Material selections for WtE

Vesna Barišić

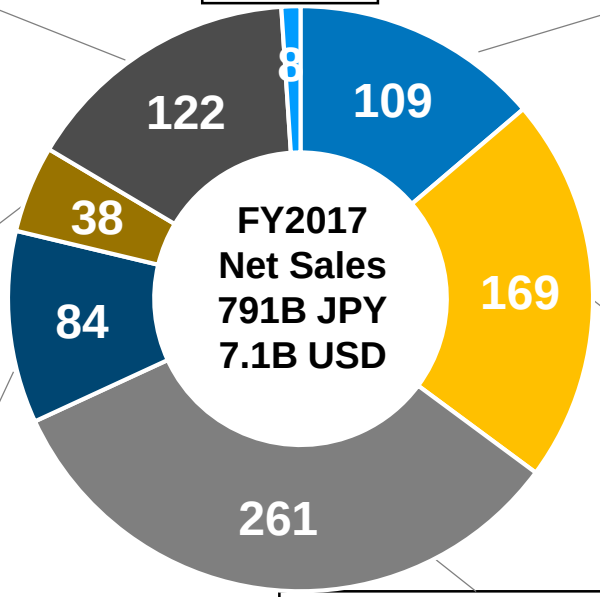
Sumitomo SHI FW

Presentation Outline

- An overview of Sumitomo SHI FW (SFW) company
- Waste as fuel
  - Corrosive elements in waste fuels and mechanisms of fouling and corrosion
- Our Waste to Energy (WtE) CFB experience
- Material selection for WtE and estimating corrosion risk
  - SFW models
  - SFW databases
  - Field exposures and collaboration with utilities
  - MetLab - physicochemical analysis of metal and deposit samples
  - Keeping up-to-date with research developments - networking with academia
- Future in digitalization

An overview of Sumitomo SHI FW (SFW) company

Sumitomo Heavy Industries Overview



6.Environmental facilities & plants

CFB(circulating fluidized bed) boiler for IPP

Water and sewage treatment systems

1.Machinery components

Power transmission and control equipment

5.Ships

Ships

2.Precision machinery

All electric injection molding machine

Cryocooler for MRI

Precision positioning systems

Ion implantation systems

3.Construction machinery

Hydraulic excavators

Mobile cranes

4.Industrial machinery

Goliath crane

Proton cancer therapy system

Cyclotrons for cancer diagnosis

Steam turbines

Our Products and Services

Sectors We Serve

- Utility Power
- Industrial Steam and Power
- Combined Heat and Power
- District Heating
- Waste-to Energy

Equipment We Offer

- CFB steam generators
- CFB gasifiers
- CFB scrubbers
- BFB steam generators
- BFB gasifiers
- Metallurgical waste heat boilers

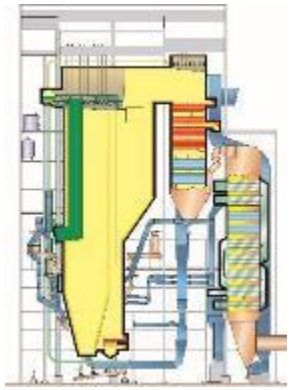
Services We Provide

- Commissioning
- Construction
- Outage & Emergency Services
- Eng'd pressure parts
- Replacement parts
- Fuel expansions & conversions
- Capacity Upgrades
- Meturigical lab
- SmartBoiler

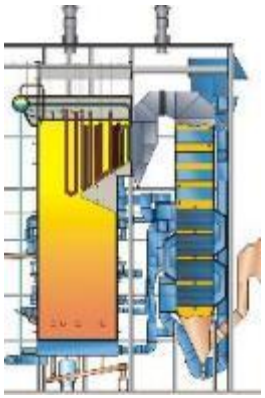
Project Delivery Options

- D&S equipment supply
- Turn-key boiler and AQCS islands
- EPC power blocks
- Basic plant maintenance
- Equipment modernizations
- Equipment upgrades
- Long term service partnerships

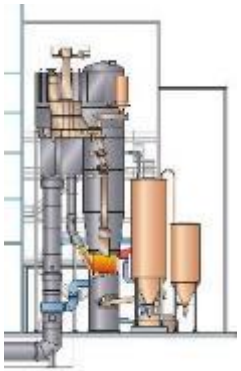
CFB Boilers



BFB Boilers

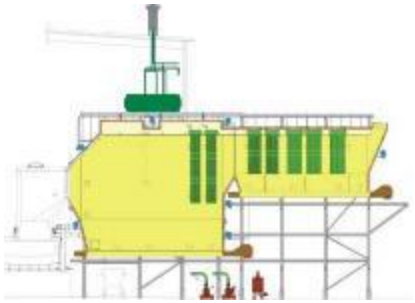


Fluid Bed Gasifiers



CFB Scrubbers

Waste Heat Boilers



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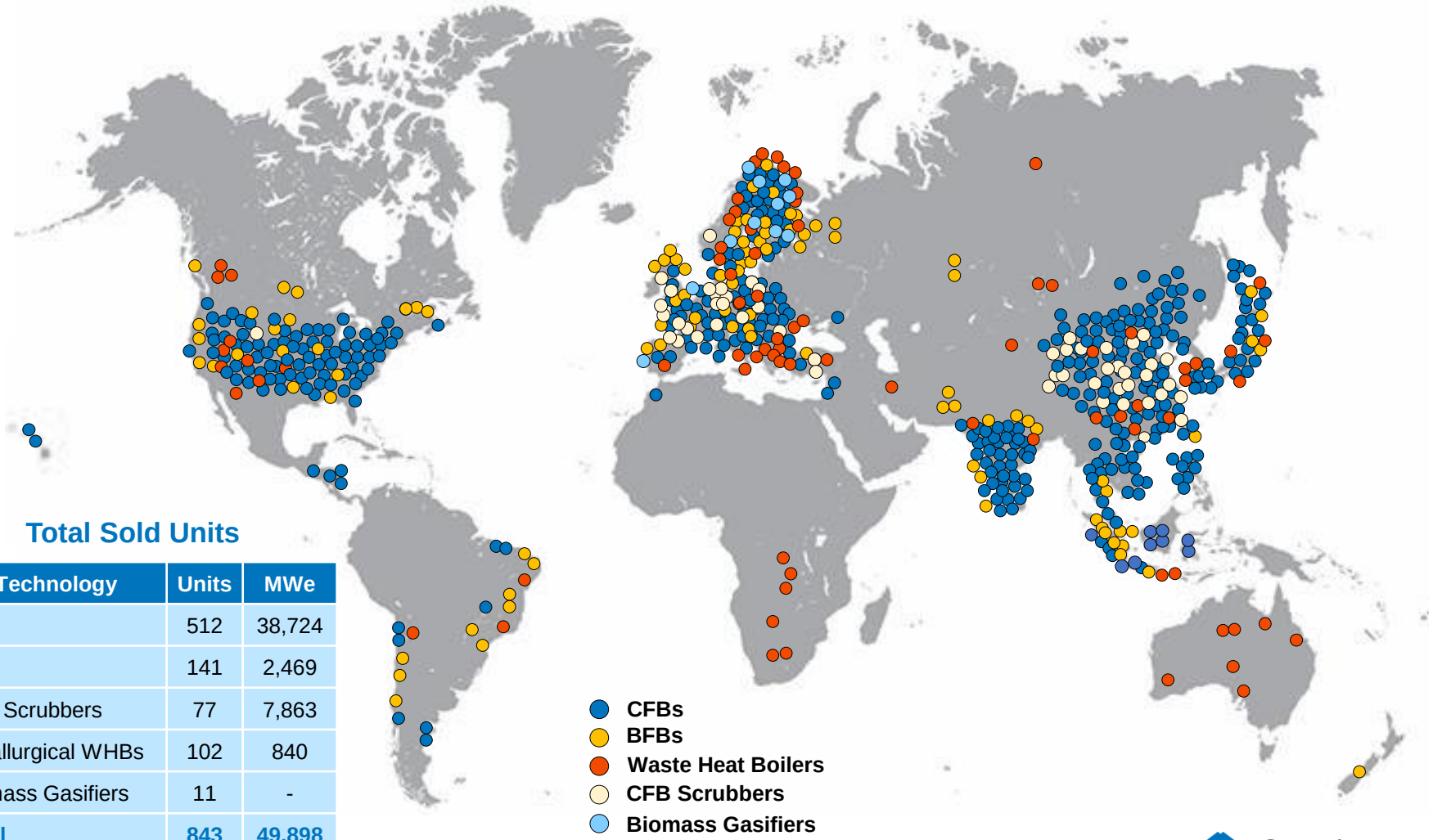
Our Global References



Total Sold Units

Technology	Units	MWe
CFB	512	38,724
BFB	141	2,469
CFB Scrubbers	77	7,863
Metallurgical WHBs	102	840
Biomass Gasifiers	11	-
Total	**843**	**49,898**

Our CFBs are Chosen the Most by Clients

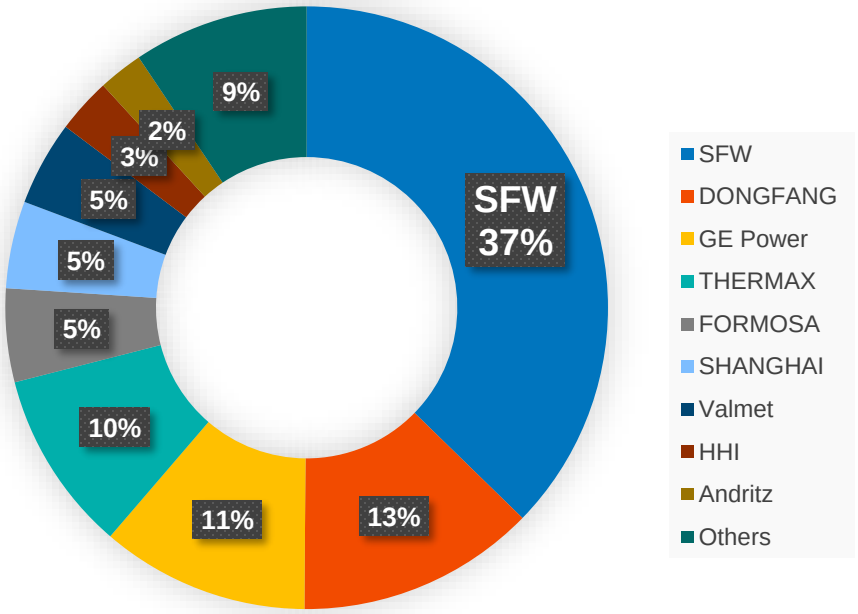
SFW has supplied 512 Circulating Fluidized Bed (CFB) steam generators from 1975 - 2019

- Totaling over 38.7 GWe in power capacity
  - 3 GWe Supercritical Once-Thru units
  - 35.7 GWe of Natural Circulation units
- Single unit capacities up to 550 MWe
- Proven by over 54m hours of operation
- Burning a wide range of premium and waste coals, biomass, petroleum cokes, oil shale, and waste fuels

World CFB Market Orders

SFW Served Market

10 Year 2009 - 2018 Period



Total Global Orders – 10 YEARS (all suppliers)
SFW Served Market:
39 GWe, 433 Units

Source: GRDS 07MAY19, CFB Boiler, All sizes. Excludes domestic orders provided by domestic suppliers in China, and India. Market share based on steam capacity GWe. Project Scope EPC, D&E, D&S, Licensing. Other includes suppliers with less than 2% market share.

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Waste as fuel

Corrosive elements in waste fuels and mechanisms of material wastage

Waste as fuel

Common waste types fired and co-fired in CFBs

RDF
fluff, pellets or briquets

SRF
fluff, pellets or briquets

Residues and by-products of various industrial processes

Recycled Wood
chips

Waste Wood Dust
briquettes or pellets

Tire Derived Fuel

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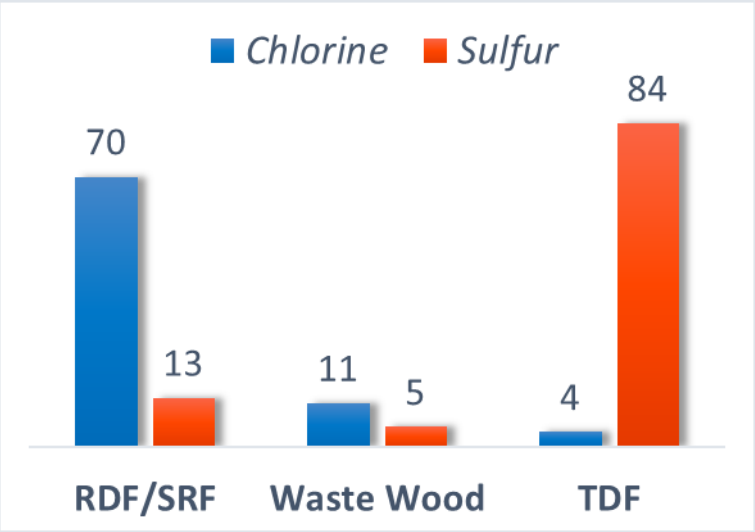
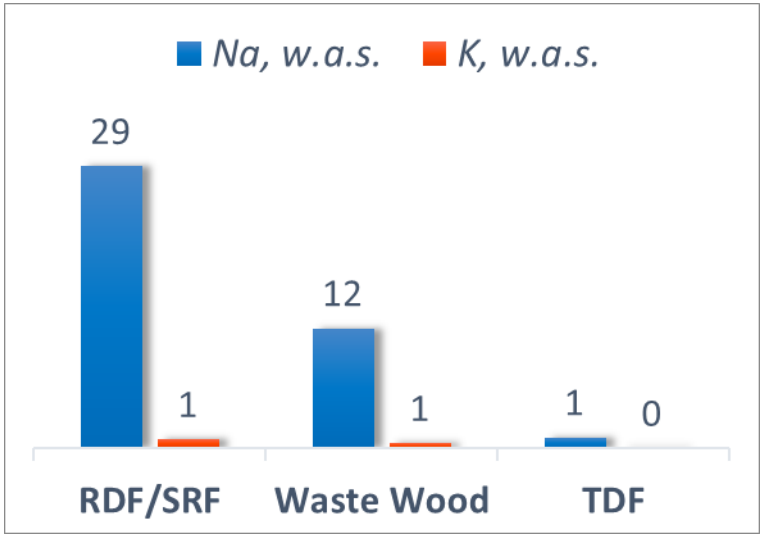
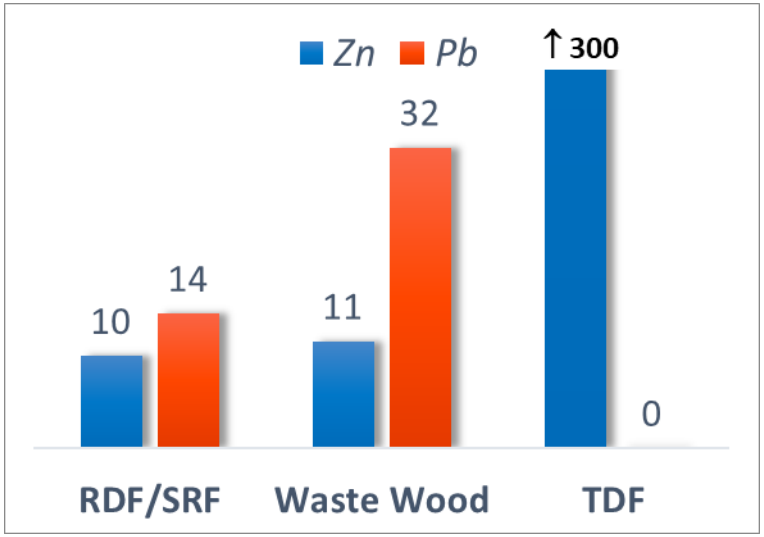
Waste as fuel

Corrosive elements vary greatly among wastes







- Figures show relative ratio of corrosive elements in different wastes as compared to virgin wood levels
  - The results are based on SFW chemical analysis database.
- Corrosive environment induced primarly by chlorides of alkali and heavy metal elements

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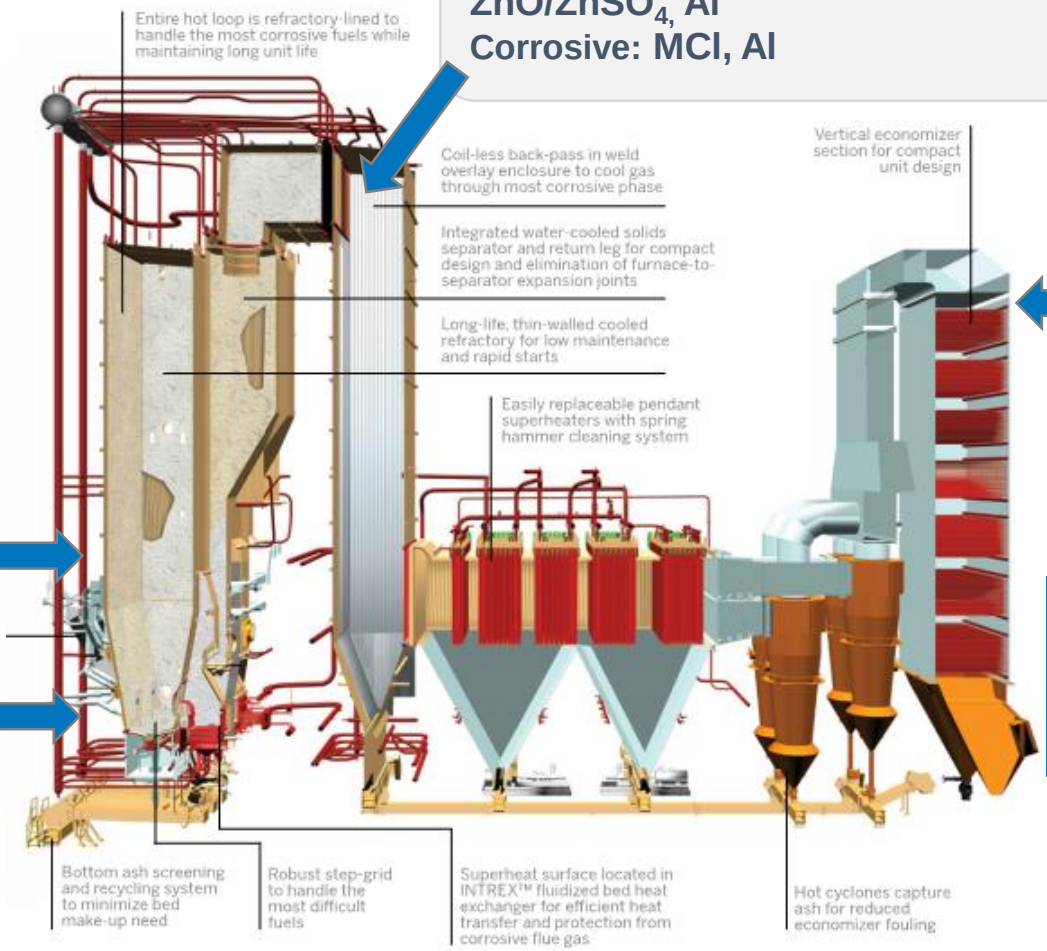
Waste as fuel

Corrosive and fouling compounds form and decompose along flue gas path

M = Na, K

Fouling: MCl, M_2SO_4, CaO, $CaSO_4$, PbO/$PbSO_4$, ZnO/$ZnSO_4$, Al
Corrosive: MCl, Al



Corrosive: MCl $PbCl_2$

Corrosive: $ZnCl_2$

Fouling and corrosive: MCl, $PbCl_2$, $ZnCl_2$, $CaCl_2$

Deposits always contain mixed salts, however, to simplify we talk in terms of pure compounds

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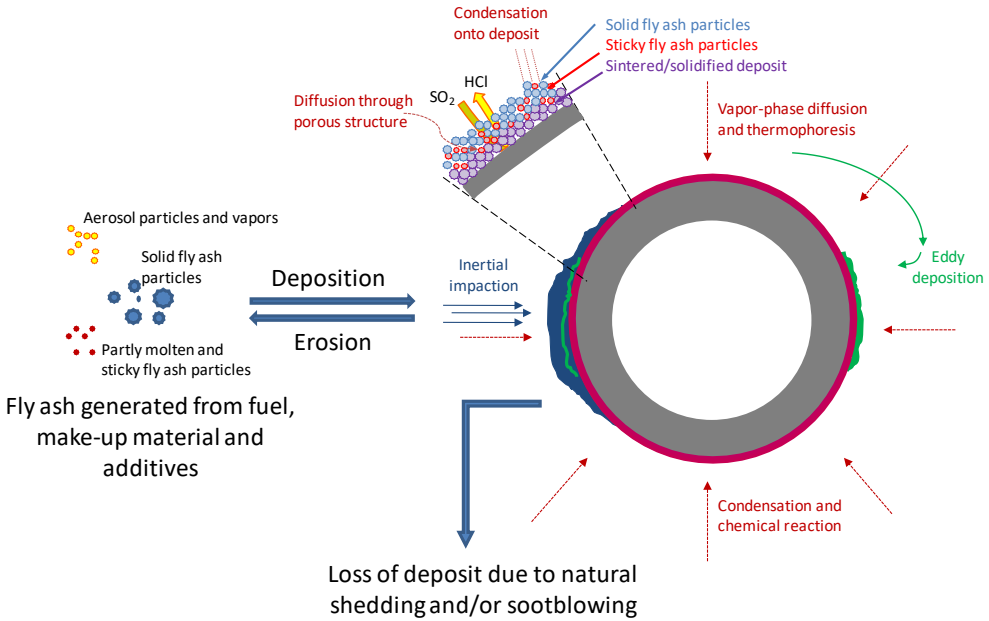
Waste as fuel

Mechanism of fouling and corrosion

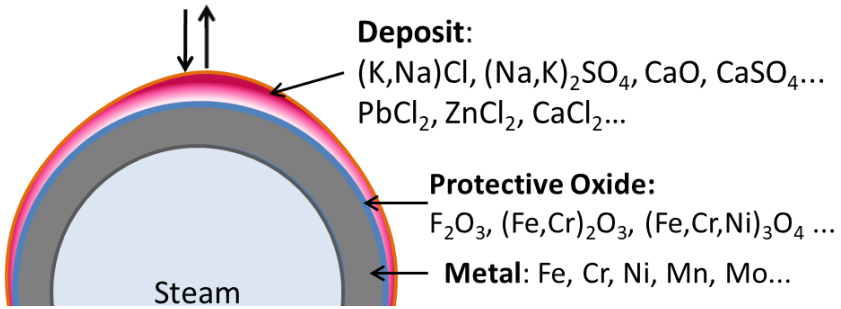
Fouling



Deposition is governed by:
- Concentration in flue gas
- Flue gas temperature
- Metal surface temperature
- Velocity of impact

Corrosion

Flue gas: H_2O, O_2, CO_2, CO, HCl, SO_2, NO_x...



Corrosion may proceed via:
- Active oxidation
- Destruction of protective oxide layer due to depletion in chromium by water and/or alkali chlorides, carbonates
- Electrochemical mechanism
- Simultaneous chlorination by KCl(s) and HCl(g)
- Formation of molten species

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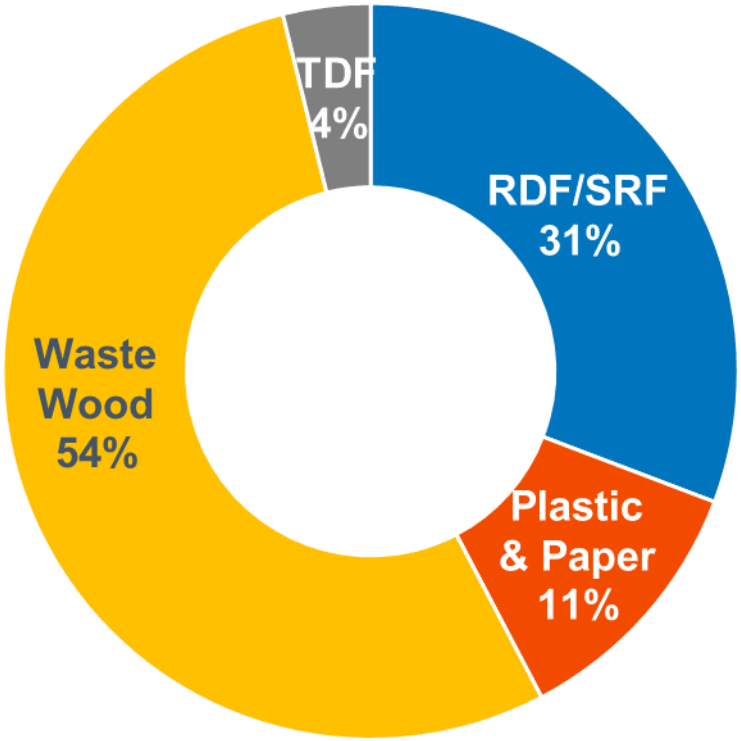
Our Waste to Energy CFB experience

We have a long experience firing Waste in CFBs

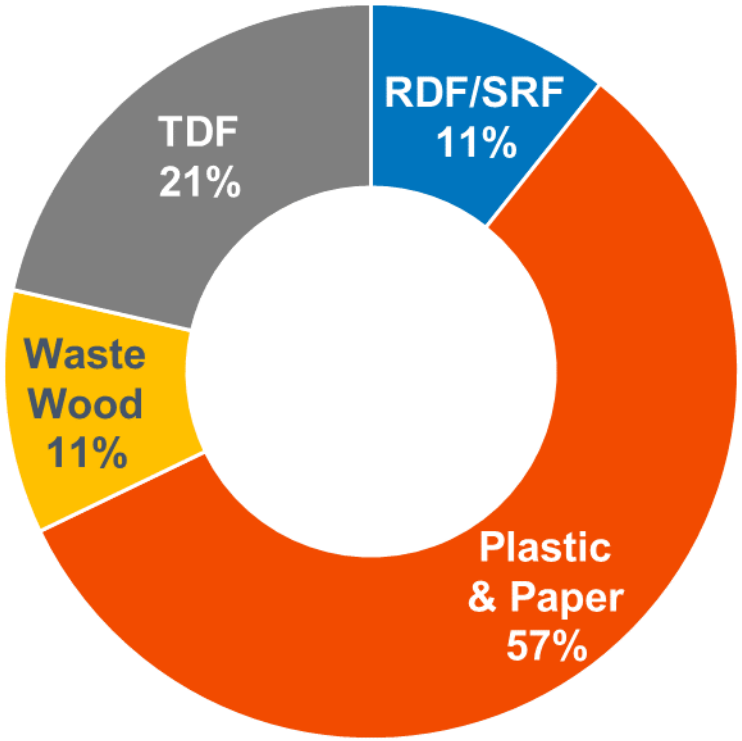
26 (632 MWe) SFW CFBs firing 100% waste fuels



Source: GRDS 24OCT19, CFBs firing waste as primary fuels for all years. Market share based on steam production converted to electric capacity GWe.

Pulp and Paper Sludge excluded

28 (1.5 GWe) SFW CFBs co-firing waste fuels



Source: GRDS 24OCT2019, CFBs co-firing waste as secondary fuel with other fuel types like coal, lignite, etc. for all years. Market share based steam production converted to electric capacity GWe.

Pulp and Paper Sludge excluded

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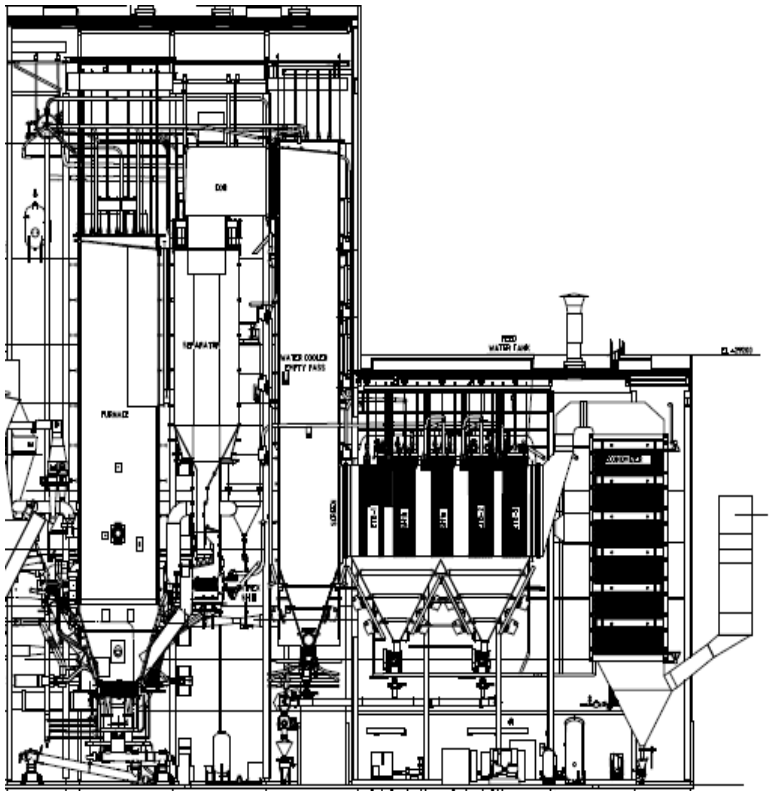
Features of Our WtE CFB Boiler 1(2)

- Fuel feed with inclined conveyor, fall duct and sweep air
  - 2 x 100 % or 3 x 100 % feed lines
- Step-Grid
  - even surface, no upcoming nozzles
  - large size removal slots for scrap and lumps
- Combustion chamber is evaporation surface
  - refractory lined
  - residence time 2 s > 850 °C
  - excess air ~40 %
- Water cooled cyclones
  - evaporation surface
  - lined with thin 30-50 mm castable refractory
- INTREX–final superheater
  - Protected by Chlorine attack in flue gas
  - Allows rapid change, possible in 3 days
- Bottom ash
  - sieving and partial recycling



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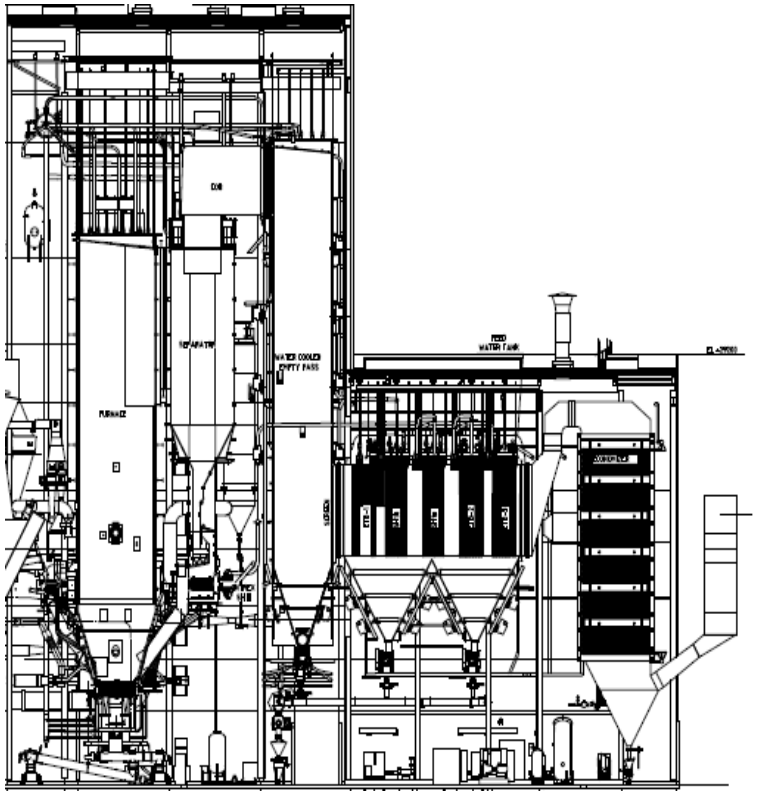
Features of SFW WTE CFB Boiler 2(2)

- Empty pass (evaporator) to reduce the gas temperature to ~650°C
  - Spring hammers & Water cannons for cleaning
- Hanging evaporator (forced circulation)
  - Spring hammers for cleaning
- Hanging superheater SH1
  - Spring hammers for cleaning
  - Steam temperature limited to max 380°C out
  - Low gas velocity
- Evaporator and SH -surfaces changeable by mobile crane
  - Identical SH –packages
- Economizer
  - Steam soot blowers for cleaning
  - Water side by-pass concept



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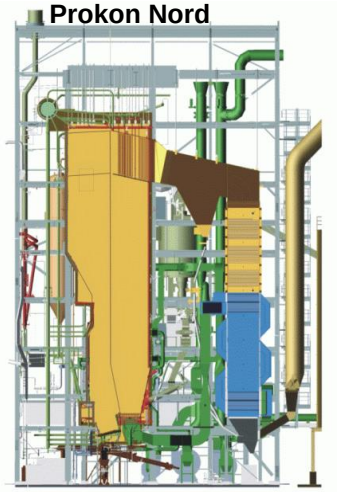
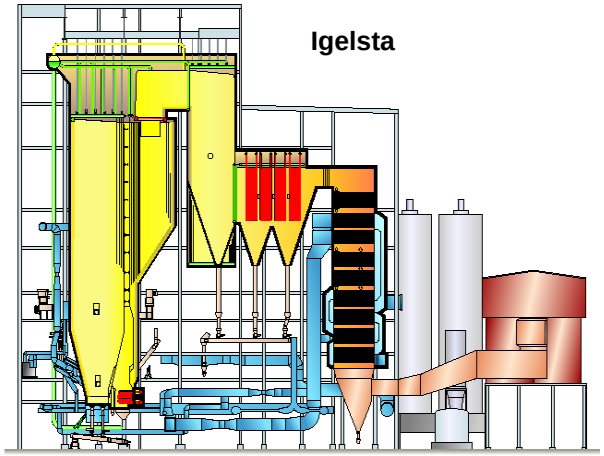
We offer multiple CFB Designs for Waste Fuels and Biomass

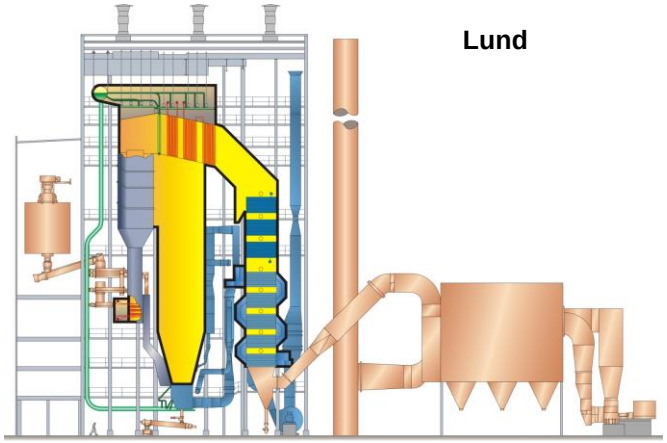
Prokon Nord



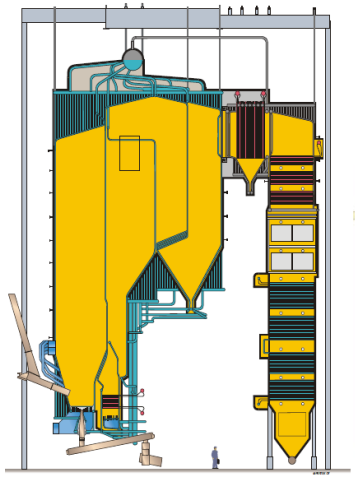
Igelsta



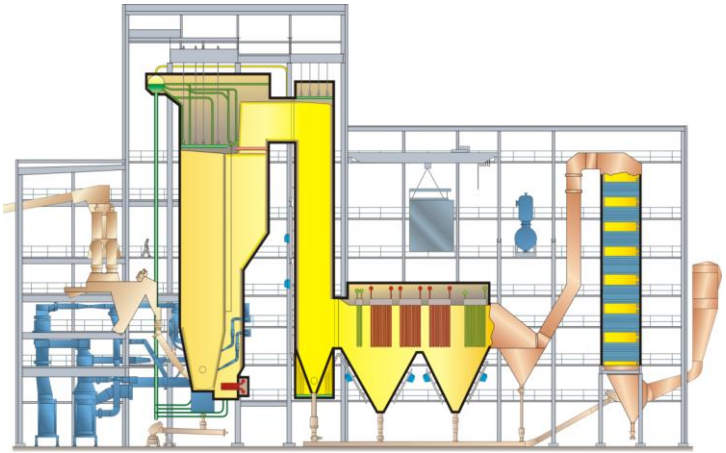
Lund



Högdalen



E.ON Händelo P15



Mälarenergi

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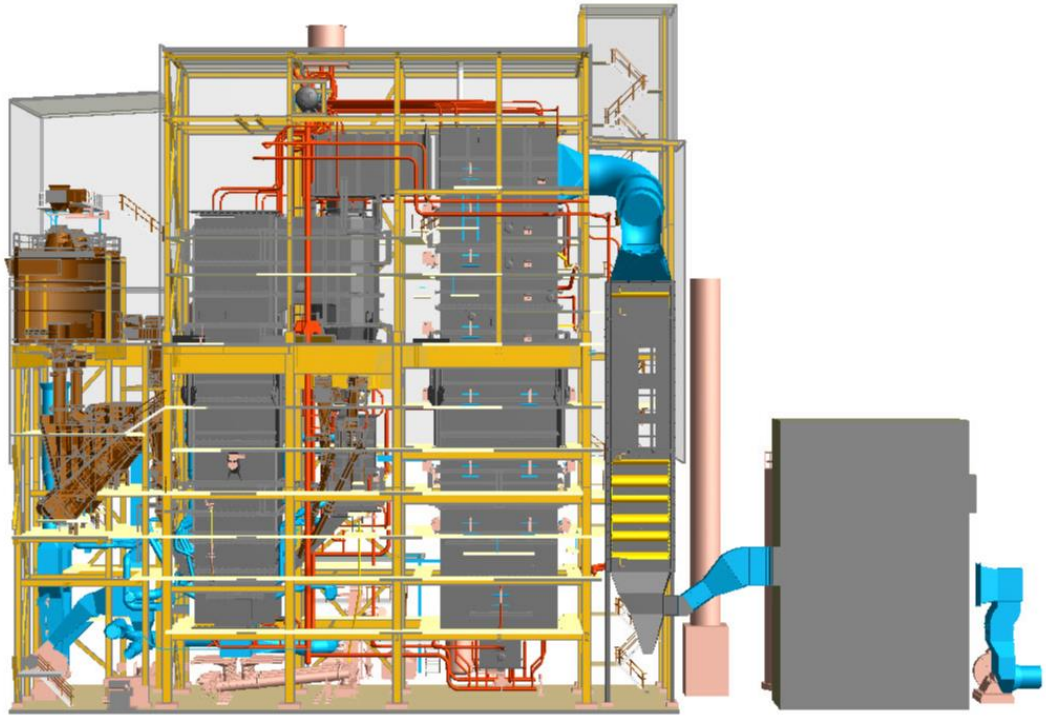
Latest CFB for P&P Industry: Cheng Loong Corporation (CLC), Chupei Mill, Taiwan

19 MW_e, 25 kg/s (90 t/h), 60 bar(a), 450 °C



CFB DESIGN FEATURES

- Refractory-lined furnace
- Step grid for effective discharge of solid impurities
- Water-cooled high-efficiency separator
- Final SH in INTREX
- Empty pass before convective heat exchangers

FUEL DATA

Paper mill rejects (fluffy and pelletized RDF)	30–100 %
Paper mill sludge	0–28 $\%_{wt}$
Coal	0–70 %

SCHEDULE

Contract Award	July 2019
Commercial Operation	July 2021

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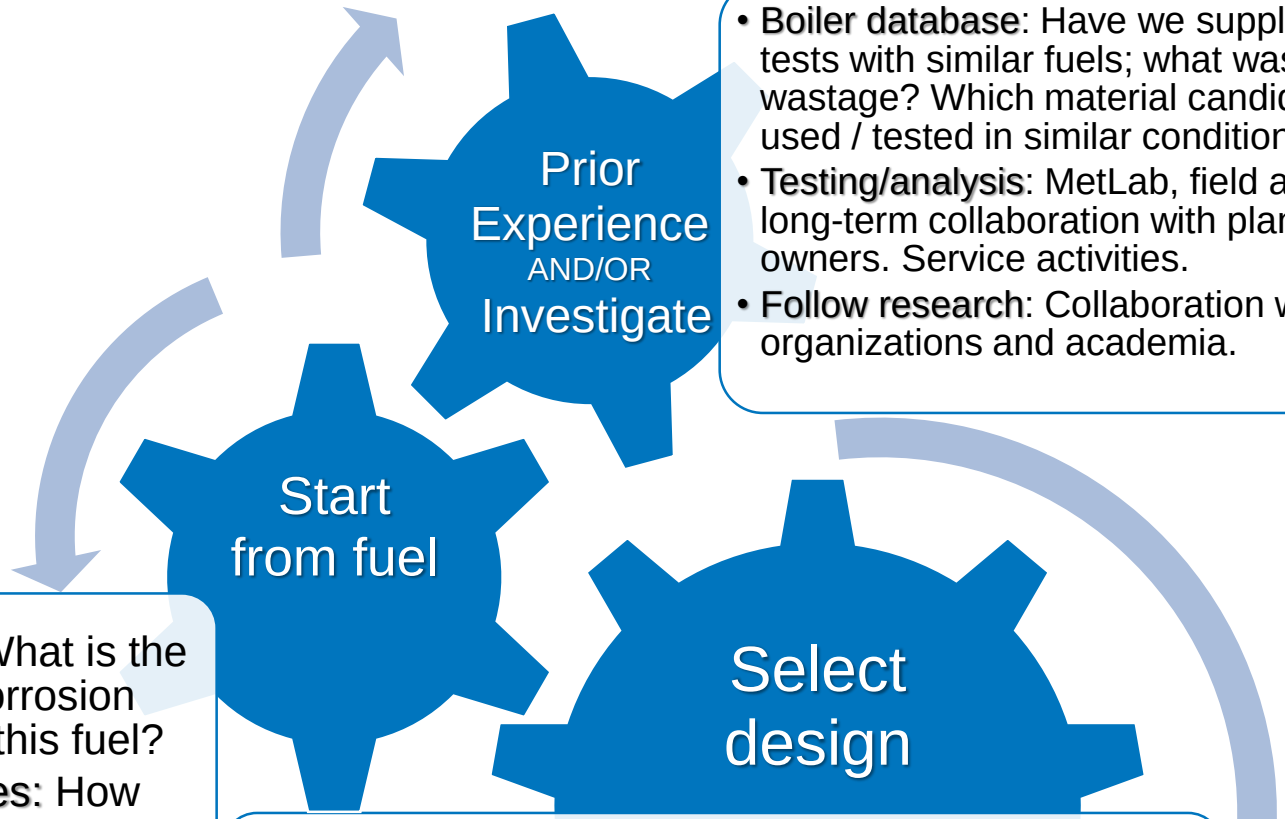
Material selection and estimating corrosion risk

- SFW models
- SFW databases
- MetLab - physicochemical analysis of metal and deposit samples
- Field exposures and collaboration with utilities
- Keeping up-to-date with on-going research elsewhere- networking with academia

Material selection and estimating corrosion risk



- **Boiler database**: Have we supplied boilers or run tests with similar fuels; what was material wastage? Which material candidates have we used / tested in similar conditions?
- **Testing/analysis**: MetLab, field and pilot testing, long-term collaboration with plant and pilot owners. Service activities.
- **Follow research**: Collaboration with research organizations and academia.

- **Fuel model**: What is the fouling and corrosion probability of this fuel?
- **Fuel databases**: How this inquiry compares with known fuels?

- Design tools: Material & Energy balance, temperature and velocity profiles, strength calculations, steam oxidation
- **Corrosion rate model:** What is corrosion rate with selected boiler design?
  - Material selection for targeted CAPEX/OPEX

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SFW models for assessment of material selection

Fuel model supports evaluation of corrosive property of fuel(s)

- Number of elements which are key players
  - > 10: Na, K, Ca, Mg, Fe, Al, Si, P, S, Cl, (Ti, Zn, Cu, Br)
- Form of active elements
  - KCl, K_2SO_4, K-organic, K-aluminosilicate
  - Organic Si, quartz, inert silicate
- Ratio of elements
  - Ca>K, Ca>S, S>Cl, etc.
- Change of compounds properties with T
- Complex interactions among ash-forming elements, plus not all of relationships are known

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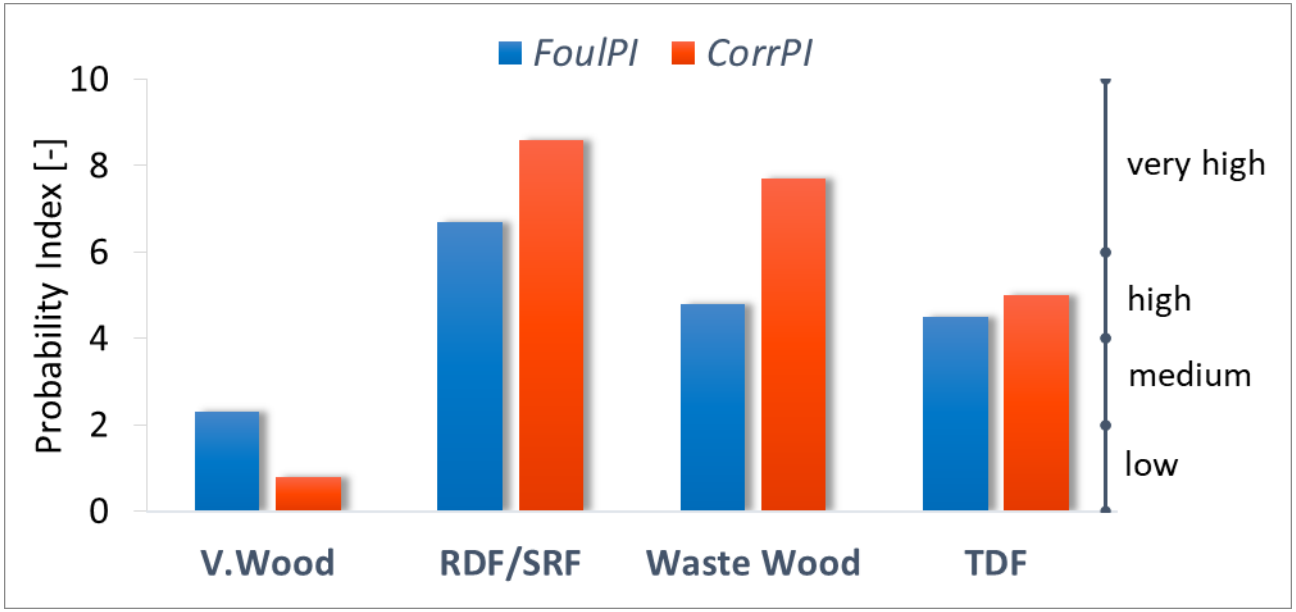
SFW models for assessment of material selection

Fuel model generates corrosion probability index

- Semi-empirical computer tools
  - Theory combined with empirical correlations. Correlations derived from SFW's experience and thermodynamic considerations.
  - Probability index ≠ Rate
  - The model describes fuel propensity towards fouling and corrosion and does not take into account specific boiler design and operational parameters.
  - Input to fuel model is detailed fuel composition including SFW chemical fractionation. Model result, CorrPI, is used as an input for corrosion rate model.



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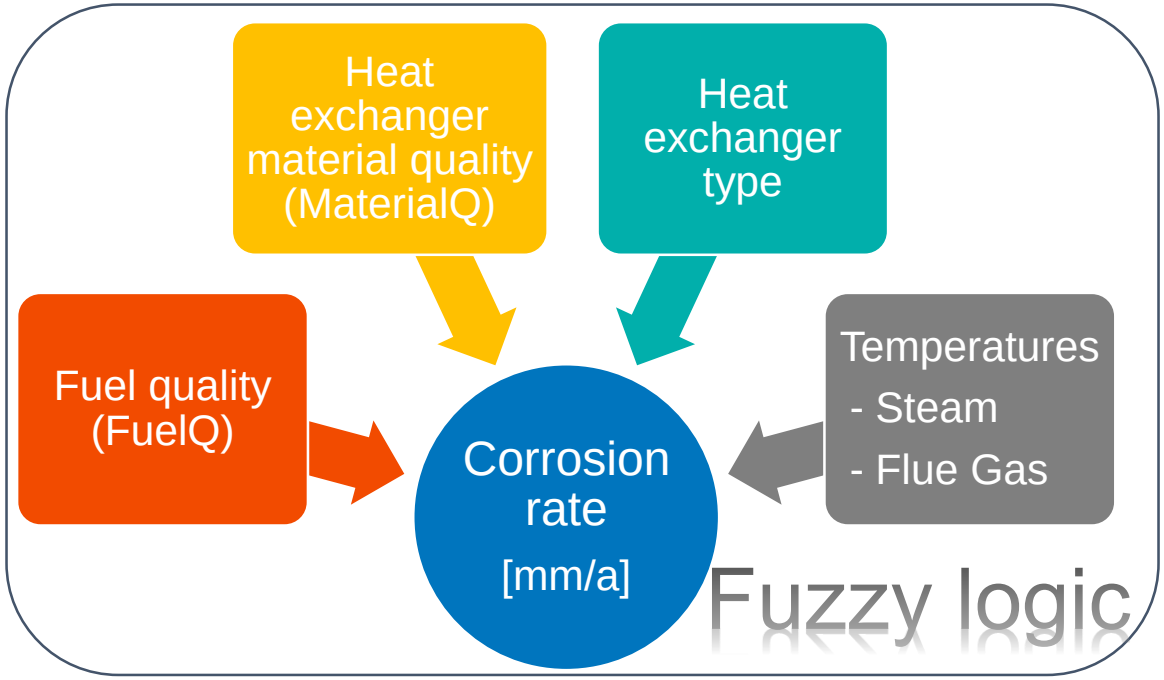
SFW models for assessment of material selection

Corrosion model estimates corrosion rate for selected heat exchanger design

- SFW model to estimate corrosion rate of heat exchangers is developed since ‘90s for large variety of fuels and fuel mixtures including waste and biomass.



- Corrosion rate model is used to support material selection in:
  - New proposals
  - Operating units for planned changes and modifications of existing heat exchangers, for example, due to shift to new fuel diet or boiler operation

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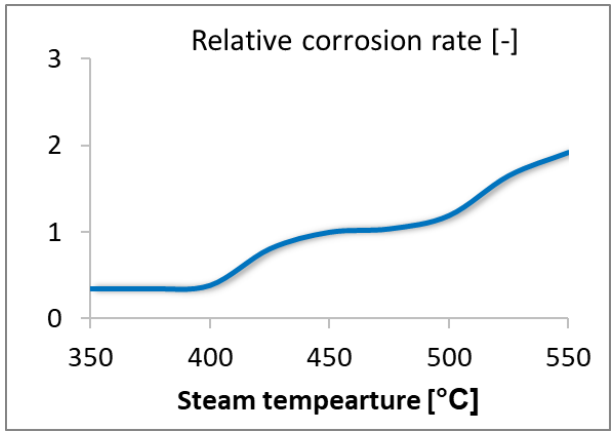
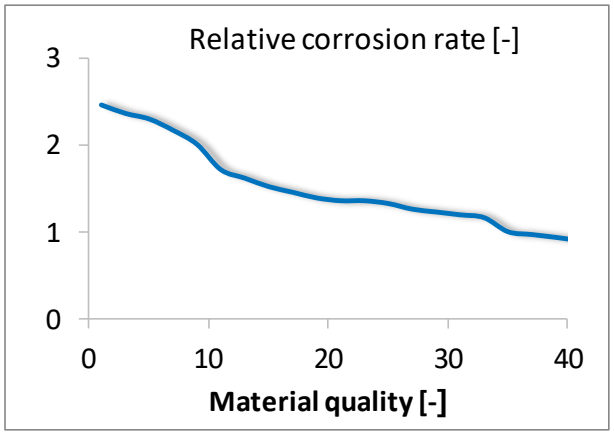
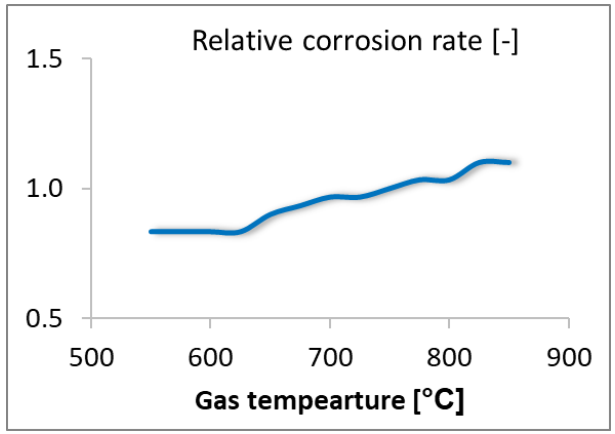
SFW models for assessment of material selection

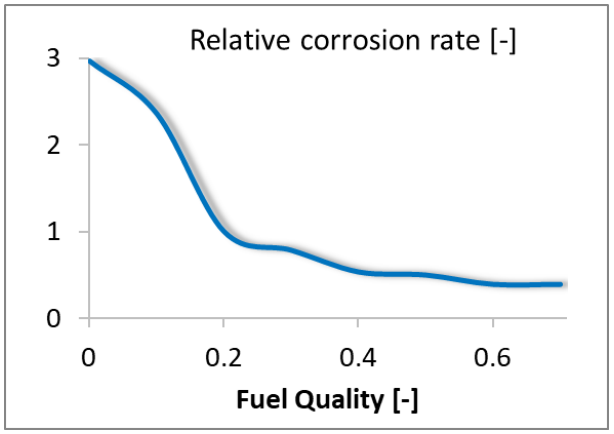
Corrosion rate model is used to fine-tune heat exchangers design

- Extensive sensitivity analyses are conducted to verify the effect of changes in:
  - process conditions (e.g. steam & flue gas temperature)
  - materials selection (material quality)
  - fuel/fuel mixture (fuel quality)









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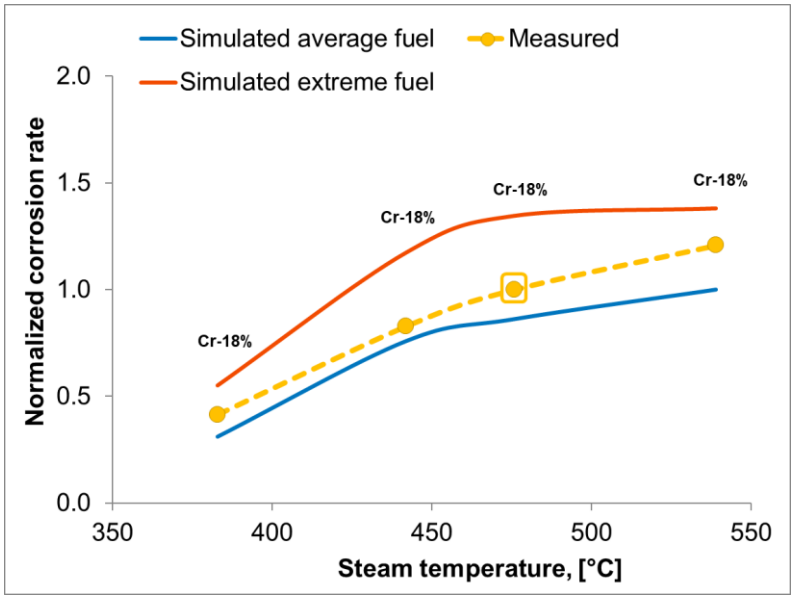
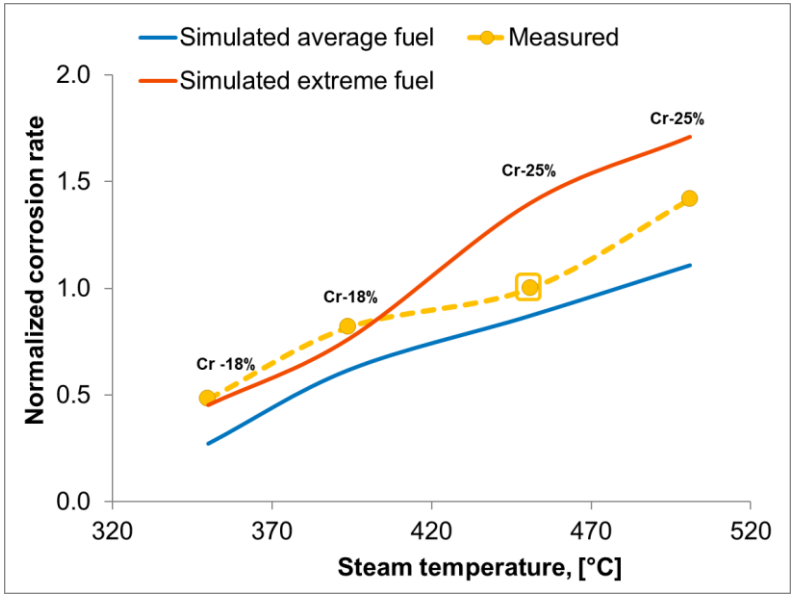
SFW models for assessment of material selection

Model performance is validated against wall thickness measurments

Case 1: CFB (<100 MWe)
Forest residues plus recycled wood



Case 2: CFB (<100 MWe)
Recycled wood



- Measured corrosion rates were within range simulated for average and extreme fuel qualities
- In both cases simulated corrosion rate was on medium level, which was verified by the measurements
- Model suggests that fuels with quality lower than average were occasionally fired

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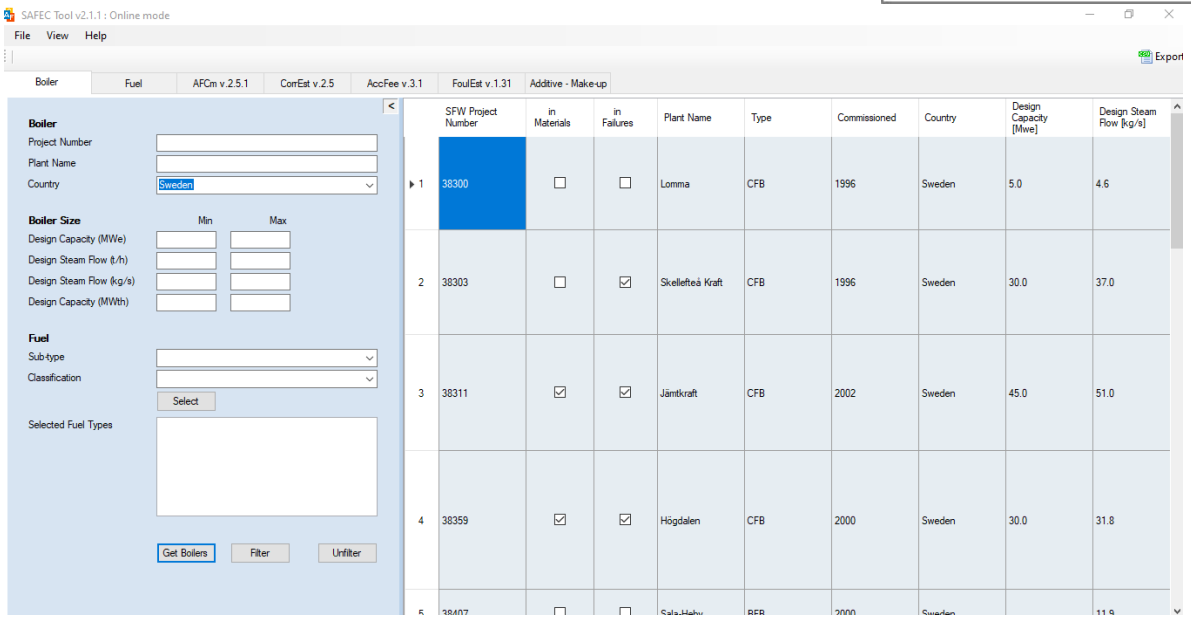
SFW tools for assessment of material selection

Models are connected to databases to retrieve experience data

- Fuel and corrosion model are linked to SFW databases with dedicated queries to
  - Boiler database:
    - Tests: ~2,200 tests in ~245 CFB units
    - Failure analysis: ~555 in 66 units
    - Wall thickness measurements:
      ~185 sets from ~50 FB
  - Fuel database:
    - Biomass ~1500 samples
    - Waste ~1000 samples



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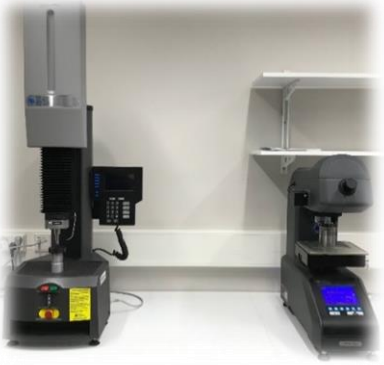
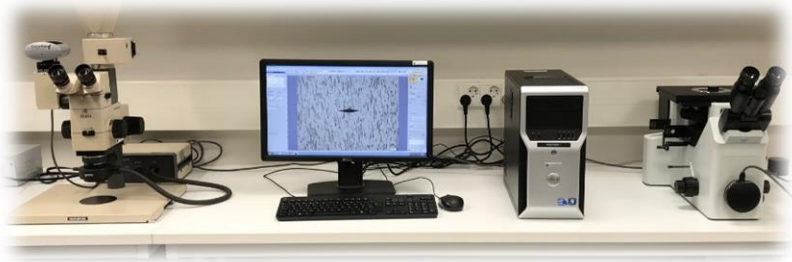
SFW Metallurgical laboratory

Physicochemical analysis of metal and deposit samples

- Metallurgical laboratory established in 1950s, today located in Varkaus
- Laboratory equipment includes:
  - Sample preparation equipment
    - Band Saw & Cutting Wheel, Mounting Press, Grinders & Polishers etc.
  - Hardness Testers
    - Vickers, Knoop & Brinell
  - Stereo & Optical Microscopes
  - XRF (Epsilon 3-XL)
  - Scanning electron microscope (Quanta FEG 450)
    - Detectors: EDS, WDS, EBSD





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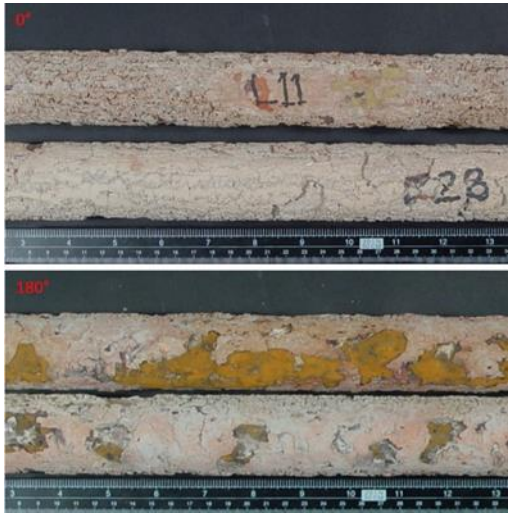
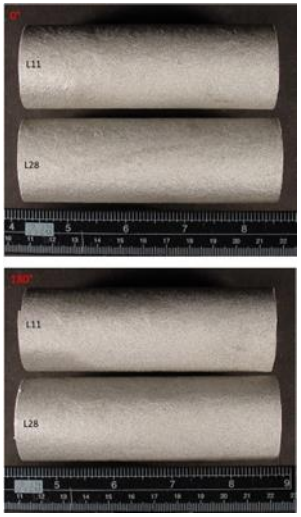
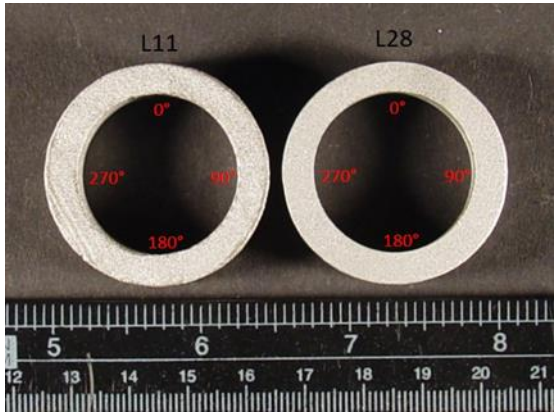
SFW Metallurgical laboratory

Case study: How corrosive is this deposit?

- Convective superheater in CFB co-firing recycled wood and forest residue
  - Macroscopic pictures show flaky deposit
  - Tube surface after grit blasting shows minor pitting
  - Wall thickness loss relatively small







Tubes with deposit → Tubes after grit blasting → Cross sectional measurement of wall thickness

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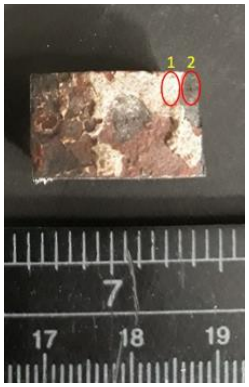
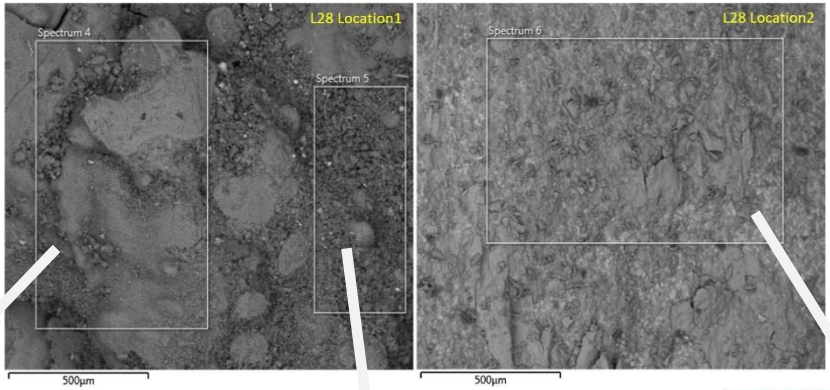
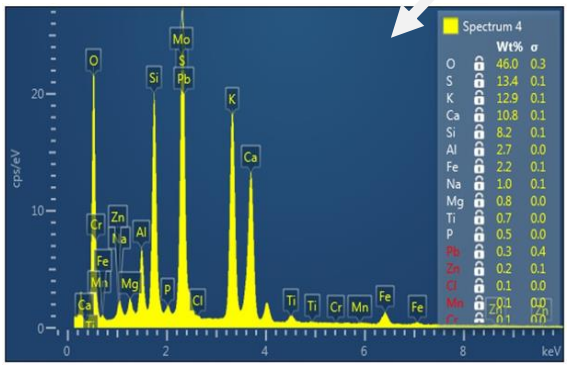
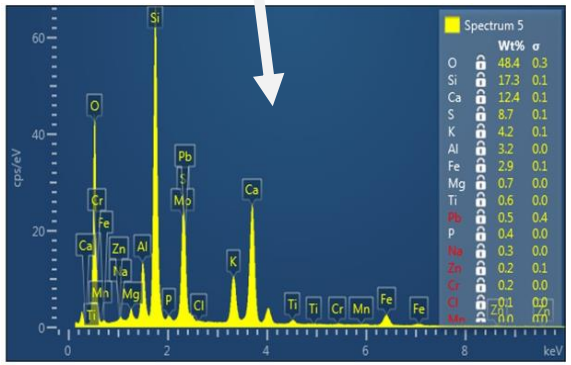
Case study: What is composition of the deposit?

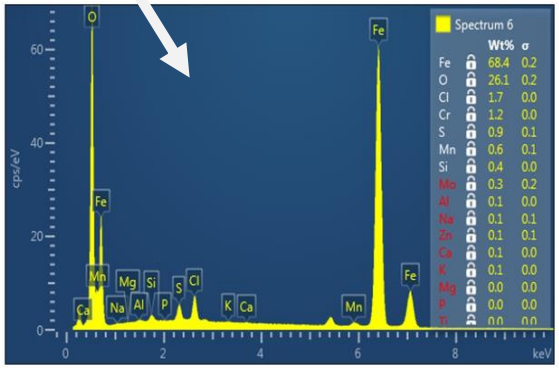
- Convective superheater in CFB co-firing recycled wood and forest residue
  - SEM/EDX analysis shows that deposit consists mainly of oxygen, sulfur, potassium, calcium and silicon. Chlorine found on tube surface explains signs of corrosion.











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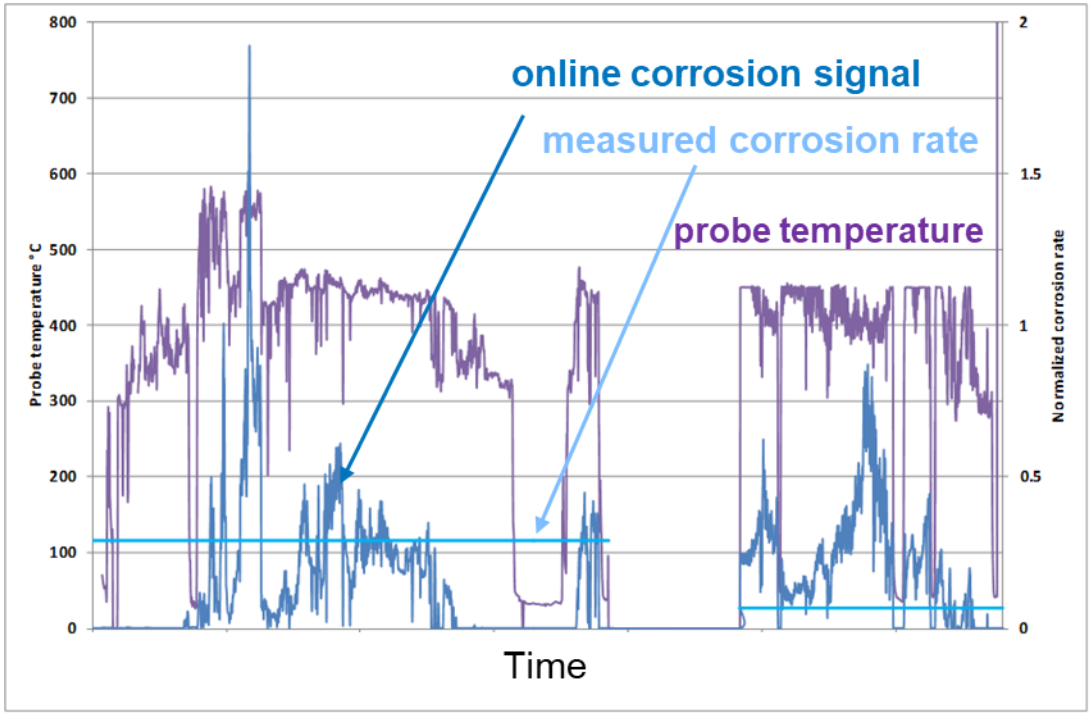
From R&D to service activities

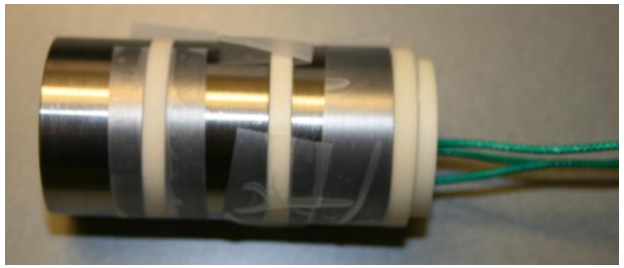
- In addition to R&D work SFW Metallurgical laboratory supports SFW Service organization by offering:
  - Failure analysis
  - Corrosion evaluation
  - Quality control
  - Entities outside SFW can buy laboratory services through SFW Service organization

Field exposures

Measuring corrosion rate by MECO-system

- Example: CFB firing fuel mix containing forest residues, recycled wood and RDF pellets
- 12 months + 10 months measurement periods
- Materials:
  - W1 18% Cr steel, W2 11% Cr steel
- Good correlation between online measurement and corrosion rate calculated from ultrasonic wall thickness measurements of boiler tubes (line level)
- K, S and Na rich deposit, also Cl rich spots found





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Field exposures

Testing new material candidates

Long-term clamp exposures
- convective HXs and Intrex tubes -

New material test tubes
OR
Surface protection by
overlay welding / coating

Short- and long-term fouling probes
- backpass conditions -

Furnace fouling probes

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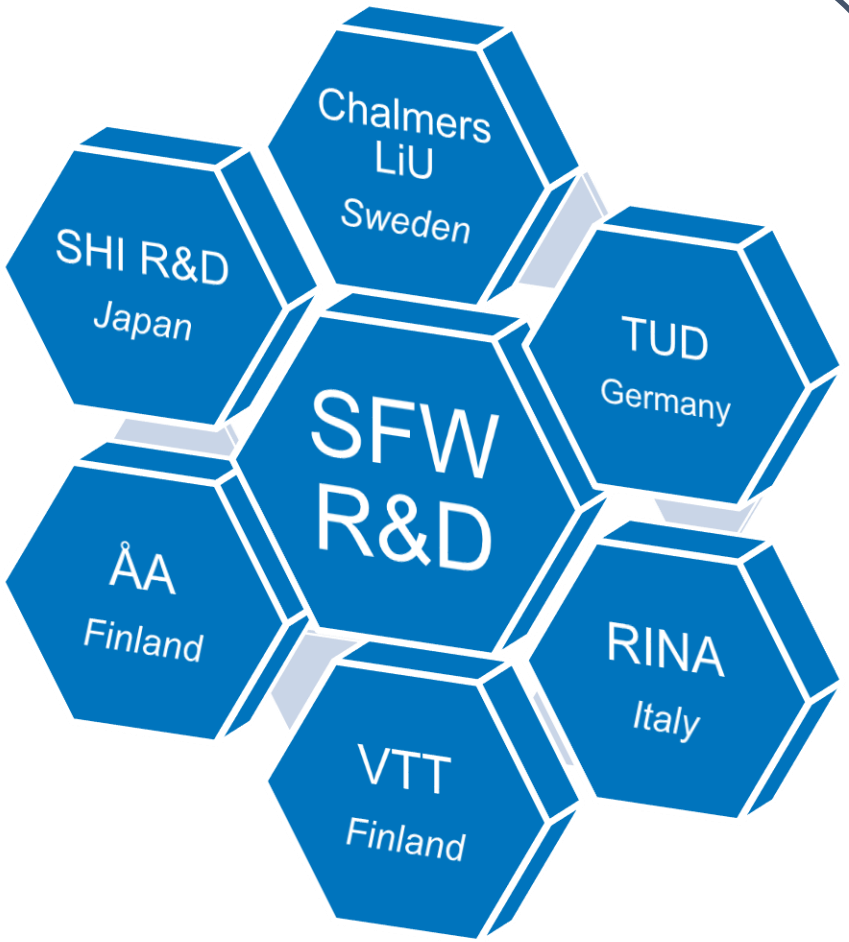
Keeping up-to-date with on-going research elsewhere

Networking with academia and research centers

KME
HTC
EU projects
SFW-funded research



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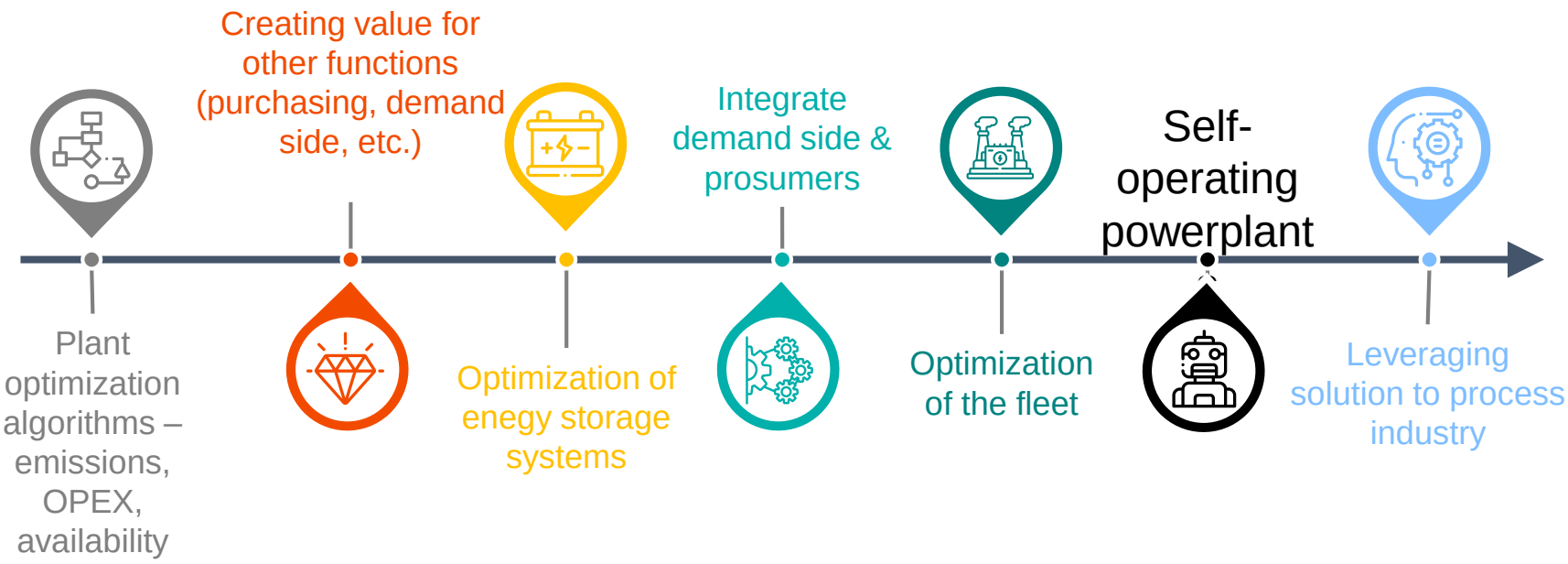
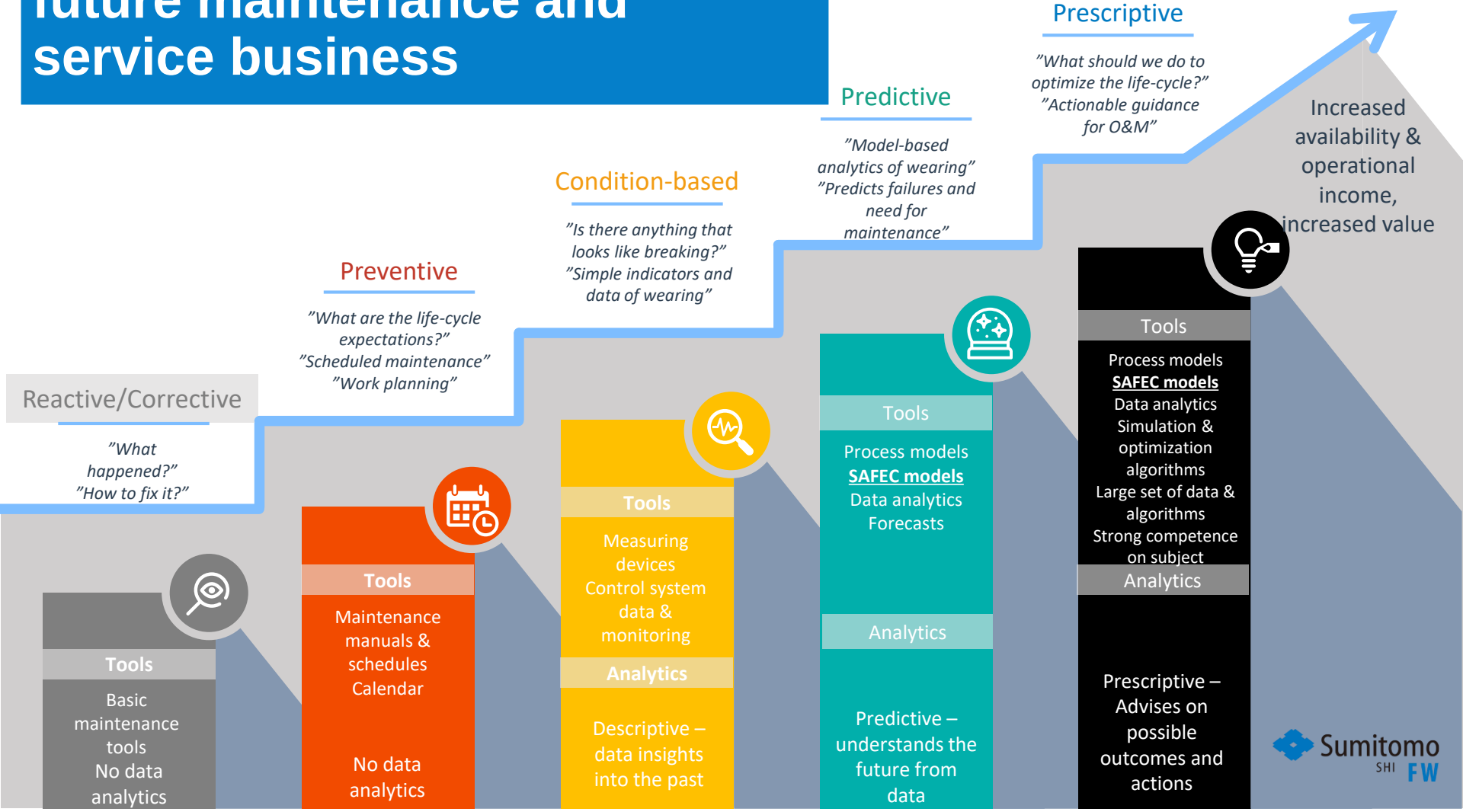
Future in digital services

SFW vision for Digital Services

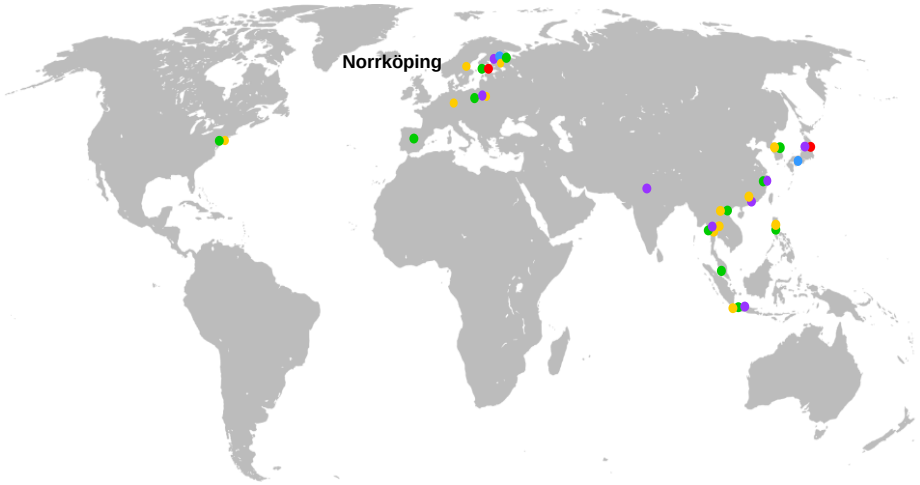
"SFW provides intelligent fleet optimization, while lowering CO_2 emissions and increasing efficiency and safety"



SAFEC model utilization in future maintenance and service business



Kontakta gärna våra kollegor i Norrköping för fortsatta diskussioner



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Thank you!

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