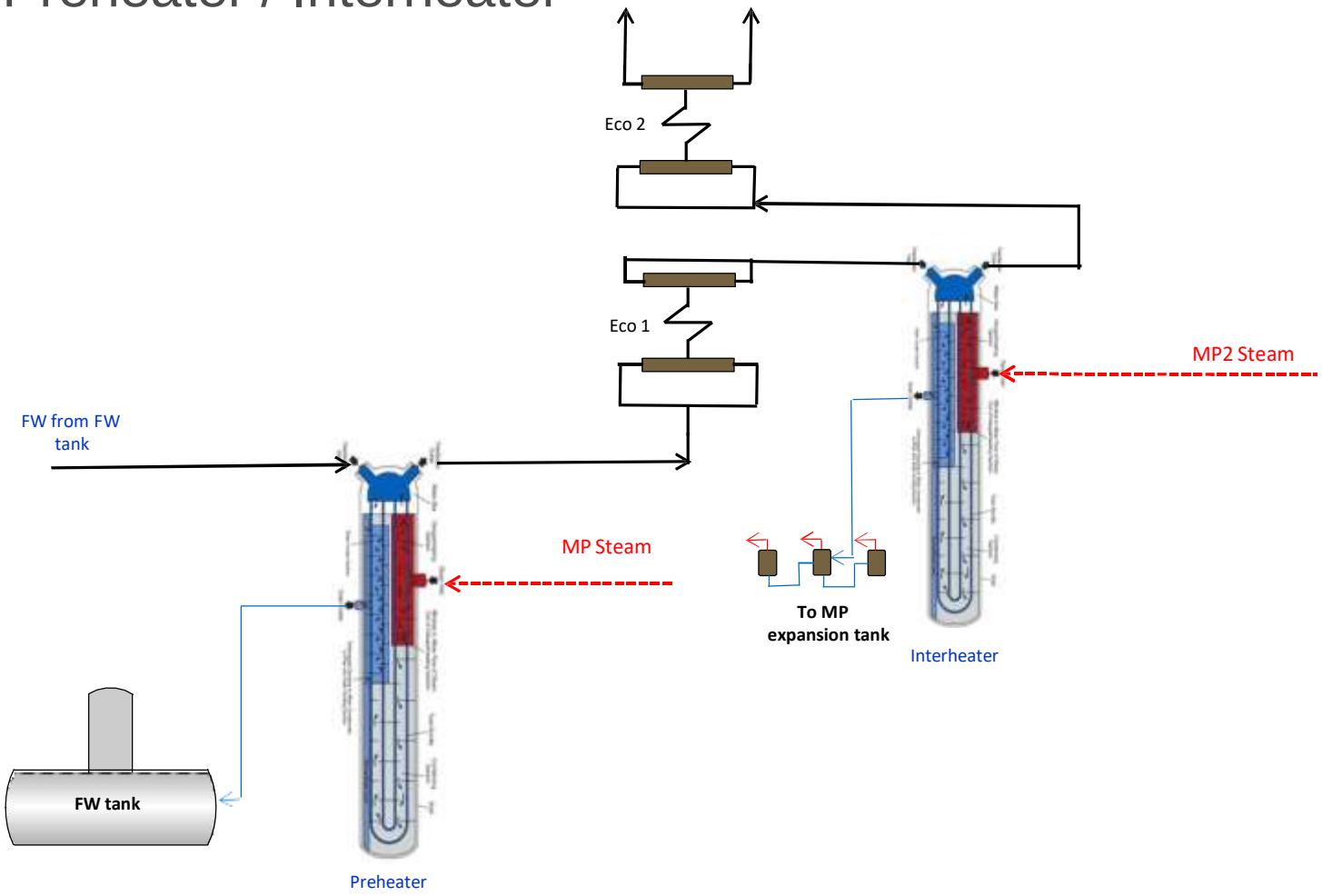
→ Main steam flow is increased

- Back-pressure and possibly medium and/or high pressure extraction steams are used
- Flue gas temperature after boiler is increased, so boiler efficiency is decreased
- Electricity generation efficiency is increased

Back-pressurised feedwater tank

- If back-pressure steam is throttled before feedwater tank, more electricity can be generated by removing the throttling (by increasing feedwater temperature and main steam generation)
- More back-pressure is then used for feedwater tank heating
- Profitability depends on the ratio between electricity and back-pressure steam prices
  - If there is no price for BP steam → profitable
  - If there is condensing turbine → profitable
  - If BP steam is used for district heating and price for that is at maximum 1/3 of electricity price → profitable
- Has proven to be very profitable!

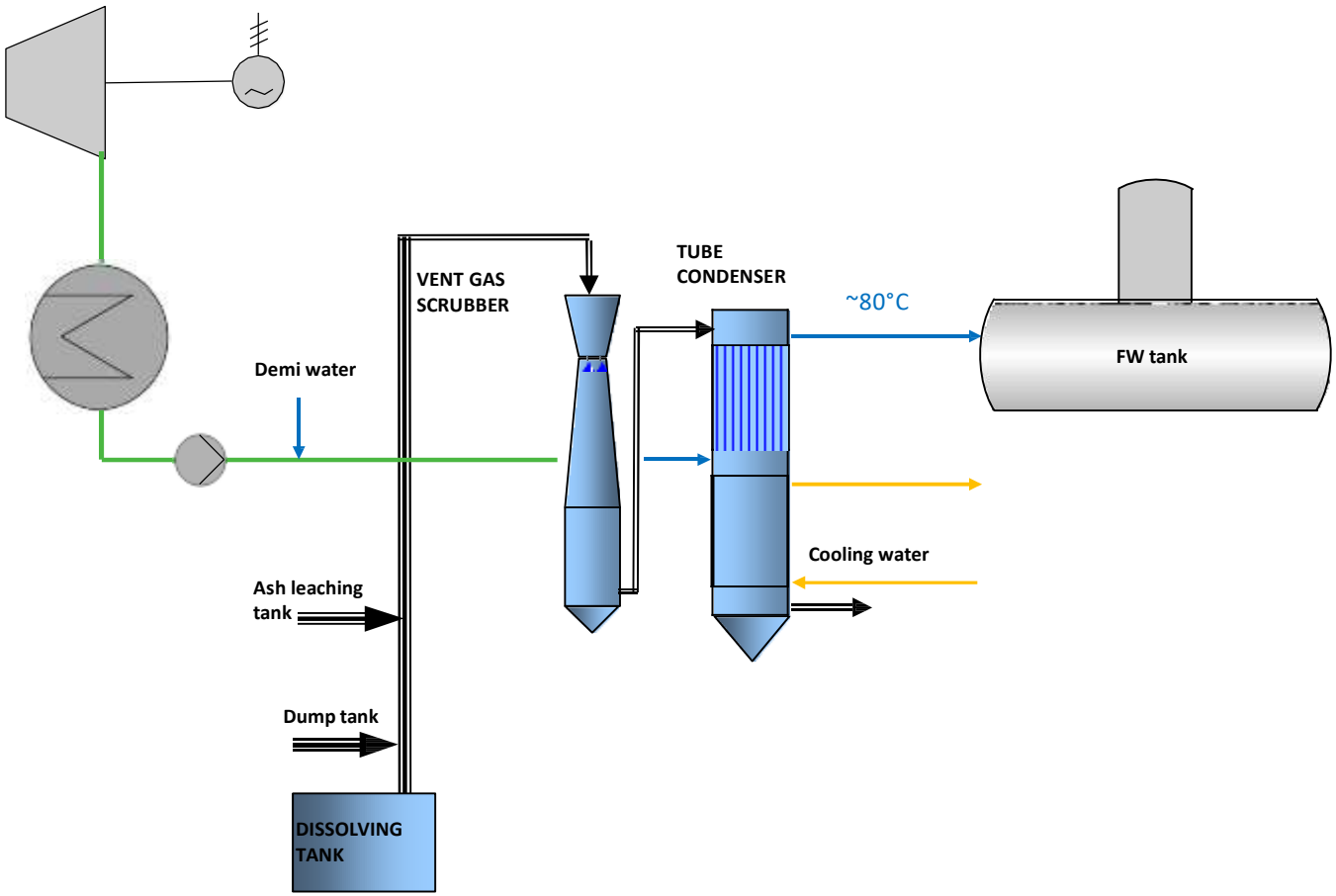
Preheater / Interheater



Preheater / Interheater

- Preheater before economizer (with MP steam)
- Interheater between economizer (with MP or MP2 steam)
- Combination of Preheater (MP steam) + Interheater (MP2 steam)
- With preheater, flue gas outlet temperature is higher due to higher feedwater inlet temperature to the boiler
- Factors affecting profitability of Interheater vs. profitability of Preheater:
  - Available extraction steam levels
  - Whether there is price for back-pressure steam or not
  - Whether there is Flue gas cooler or not
  - Limitation for flue gas outlet temperature
  - Whether there is Eco 3 / Dolezal or not

Heat from vent gas tube condenser



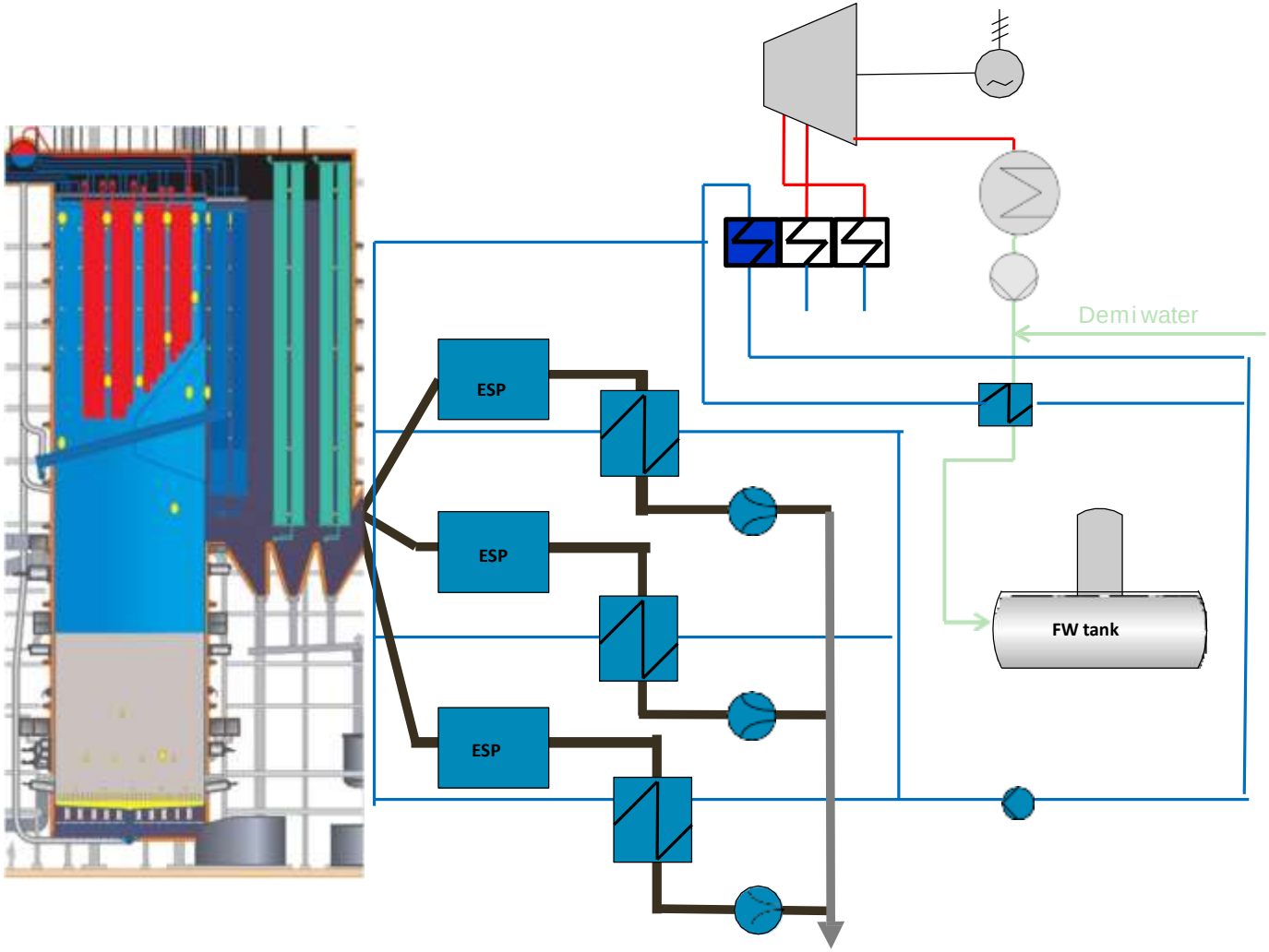
Heat from vent gas tube condenser

- Back-pressure steam can be saved by recovering heat from vent gas tube condenser
- Heat from vent gas tube condenser is transferred to:
  - Deminarilised water
  - Mixture of demi water and condensates
  - (Combustion air)
- Demi water can be heated up to >80 °C in vent gas tube condenser
- Vent gas heat recovery is profitable if there is high enough price for back-pressure
- A lot of heat available – very profitable with condensing turbine!

Flue gas cooler

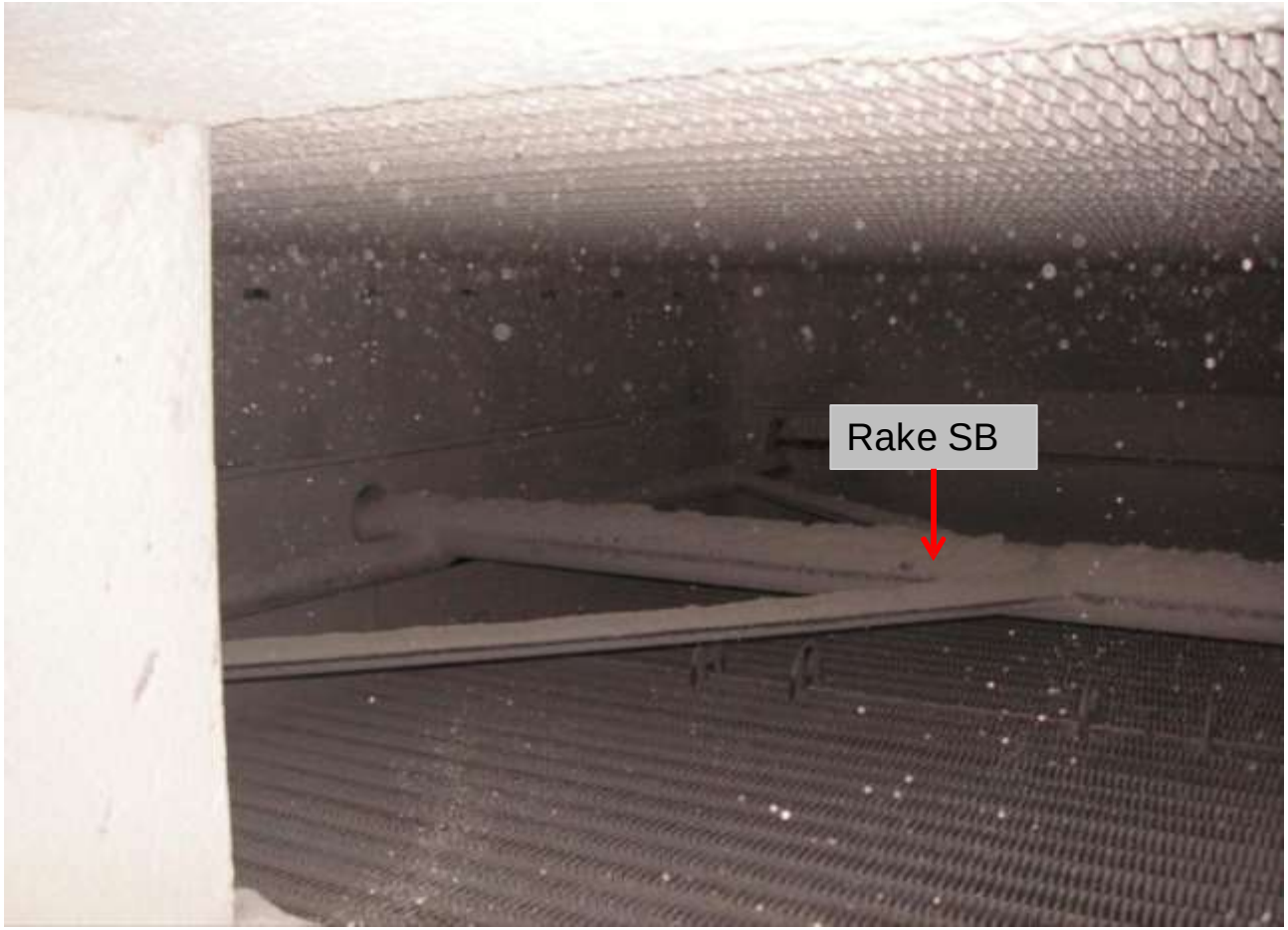
- Back-pressure steam (also MP steam) can be saved by recovering heat left in flue gases after electrostatic precipitator
- Heat from flue gases is transferred to circulating water and then to:
  - Deminarilised water
  - Mixture of demi water and condensates
  - Combustion air (even some MP steam can be replaced)
- In normal operation flue gases can be cooled down to ~120°C
- Flue gas cooler is profitable if there is high enough price for back-pressure
- A lot of heat available – very profitable with condensing turbine!

Flue gas cooler



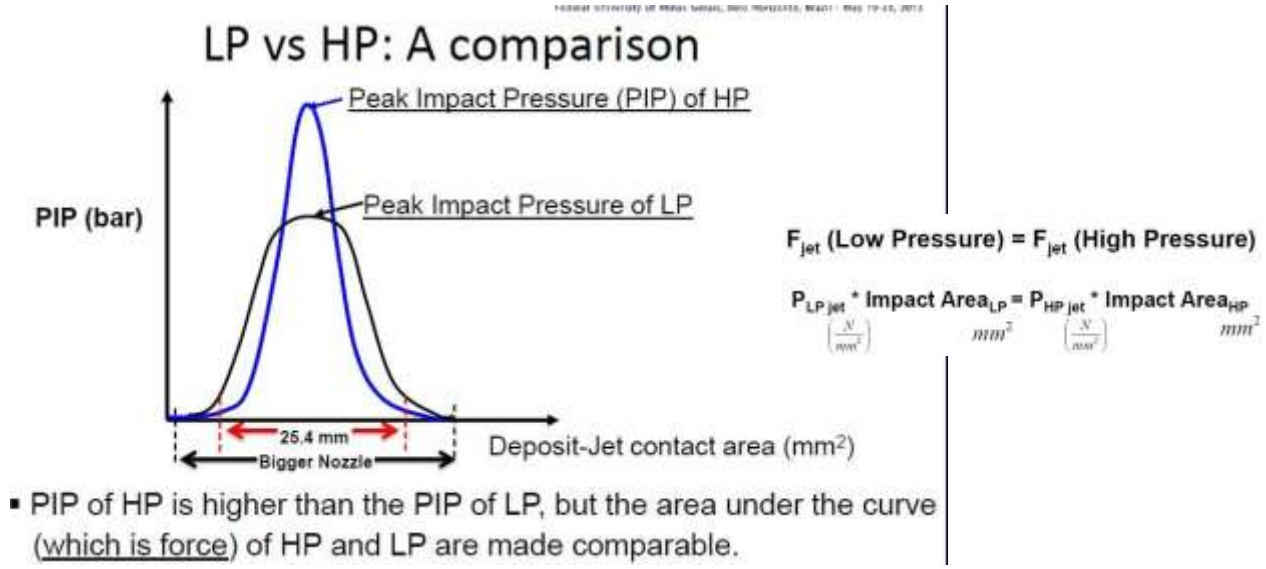
Flue gas coolers

Flue gas cooler – view inside



Low pressure sootblowing

- By using lower pressure extraction steam for sootblowing more electricity can be generated
  - Steam expands further in the turbine
  - But ~ 20% more steam is required with LP sootblowers than with conventional sootblowers (according to Diamond)



High steam parameters

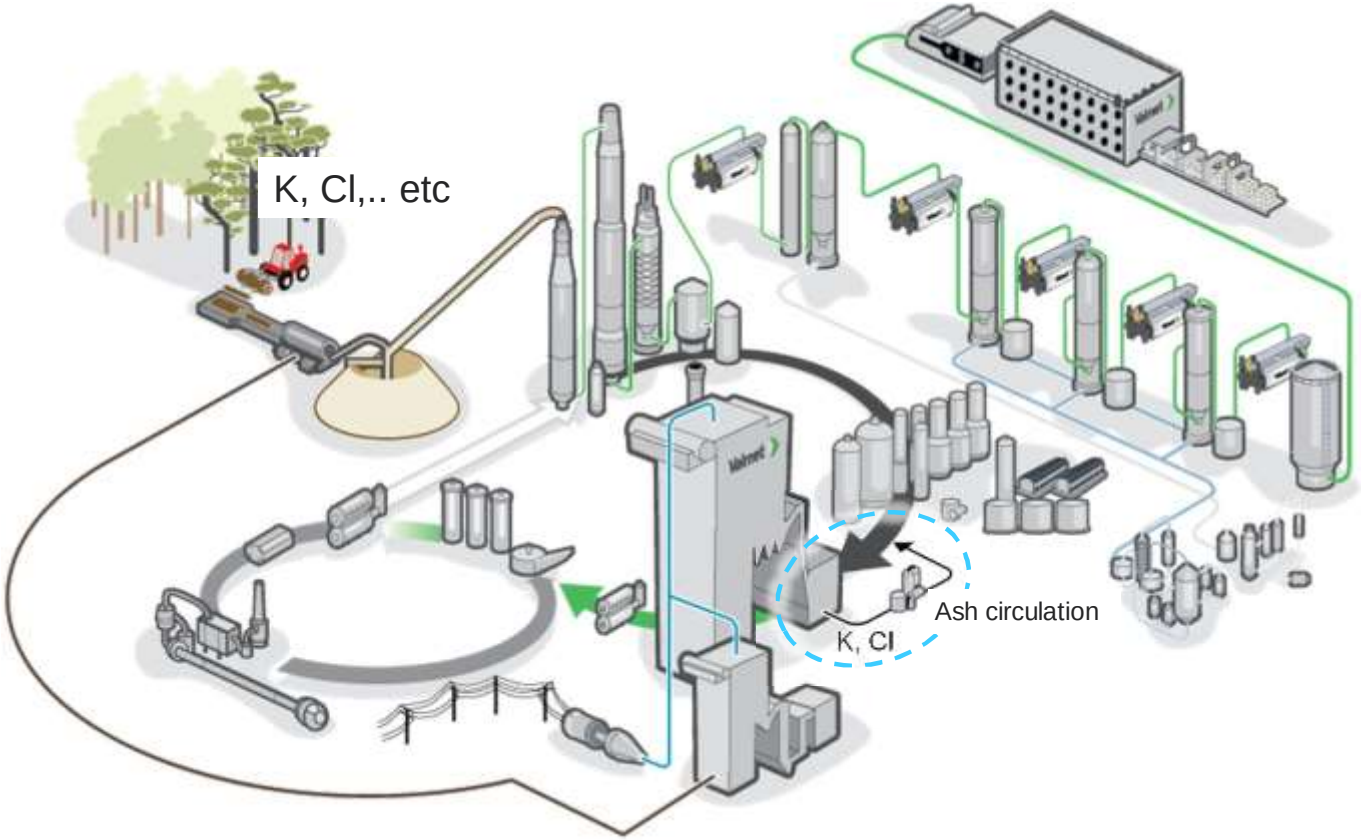
- Increasing main steam temperature always increases electricity output from generator
- Main steam pressure to be chosen according to temperature
- Increasing pressure increases condensate steam quality,
- Limitations for main steam temperature from superheater corrosion
- Levels of chlorine and potassium in black liquor tightly connected to reachable main steam temperature
- With constant Cl and K levels, higher main steam temperature can be reached if better superheater materials are chosen
- Cl and K in black liquor can be controlled by treating recovery boiler ash in Ash Leaching → Decreases also boiler plugging problems!
- Optimization between more expensive superheater materials and make-up costs caused by Na losses in ash treatment

Limiting Factors for High Power Generation

- Preheating of FW and combustion air is limited by extraction steam pressures and/or drum pressure
- Heat recovery from flue gases is limited by FG dew point corrosion
- Heat recovery from vent gases is limited by vent gas temperature
- Dry solids content is limited by feasible evaporation capacity and BL viscosity
- Steam parameters are limited by corrosion,
- Limitations for main steam temperature with boiler capacity
- In addition, ash quality limits the RB design through fouling

Recovery boiler ash circulation

Chemical recovery of recovery boiler

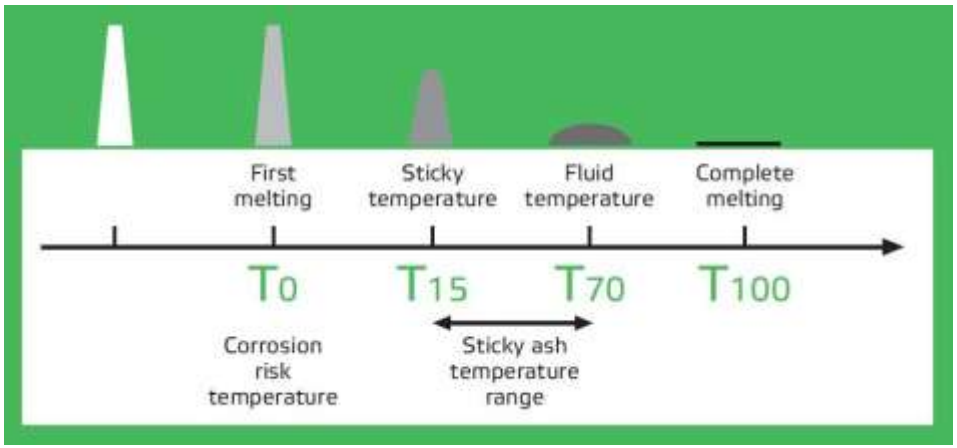


Combustion of black liquor generate large amount of ash, which contains valuable cooking chemicals. Ash is further circulated back to combustion liquor.

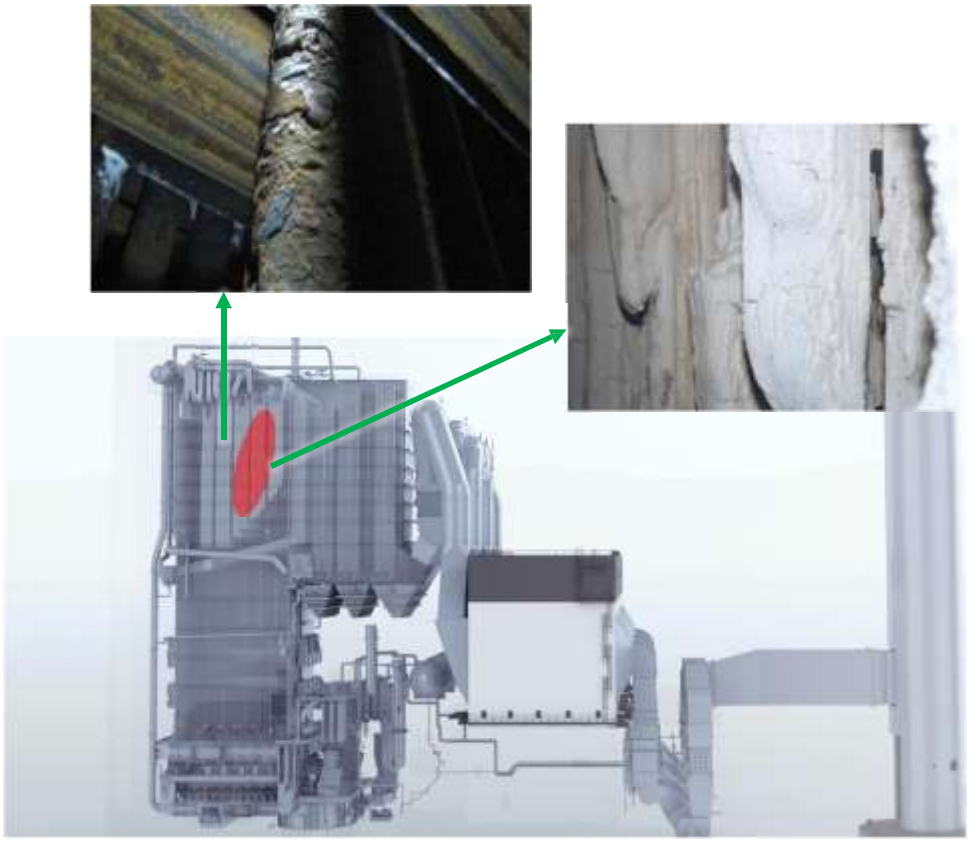
This circulation enriches chloride (Cl) and potassium (K) into recovery boiler ash.

Too high Cl and K concentration in recovery boiler ash reduces boiler availability due to increased corrosion and plugging risk.

Ash composition and recovery boiler operation



- Ash chemistry defines ash melting temperatures* (T0, T15, T70)
  - General rule is the higher the Cl and K concentration, the more difficult boiler operation becomes, eventually leading to boiler plugging and to an unplanned shutdown



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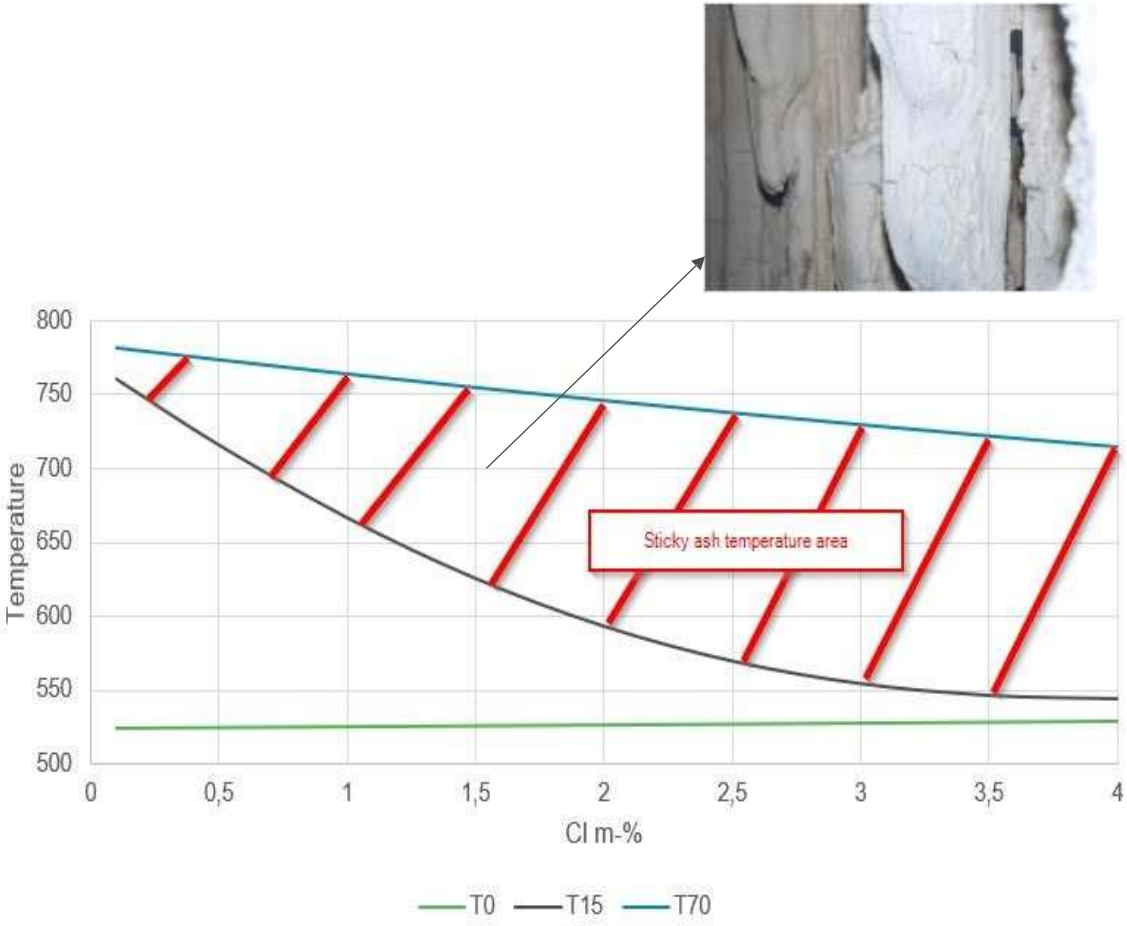
Cleanability

Effect of ash chemistry to recovery boiler cleanability

- The ash is sticky on temperature range between T15-T70, causing scaling in the recovery boiler
  - This is always happening in recovery boiler, regardless how much ash is treated
- Increasing chloride concentration in ash lowers the T15 and T70 melting temperatures.
  - Sticky area becomes wider, reaching further back in the recovery boiler, where the distances between the tubes are much smaller
  - Eventually the boiler plugs up and water wash is only way to clean the boiler. Water wash means full stop of pulp mill for 2-3 days.
- Sulphate and carbonate ratio also changes the ash melting temperature.
  - It is not enough to just measure Cl and K



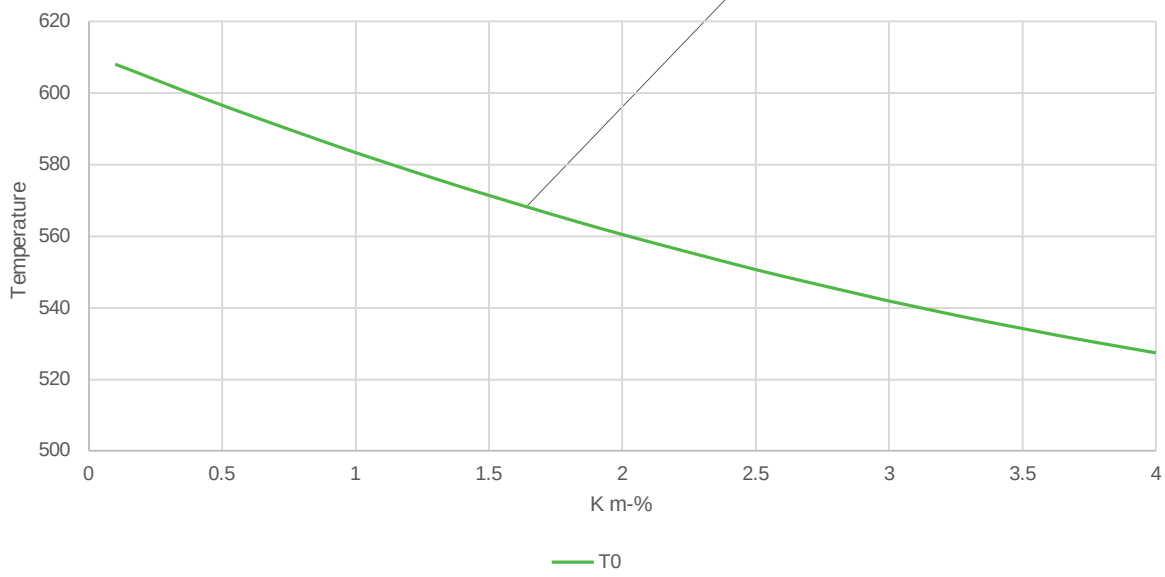
Corrosion

Effect of ash chemistry to recovery boiler corrosion

- Corrosion is an expensive problem at high power and steam temperature recovery boilers
- Corroded superheater tubes need to be replaced, causing a long mill shutdown

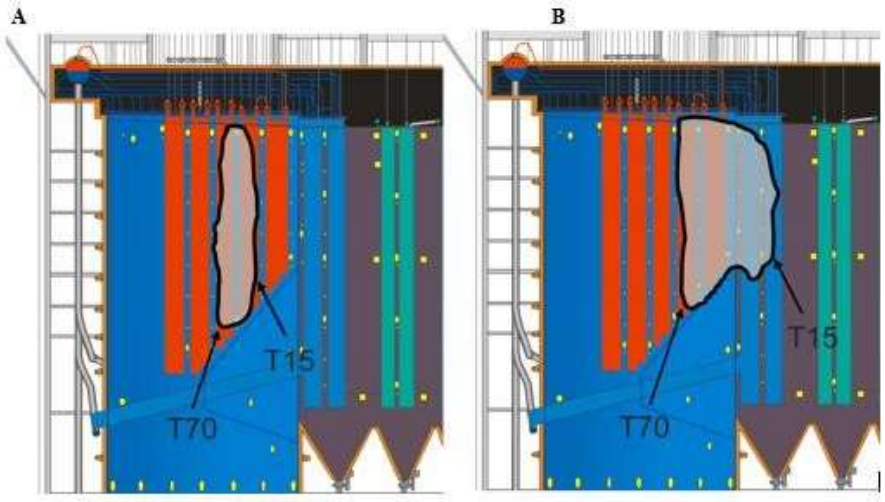
- Corrosion risk can be minimized by running the boiler at lower than design steam temperatures -> lost energy production

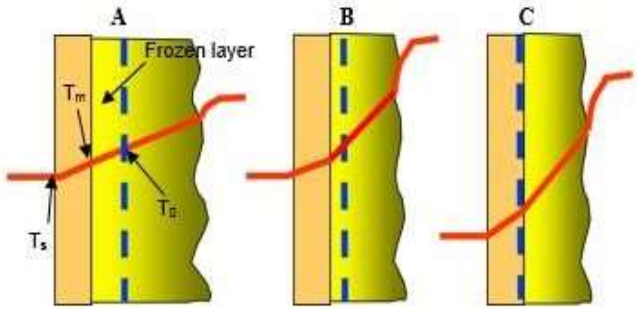
- Increasing potassium content lowers first ash melting temperature (T0)
  - Normally there is a dry ash layer protecting the superheater tubes.
  - When T0 gets close to steam temperature in superheater pipes the ash melts on superheater tube surface -> Corrosive conditions on the tube surface



Corrosion and Fouling

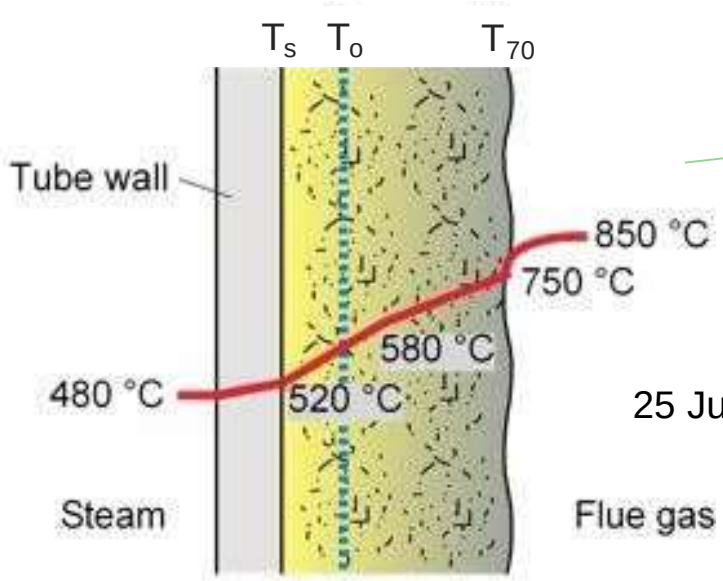
- High chlorine content increases the depth of the sticky area and moves it closer to II-pass
- High potassium content moves molten ash closer to tube surface accelerating corrosion
- Chlorine content also affects to corrosion

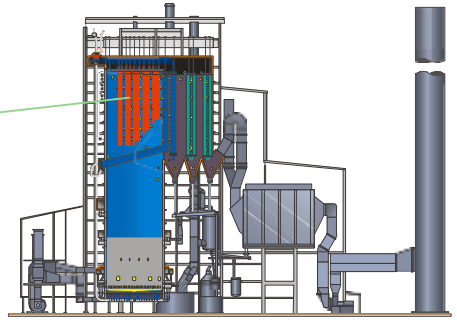




Molten corrosive ash close to tube surface

Ash behaviour





25 July 2022

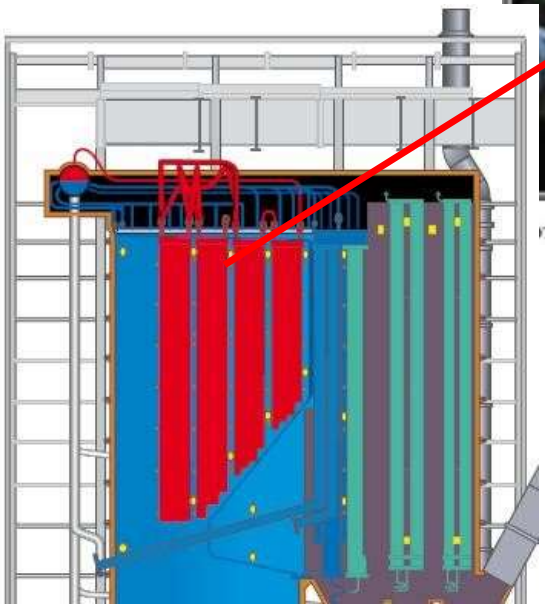
Corrosion
Accelerates when tube surface temperature approaches T_0 (ash first melting temperature)

→

Three choices:
- **Lower steam parameters**
- **Better superheater materials**
- **Lower K and Cl in ash**

Superheater materials

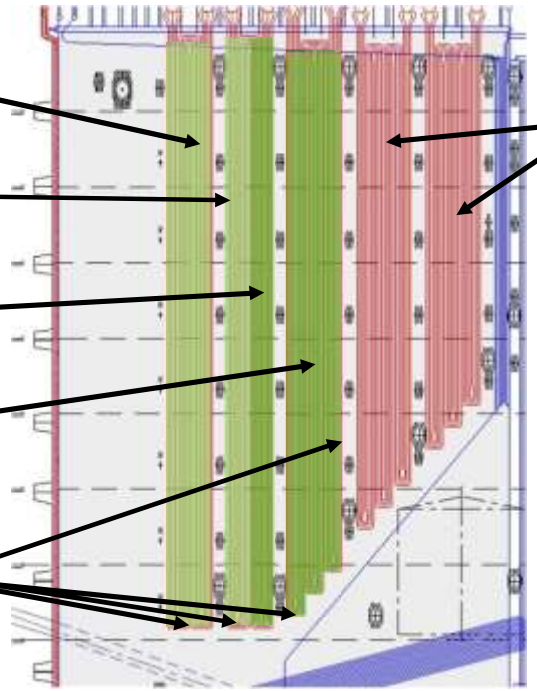
Cl and K must be followed and controlled strictly in order to minimize corrosion risk



TERTIARY SUPERHEATER

Selecting the right superheater material

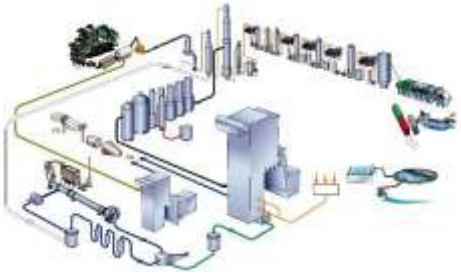
- The basis is steam pressure and temperature
- With the hottest sections the optimization is between expensive austenitic stainless steel or nickel based alloys materials and operating cost
- Best solution depends on price of superheater versus price of make-up chemicals



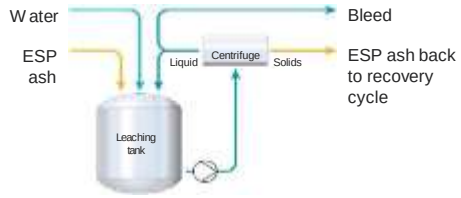
Bended SH tubes
with 309L Weld overlay

Ash Treatment systems

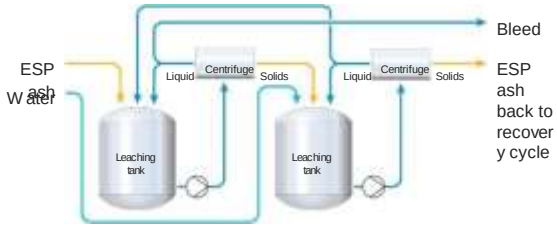
- Removes Cl and K
- Recovers cooking chemicals



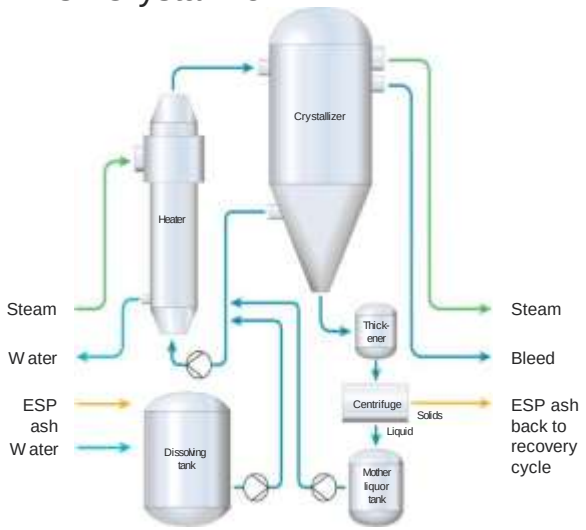
AshLeach



AshLeach Duo



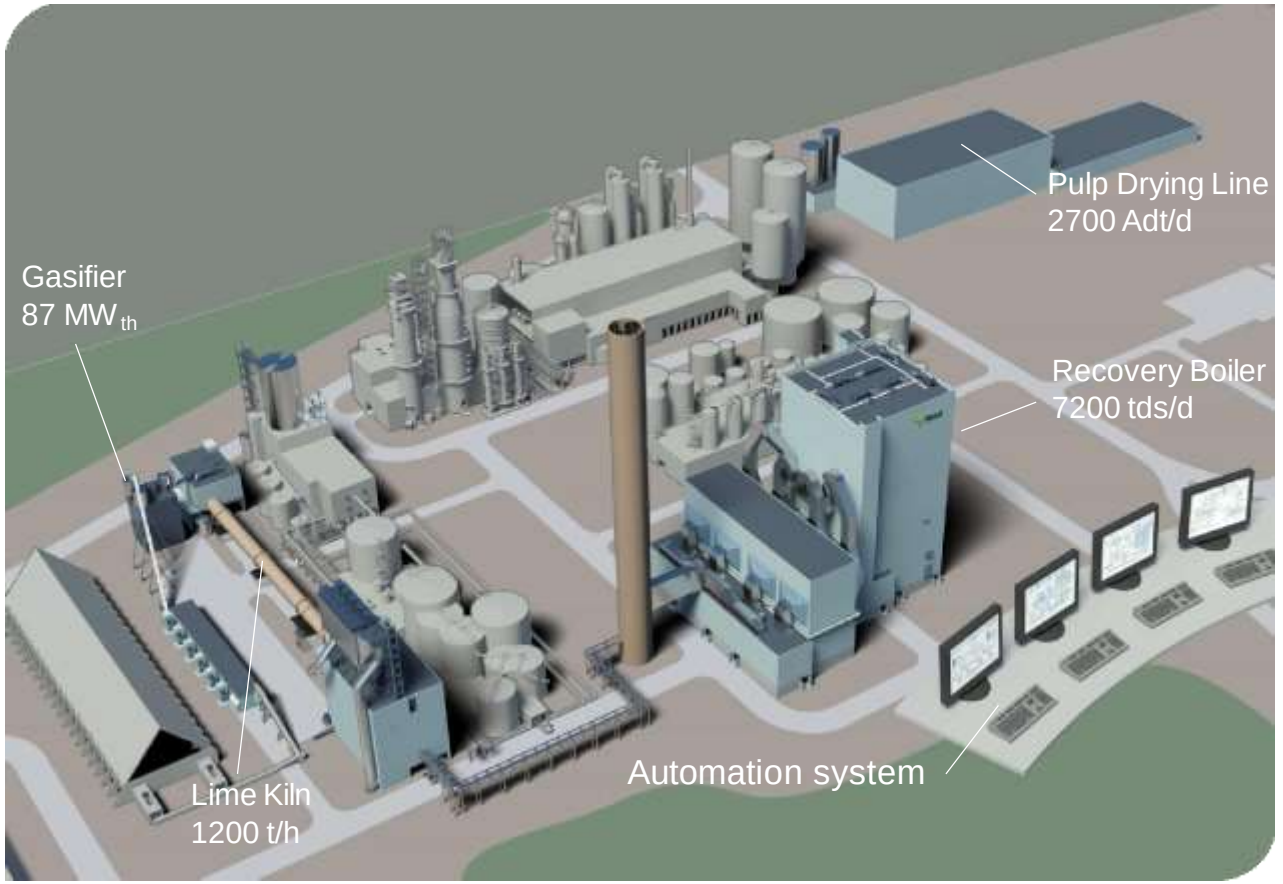
Ash Crystallizer



Case study 1 – High Power Recovery Boiler

Case Study 1: High Power Recovery Boiler

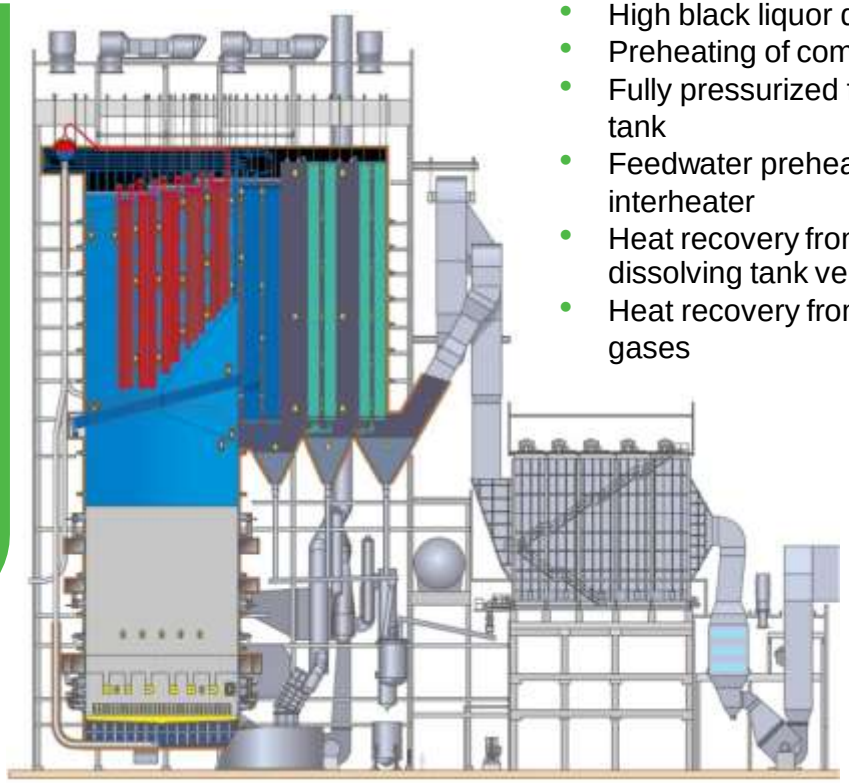
Pulp capacity 1,3 million t/a



Case study 1 – High Power Recovery Boiler

A modern day High Power Recovery Boiler

Capacity	**7200 t ds/24h**
Steam	**363 kg/s** **110 bar** **515 °C**
Liquor	**Kraft, 83 % ds, without ash**

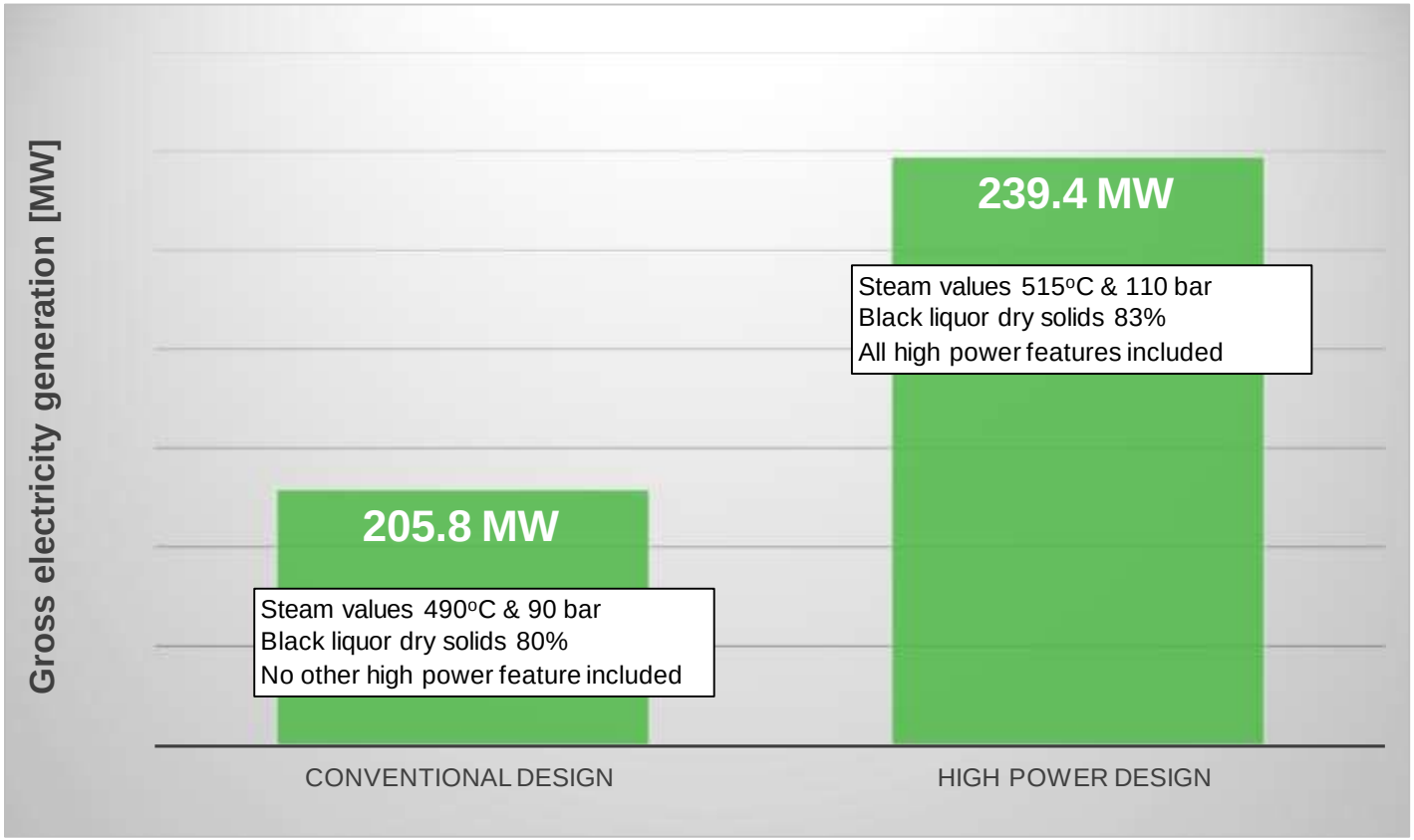


All the High Power features:

- High black liquor dry solids
- Preheating of combustion air
- Fully pressurized feedwater tank
- Feedwater preheating and interheater
- Heat recovery from dissolving tank vent gases
- Heat recovery from flue gases

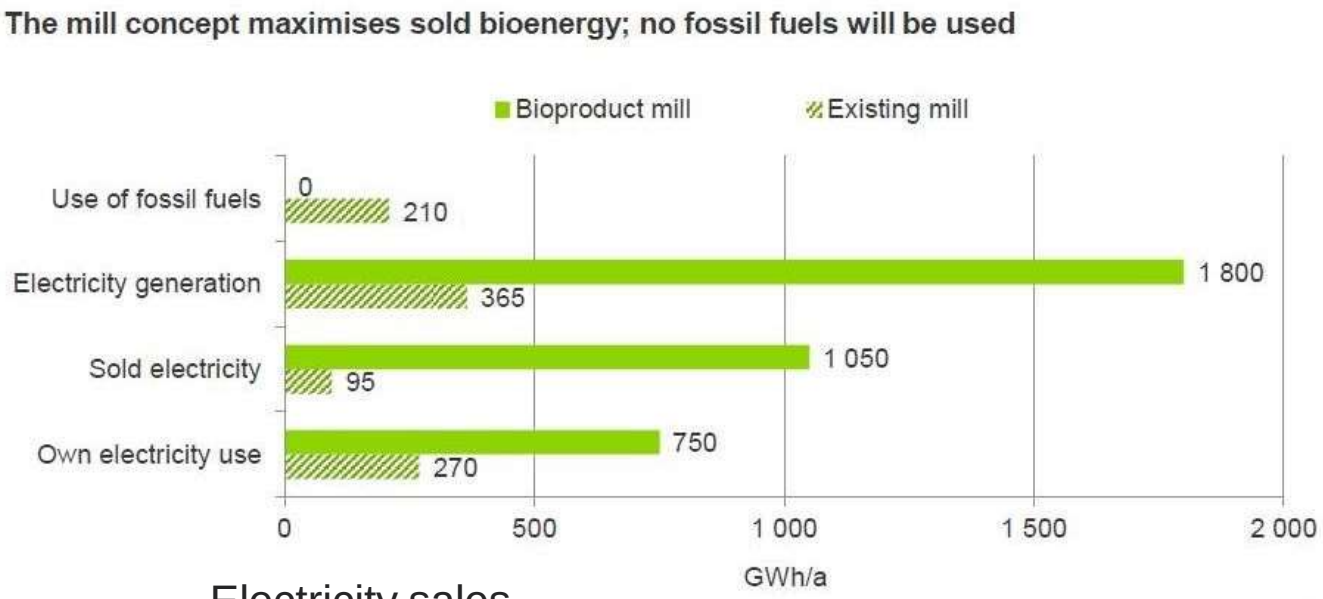
Case Study 1: Recovery boiler power generation

Substantial amount of renewable energy to the grid



Case study 1 – High Power Recovery Boiler

Electricity self-sufficiency, 1050 GWh/y sold electricity



Electricity sales

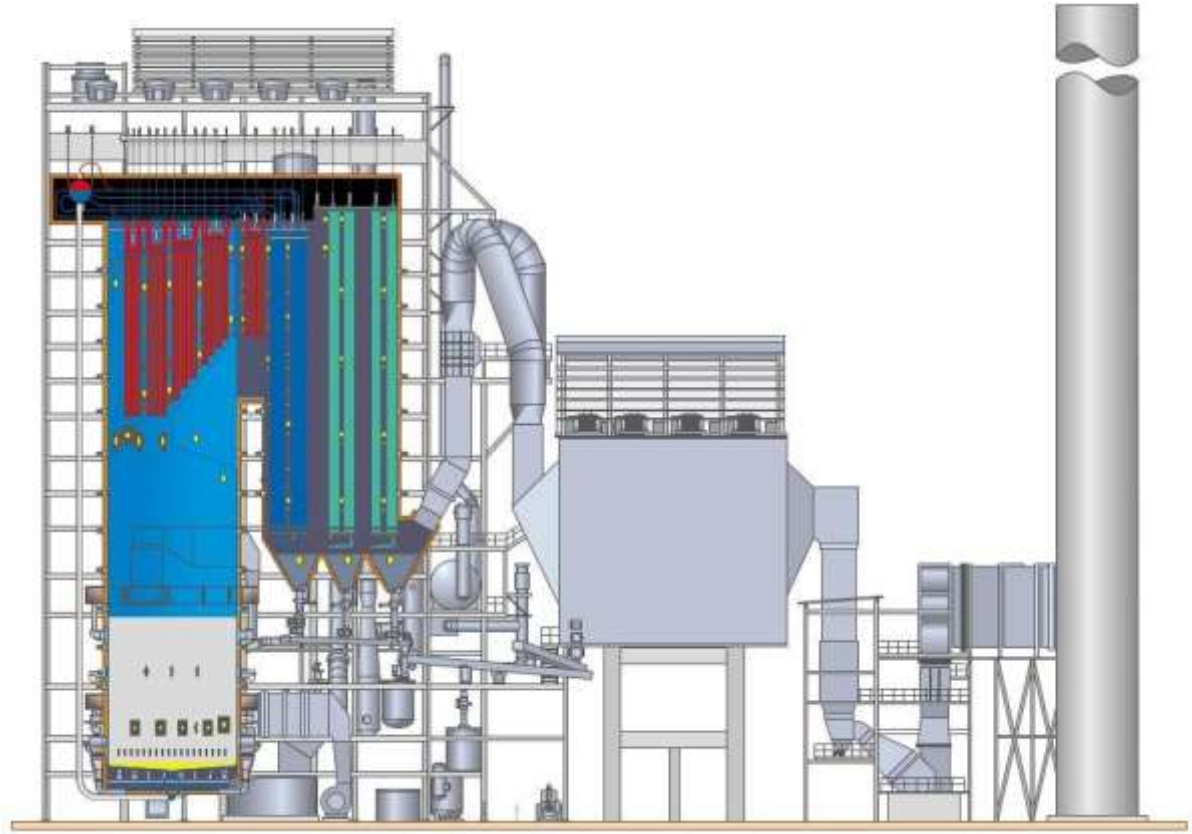
- Renewable energy

will increase the share of renewable energy by approx. 2 percentage points, from 28,5 % to 30,5 %

Source: Äänekoski bioproduct mill, Metsä Group's press conference, 21 April 2015

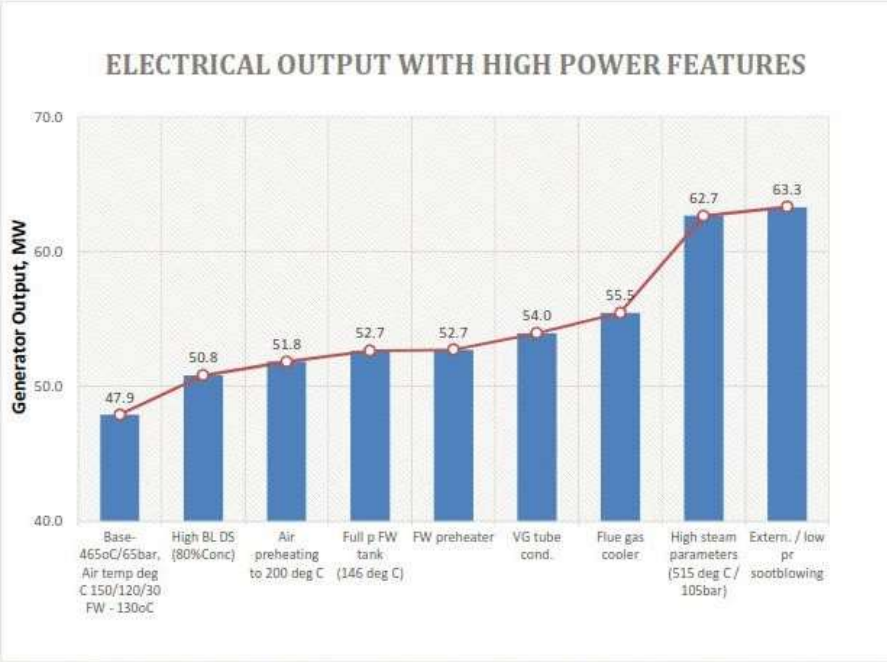
Case study 2 - High Power Recovery Boiler

Capacity	**2700 t ds/24h**
Steam	**118.9 kg/s** **110 bar** **515 °C**
Liquor	**Kraft, 75 % ds, without ash**

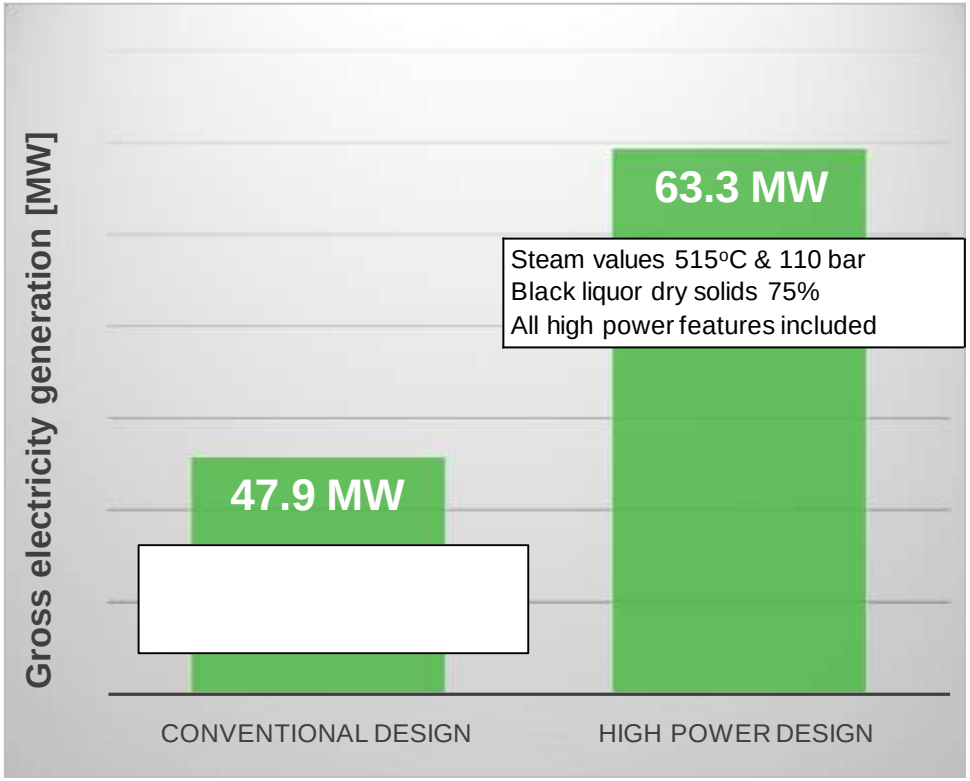


Case Study 2: - High Power Recovery Boiler

Expected Power Increase with High Power features addition to Recovery Boiler

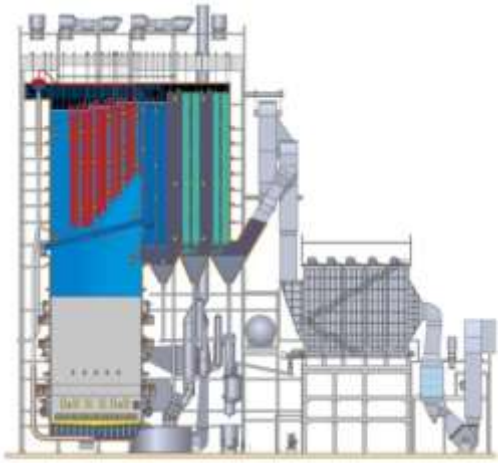
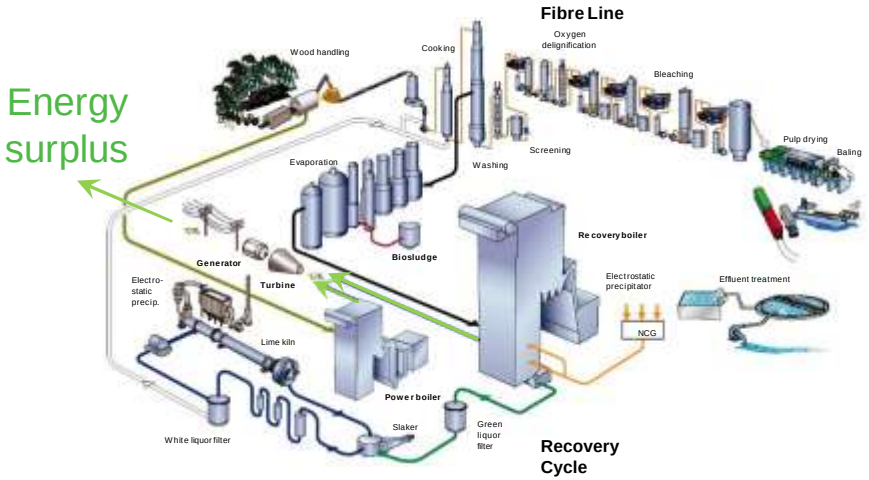


Note: The chart above is indicative and should be read to understand the approximate power gain with respect to addition of each high power features and the numerical values indicated shall not be used for design.



Summary (High Power Recovery Boilers)

The High Power features:

- High Steam parameters
- High black liquor dry solids
- Preheating of combustion air
- Fully pressurized feedwater tank
- Feedwater preheating and interheater
- Heat recovery from dissolving tank vent gases
- Heat recovery from flue gases

Initiation towards energy and resource efficiency improvement in Recovery.