Materials Issues in Co-fired and Oxy-fired Combustion Power Plants

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Materials Issues in Co-fired and Oxy-fired Combustion Power Plants

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Outline

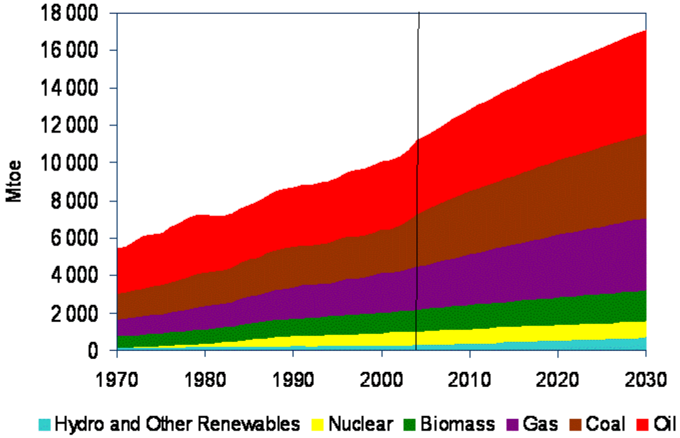
- Background
- Fuels & compositions
  - Coal vs biomass
- Heat exchangers
  - Operating requirements
  - Biomass/coal co-firing
    - Gas compositions
    - Deposit compositions
    - Fireside corrosion
  - Oxy-fuel firing
    - Differences with conventional systems
- Summary

Background

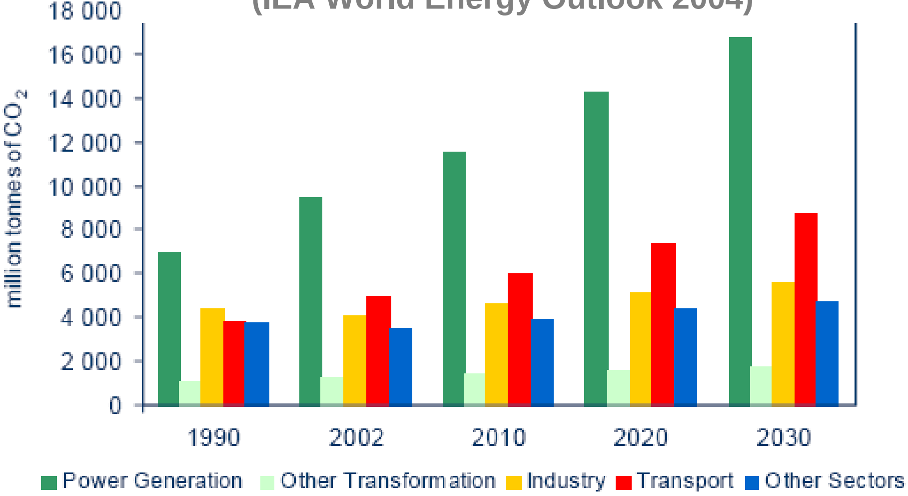
Issues for solid fuel power generation systems:

- Environmental performance
  - CO_2 emissions
  - SO_X, NO_X, particles, …
- Efficiency
- Fuel flexibility
  - Fuel supply
  - Fuel availability
- Cyclic operation
- Reliability, availability, maintainability, operability
- Cost of electricity generated

World Primary Energy Demand by Fuel in the Reference Scenario



Global CO_2 Emissions by Sector: 1990-2030 (IEA World Energy Outlook 2004)



Options for Solid Fuel based Advanced Power Generation Systems

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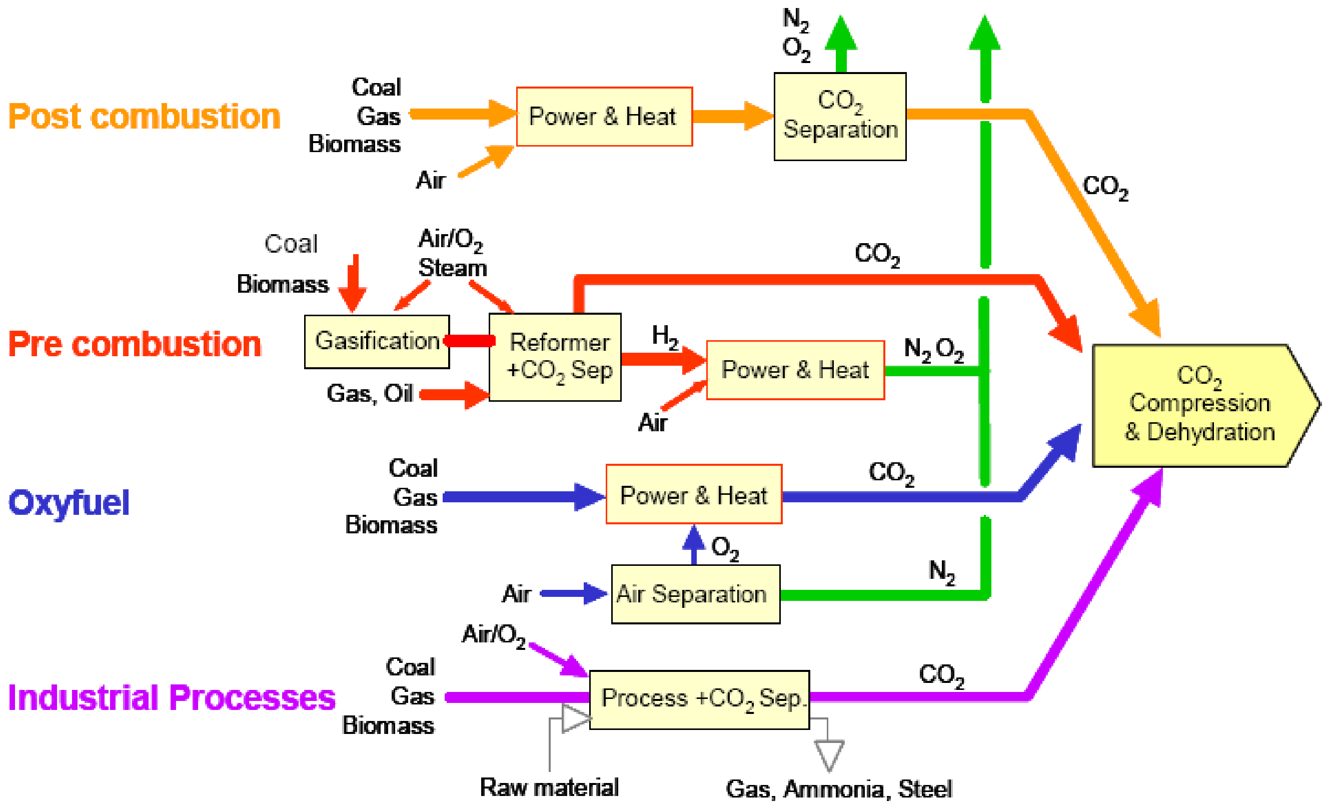
- Increase in generating efficiencies
  - Higher operating temperatures / pressures in steam & gas turbines
- Fuel switching, e.g.
  - Replace coal by natural gas
  - Replace coal with biomass – co-firing
- Capturing and storing CO_2



Carbon abatement approach: Strategic Trajectories (CAT)

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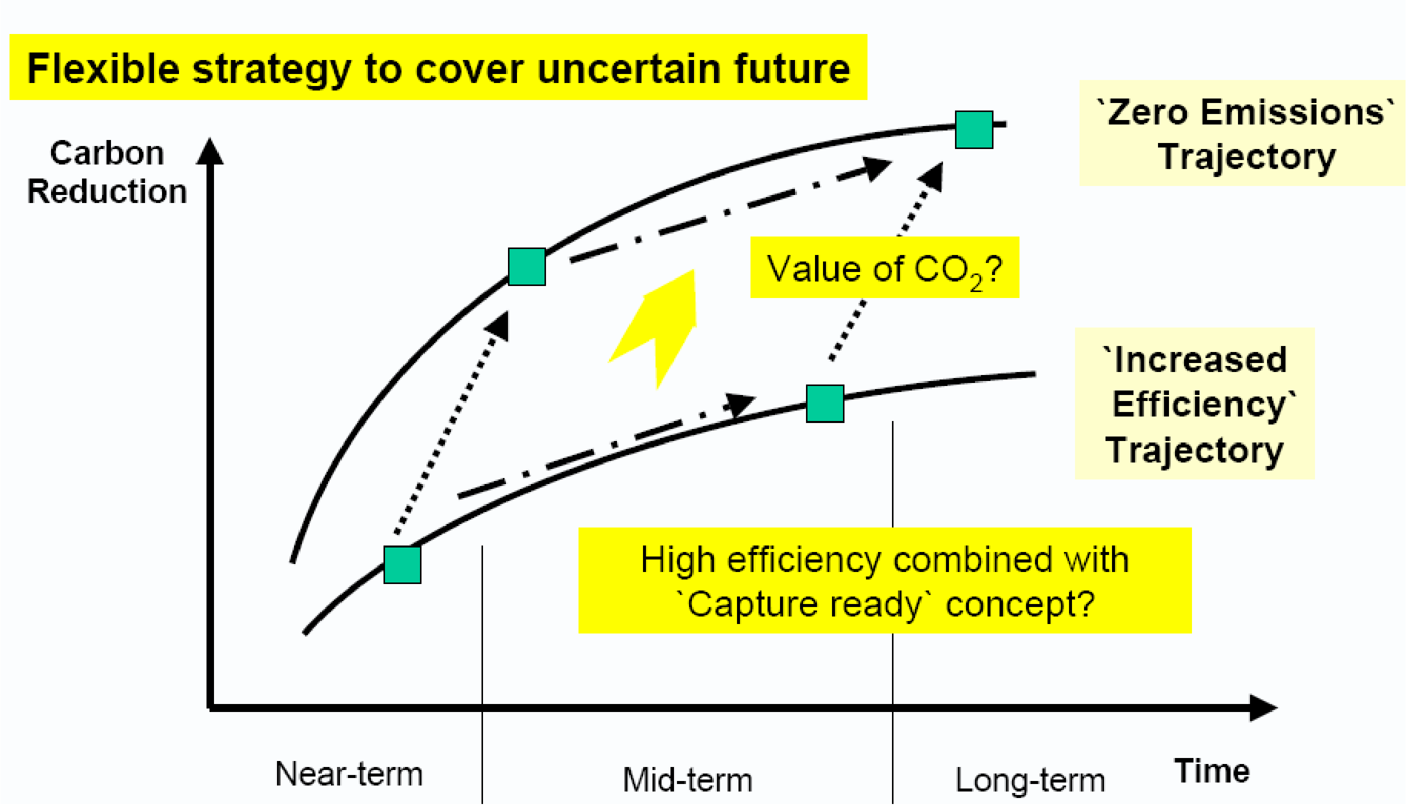

- Track 1 approaches, available now, include improved efficiency by introduction of advanced supercritical boiler/turbine technology and biomass co-firing (substitution of up to 20% of the coal fuel by biomass which is CO_2 neutral).

- Track 2 approach, carbon dioxide capture and permanent underground storage, is necessary to achieve much larger reductions, up to 95%.

Materials Issues in Advanced Solid Fuel Power Generation Plant

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More challenging component operating conditions:

- Higher operating temperatures / pressures
- Cyclic operation
- Wider range of fuels

Resulting materials issues:

- Fireside corrosion / hot corrosion
- Steamside oxidation / scale spallation / erosion
- Dewpoint (aqueous) corrosion
- Creep
- Fatigue (LCF, HCF, TMF, ..)
- Alloy / coating selection

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Potential solid fuels

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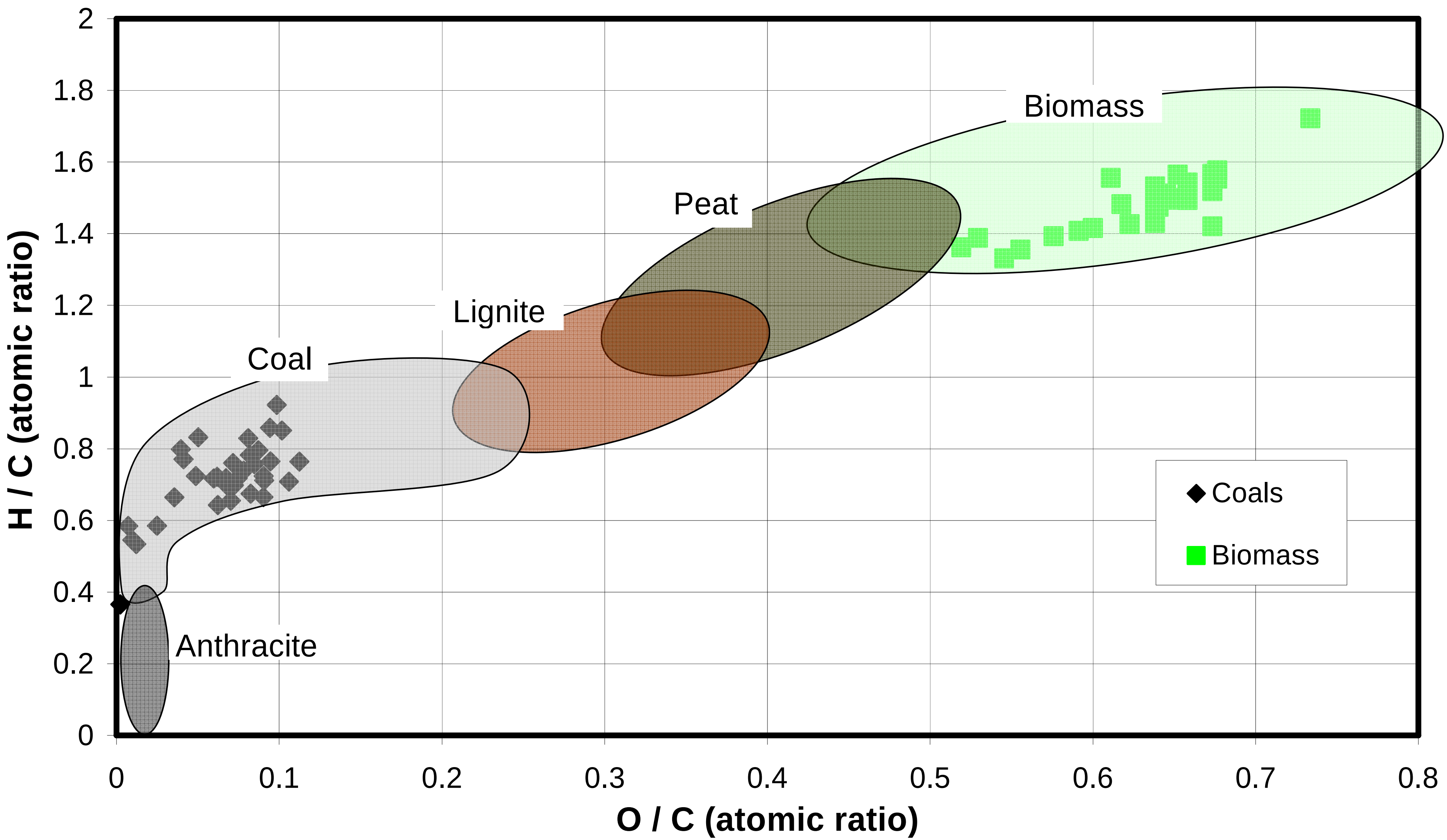
- Coal
  - Locally mined
  - World traded
- Biomass
  - Specifically cultivated biomass (‘energy crops’) - e.g.: coppiced willow, miscanthus
  - Waste biomass – e.g. straws, wood waste, forestry residues
  - World traded biomass – e.g. palm nut / olive / almond residues, pelletised wood, cereal co-product (CCP)
- Waste
  - Sewage sludges; animal wastes
  - Municipal solid waste (MSW)
  - Refuse derived fuel (RDF)
  - Solid recovered fuel (SRF)

Relationships between C, H & O for solid fuels



Cl vs S for biomass & coals

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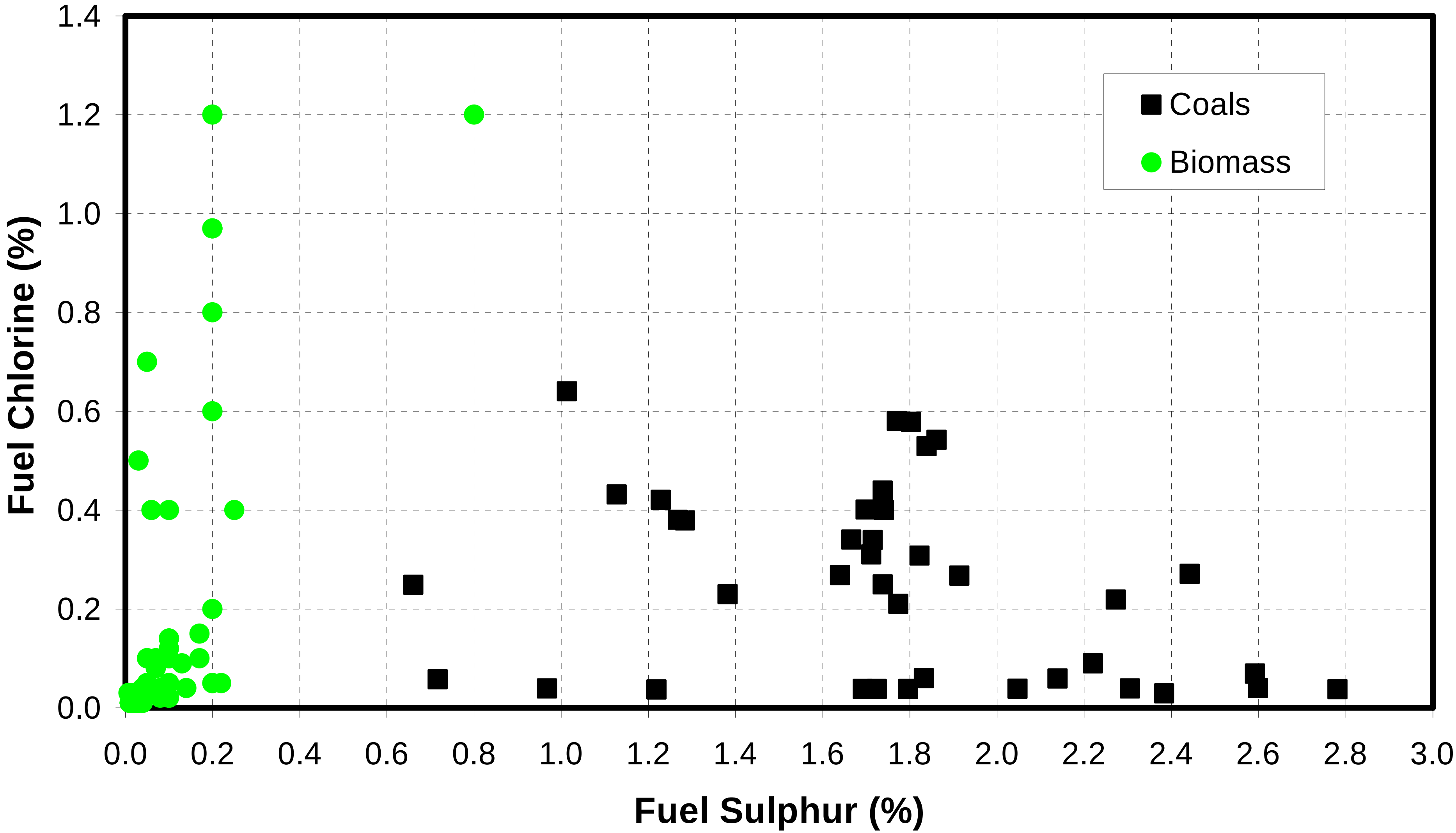
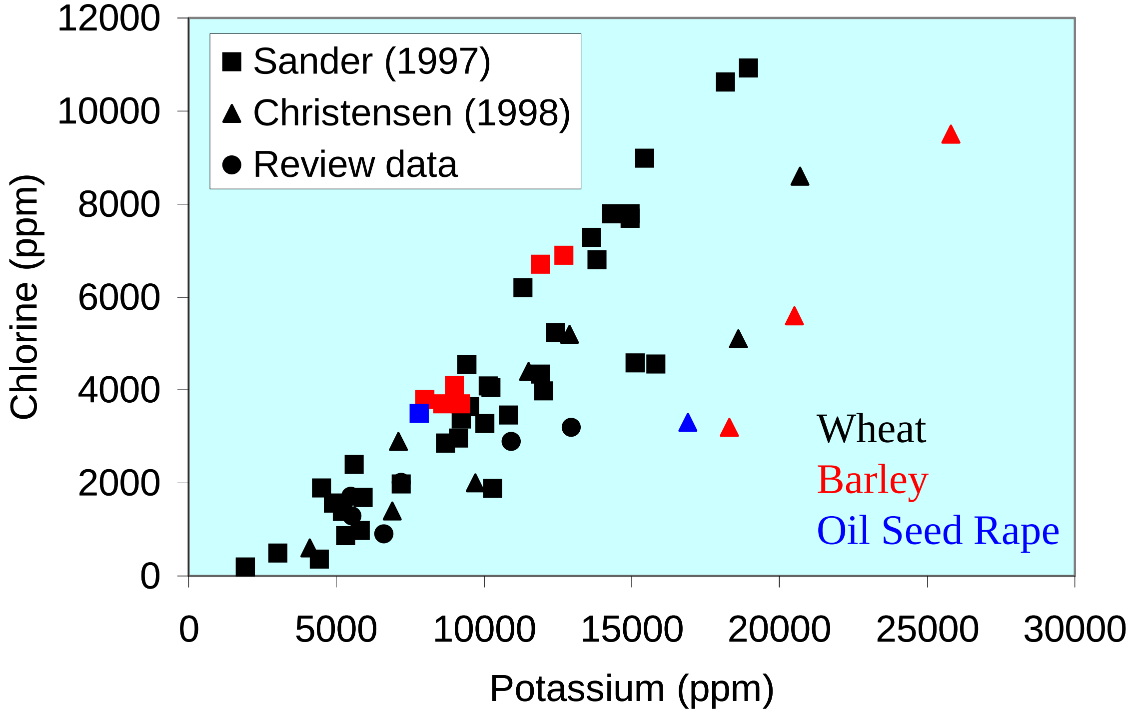


Fuel composition variability



- Biomass
  - Plant types
  - Growth location (country, soil type)
  - Fast vs slow growing
  - Harvest time
  - Post-harvest storage / treatment
  - Batch to batch as-delivered
- Coals
  - Coal type
  - Origin (eg UK vs South America)

Minor / Trace Element Concentrations

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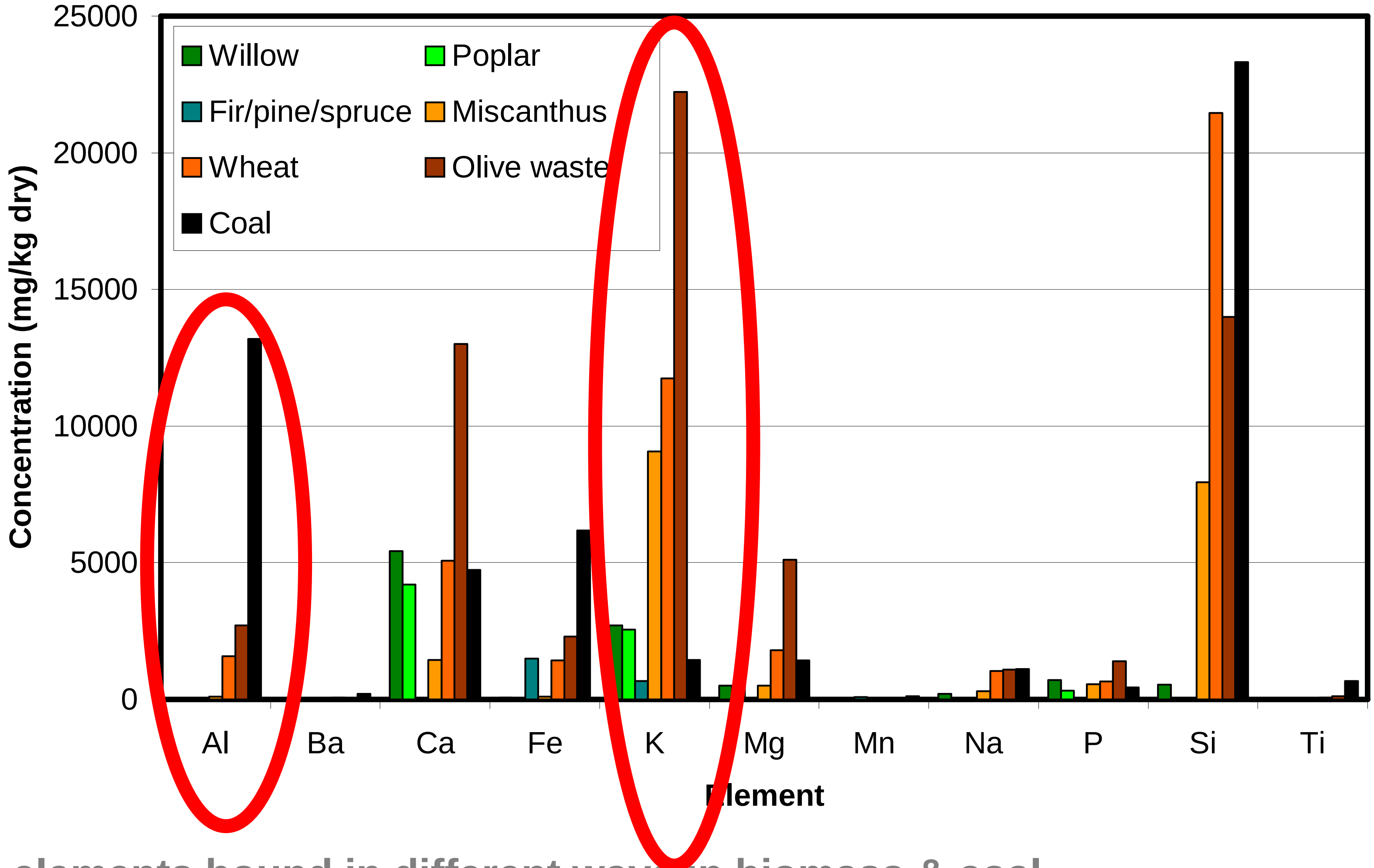

- Also elements bound in different ways in biomass & coal
  - Elements in coal can be bound in stable mineral matter
  - Elements in biomass more readily releasable (water / acid solubility)

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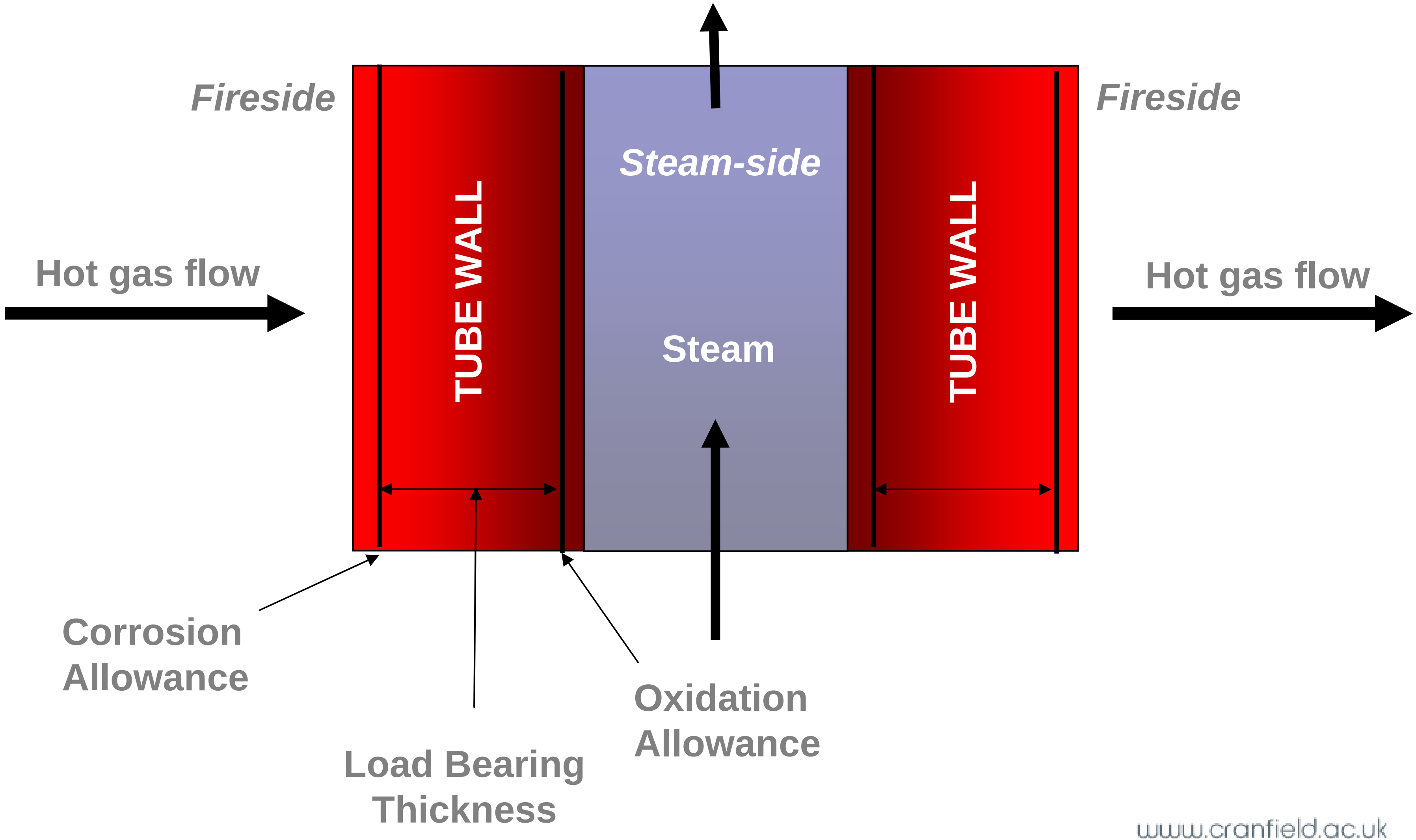
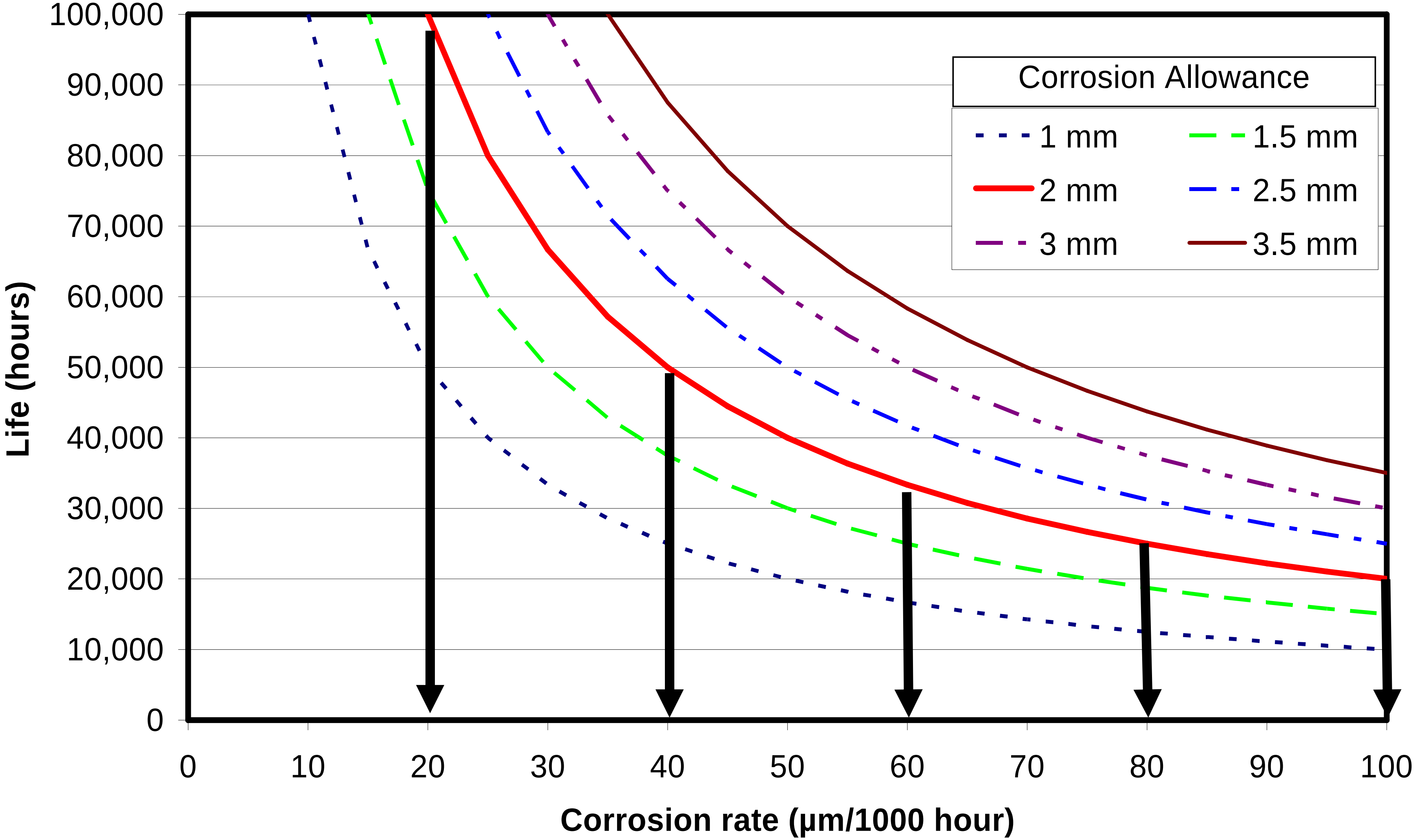
PULVERISED FUEL SYSTEMS

- Coal-fired
  - Older plants ~540-560°C / ~160 bar steam
  - Current plants ~600-620°C / ~290 bar steam
  - Future plants – steam temperatures
    - 650°C - COST
    - 700°C - EU THERMIE
    - 750°C - USA
- Co-fired coal and biomass
  - New fuel compositions/mixes
  - Current and future steam conditions
- Oxy-fuel fired
  - New basic combustion gas composition
  - Current and future steam conditions
  - Biomass co-firing

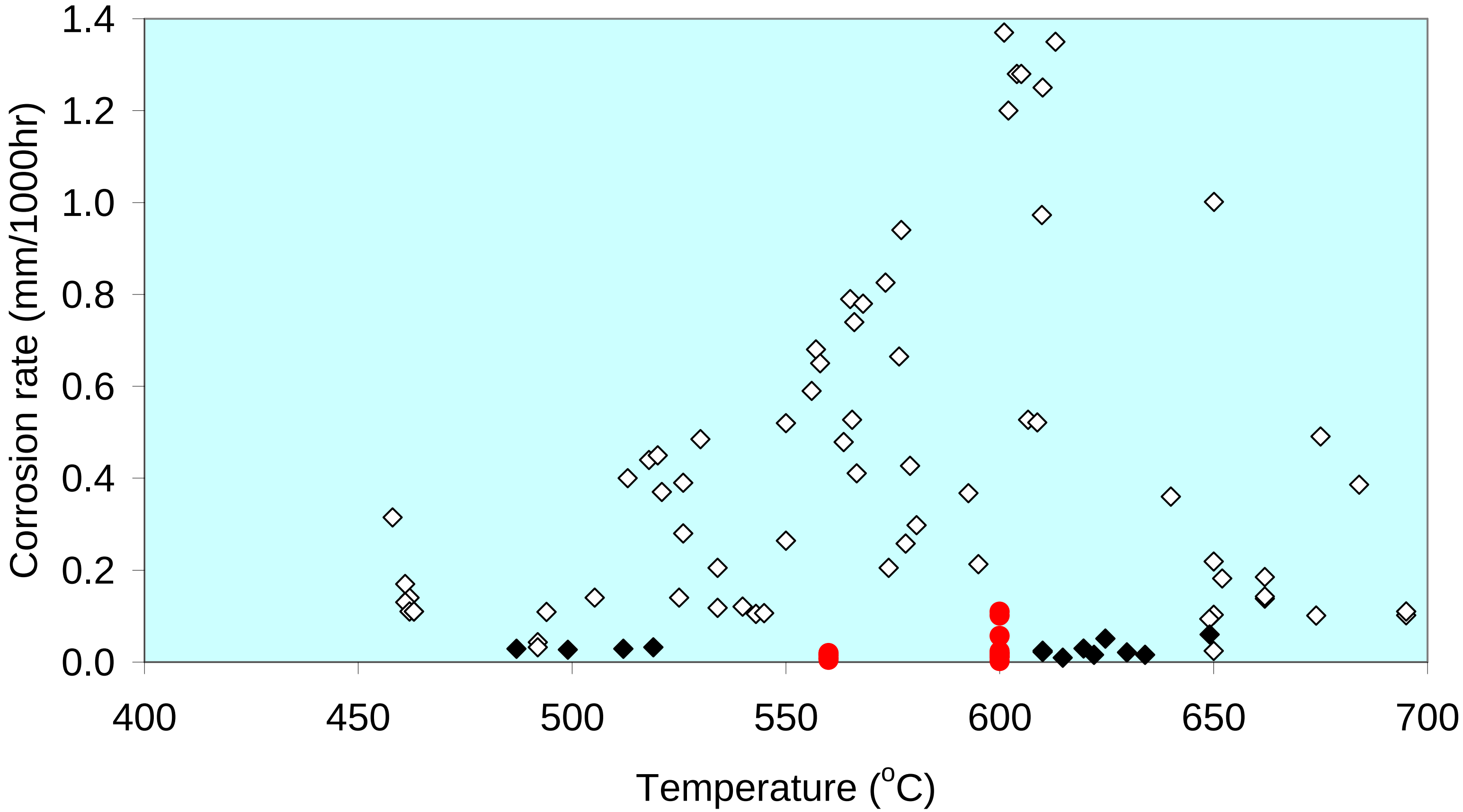
Superheater tubing
– cross-section through tube wall



Heat exchanger life, corrosion allowance, acceptable corrosion rates



Comparison of corrosion data for 347H and 347HFG with coal and straw firing (plant data) and co-firing (pilot plant data) (median data)



Source: COST522 / 538

Plant operating conditions for heat exchanger tubes

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- Fuel: coal / biomass
- Oxidant: air / oxygen
- Gas stream characteristics:
  - Gaseous species – e.g. SO_2, HCl, O_2, CO_2, H_2O, NO_X, N_2
  - Vapour species – e.g. Na, K
  - Particles
    - From ash in fuel
    - Condensed vapour species
  - Gas temperature
- Heat exchanger characteristics:
  - Water / steam temperature (& pressure)
  - Metal temperature (& heat flux)
  - Deposit
    - rate of formation
    - composition

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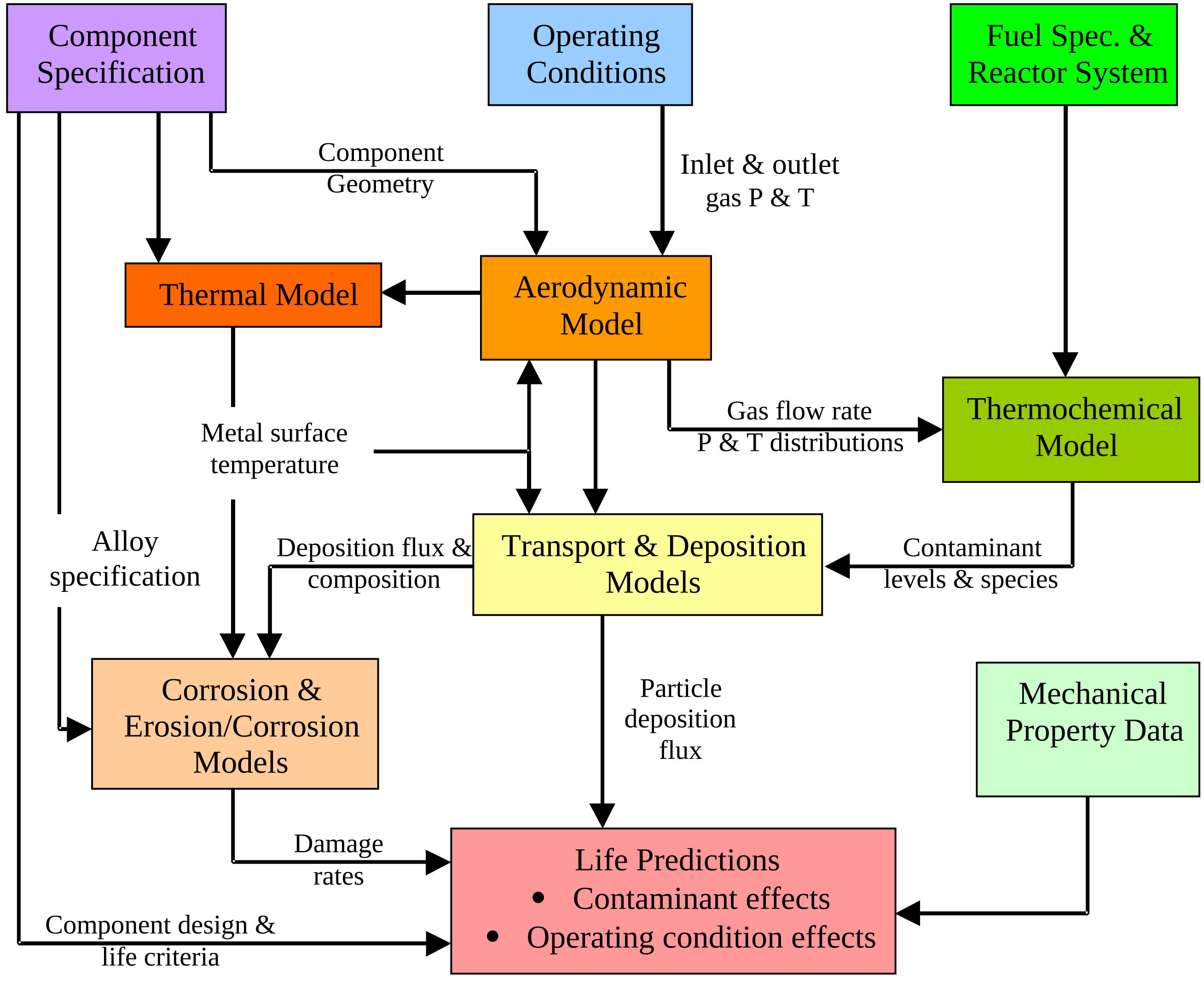
Flow Diagram for Component Life Modelling



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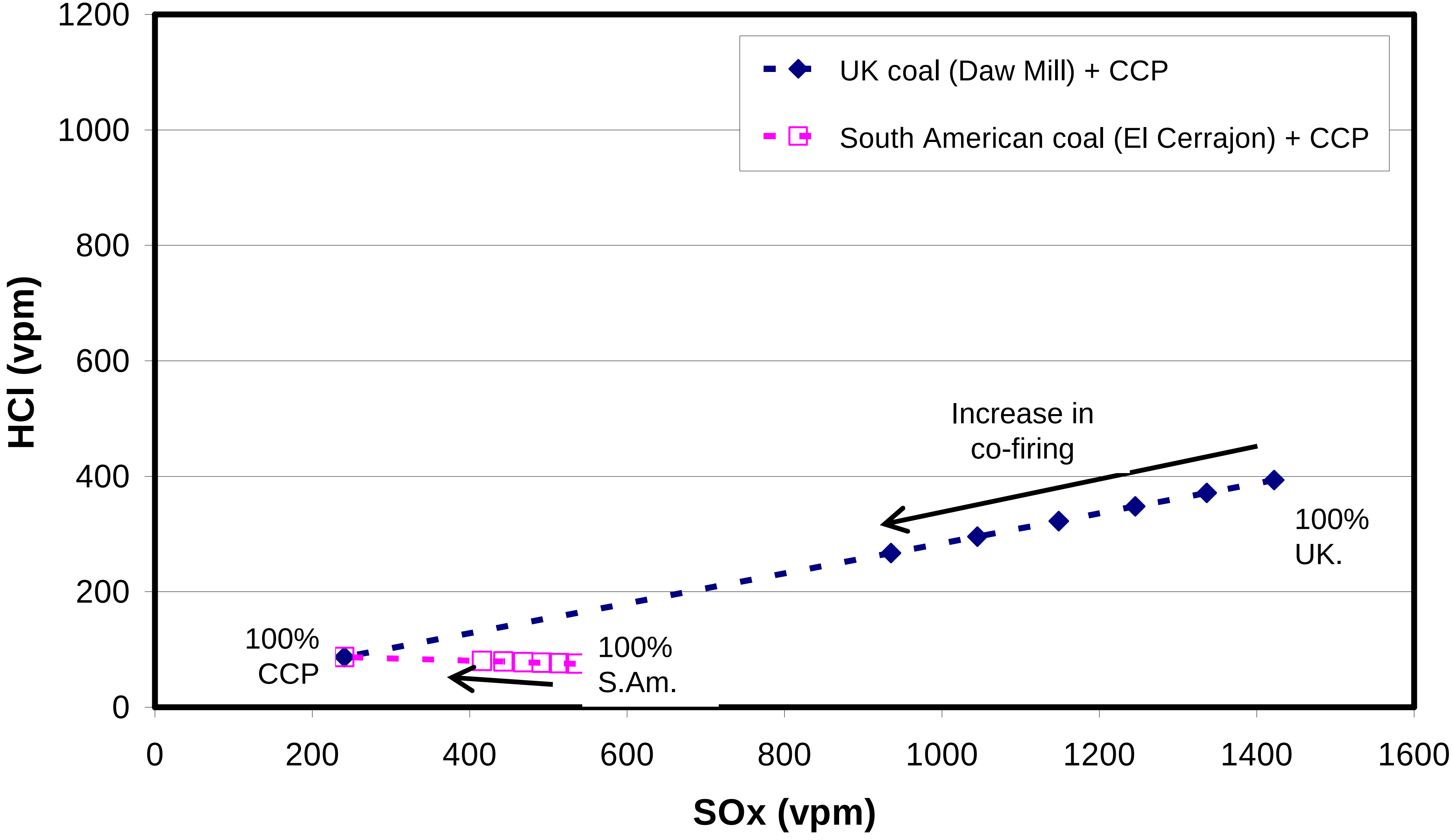
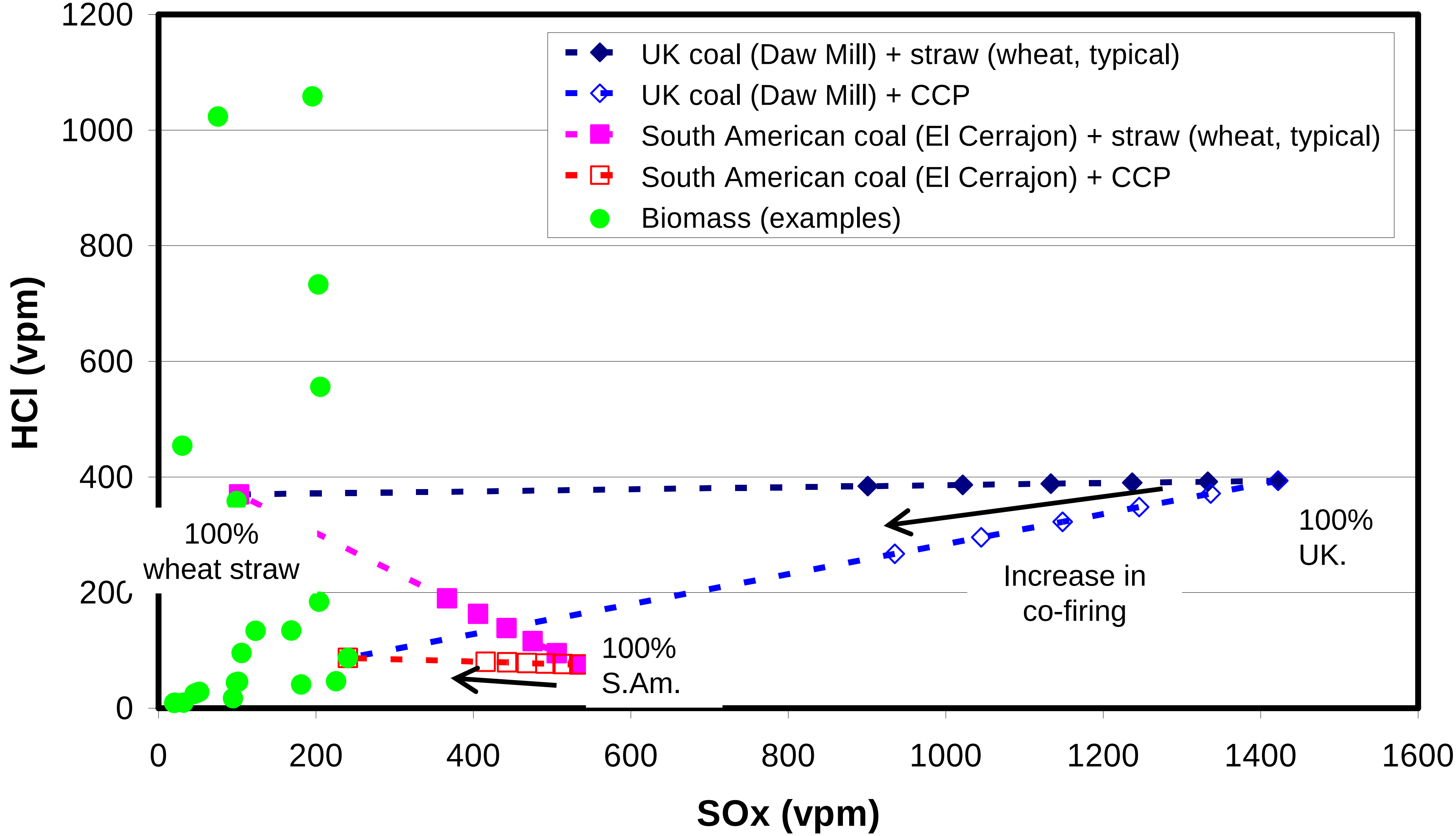
Sensitivity of SO_2 vs HCl to changes in cereal co-product (CCP) co-firing with two coals



Sensitivity of SO_2 vs HCl to changes in cereal co-product (CCP) or typical wheat straw co-firing with two coals compared to example biomass



Deposition on Superheater / Reheater Tubing

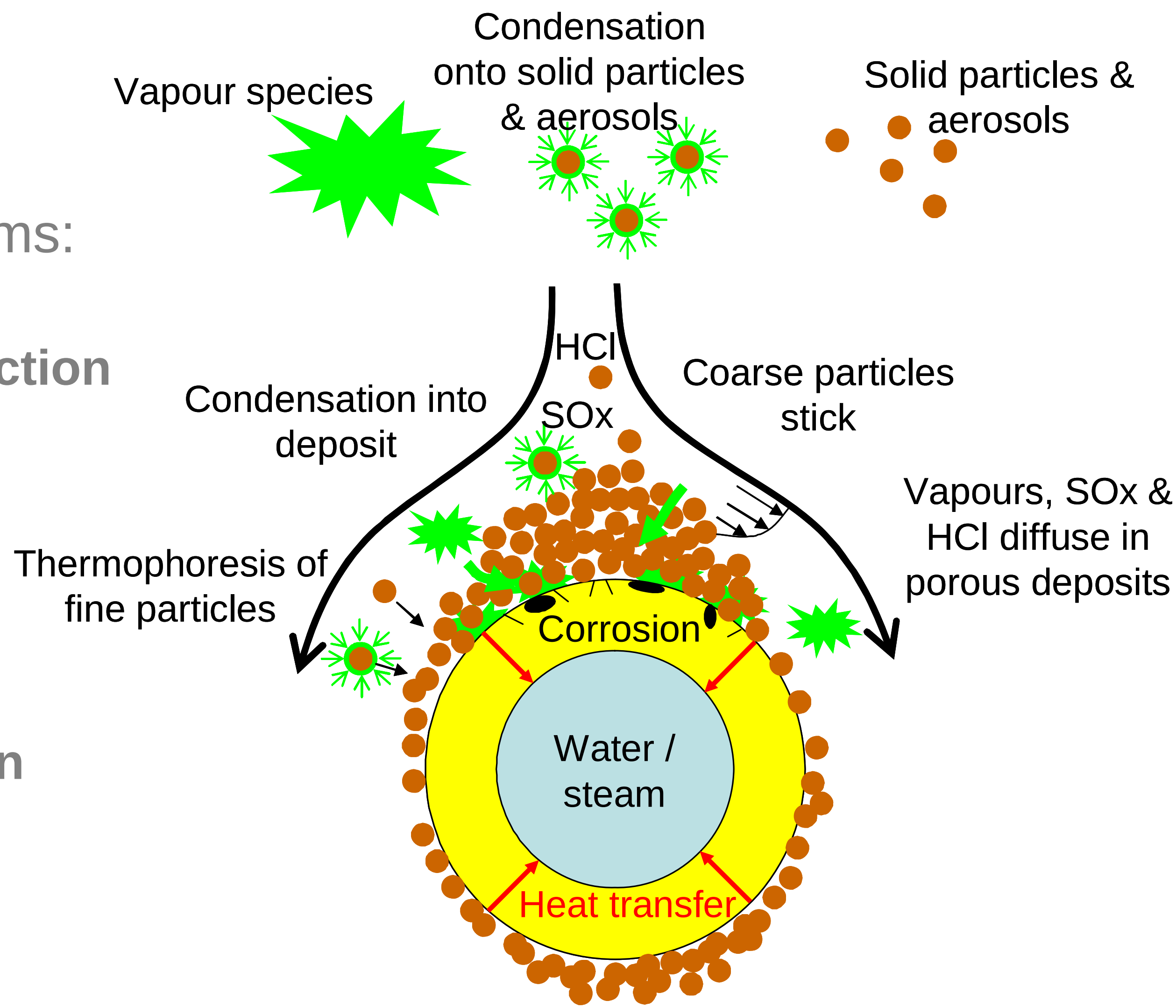
Deposition mechanisms:

Particles:

- **Direct inertial impaction**
- **Thermophoresis**
- **Eddy diffusion**
- **Brownian**

Vapour:

- **Direct condensation**
- **Condensation on particles**



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Fuel derived deposit compositions

Deposit compositions:

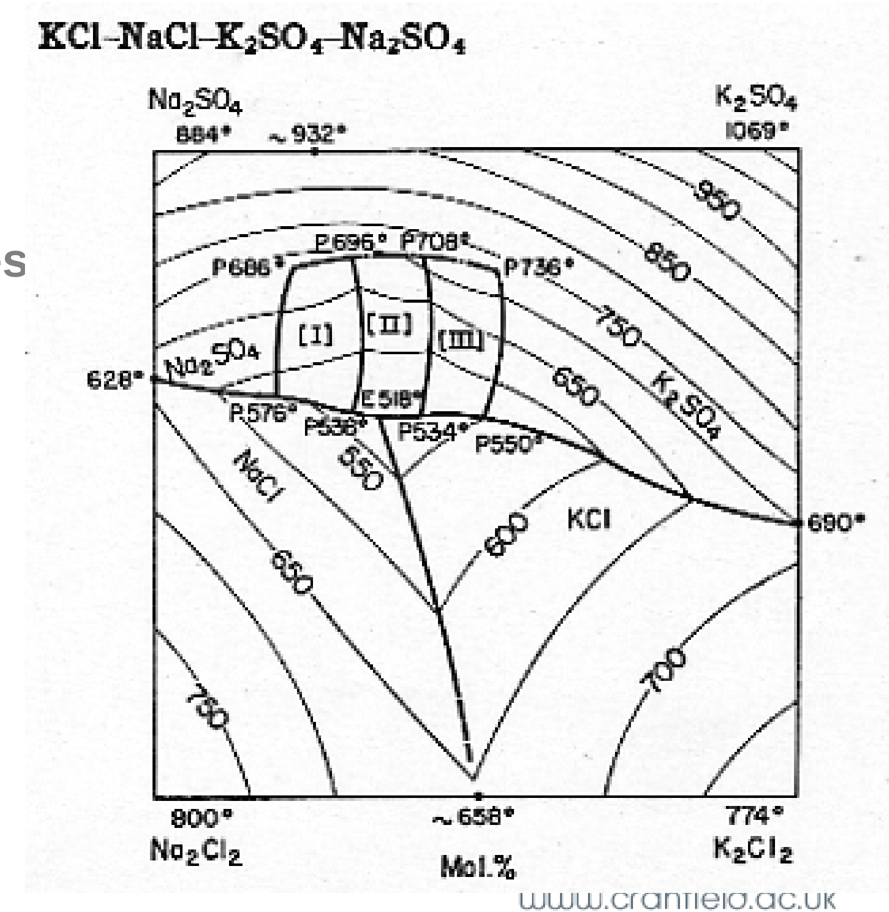
- Si-Al-O compounds
  - can fix Na, K if particle temperatures high enough
  - Al only if coal co-fired
- Ca/Mg carbonates / sulphates / chlorides
- Na / K sulphates / chlorides
- Fe sulphates / chlorides / oxides / sulphides
- Phosphates – from biomass

Important factors

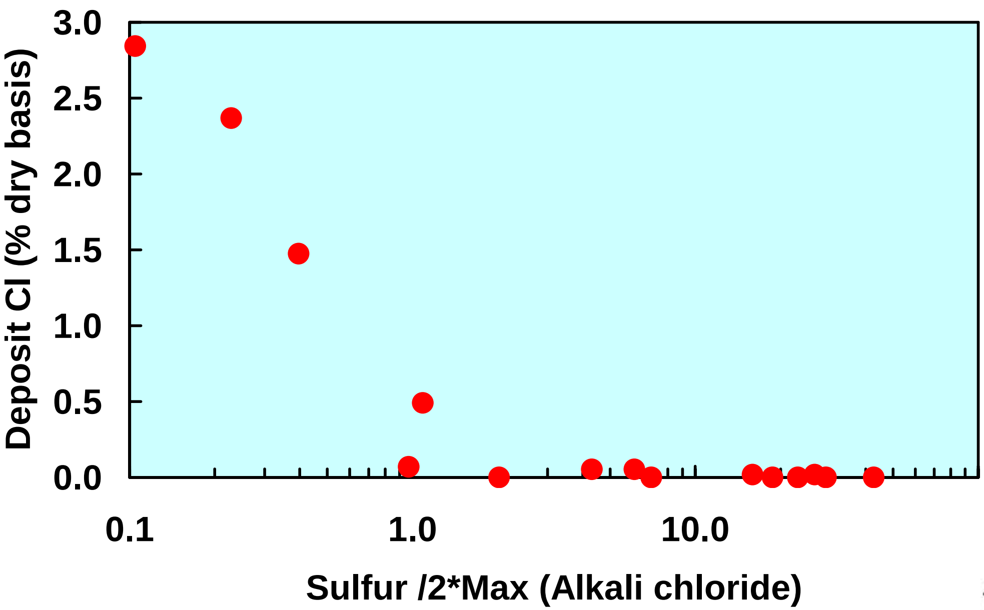
- Minerals in fuels
- Balance between elements

Corrosion aggravated by:

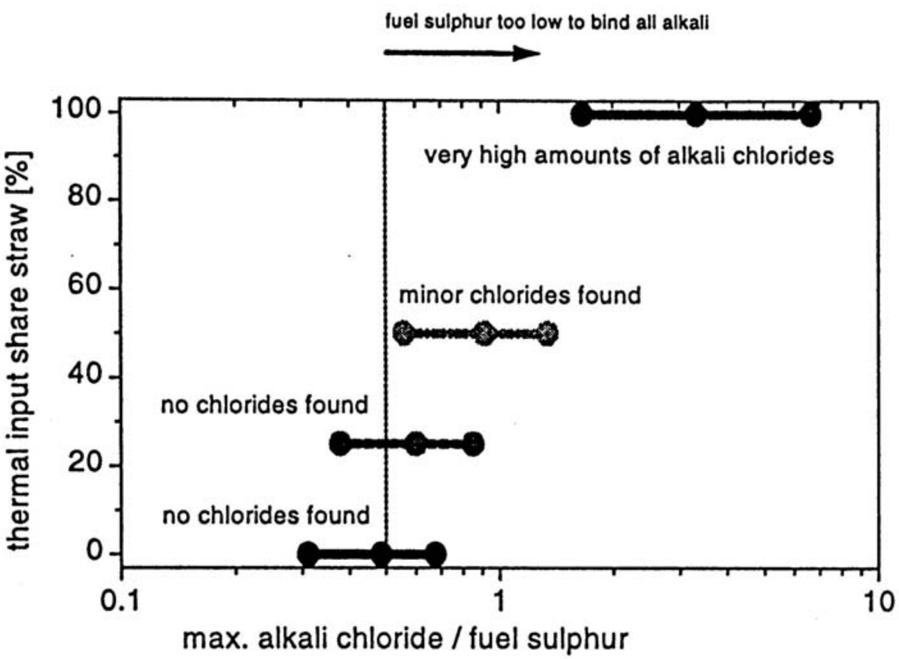
- Low melting point deposits
- High chloride deposits



Effect of fuel S/Cl balance on deposit compositions

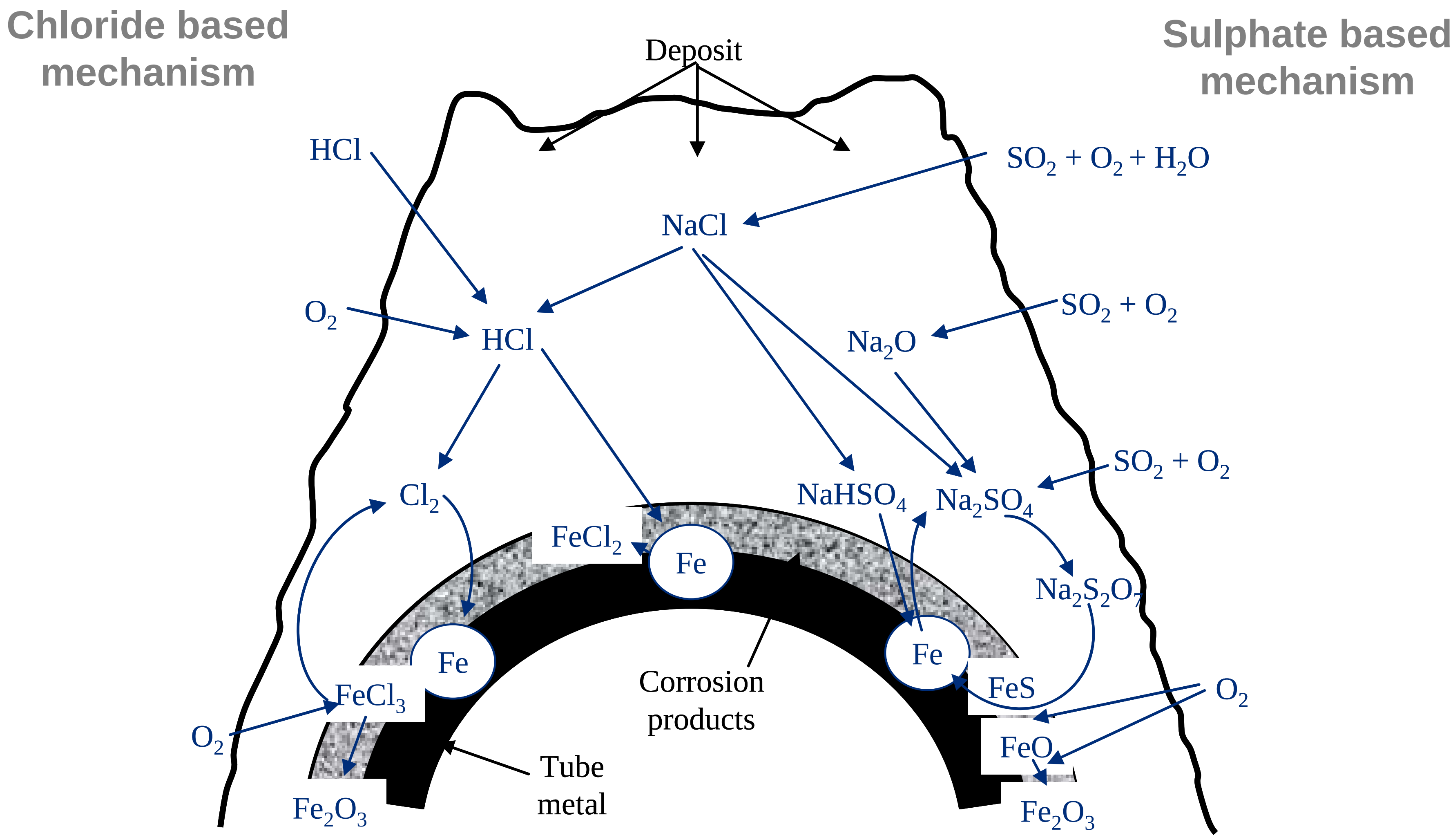


Dependence of deposit chlorine content on fuel sulphur and alkali chloride contents
[US DoE Research]

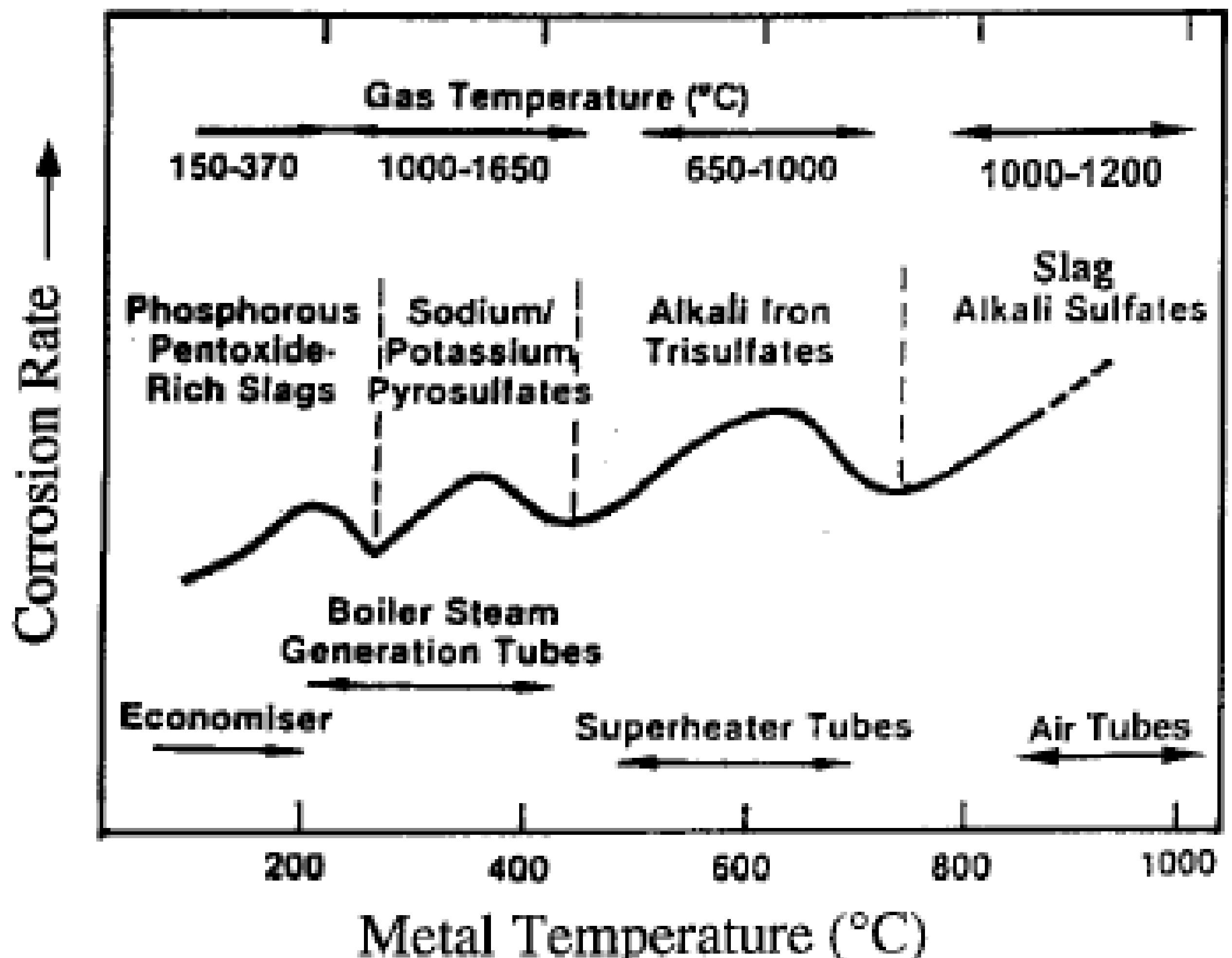


Appearance of chlorides in deposits as a function of maximum alkali chloride, fuel sulphur and % straw (on thermal basis)
[EU research]

Possible fireside corrosion mechanisms in sodium chloride / sulphate dominated deposits



Alkali sulphate dominated corrosion regimes in combustion gases



[Natesan, Purohit & Rink, US DoE Fossil Energy Materials Conf. 2003]

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Oxy-fuel firing

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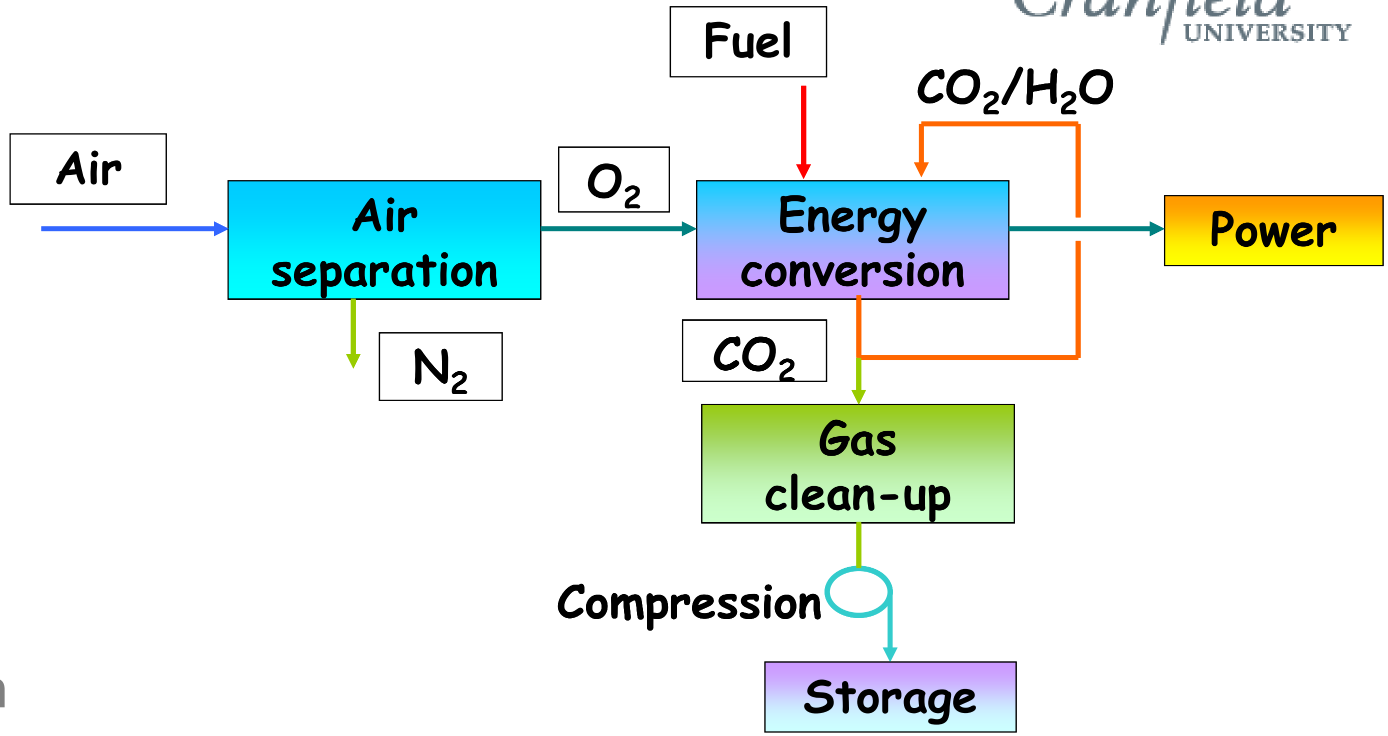
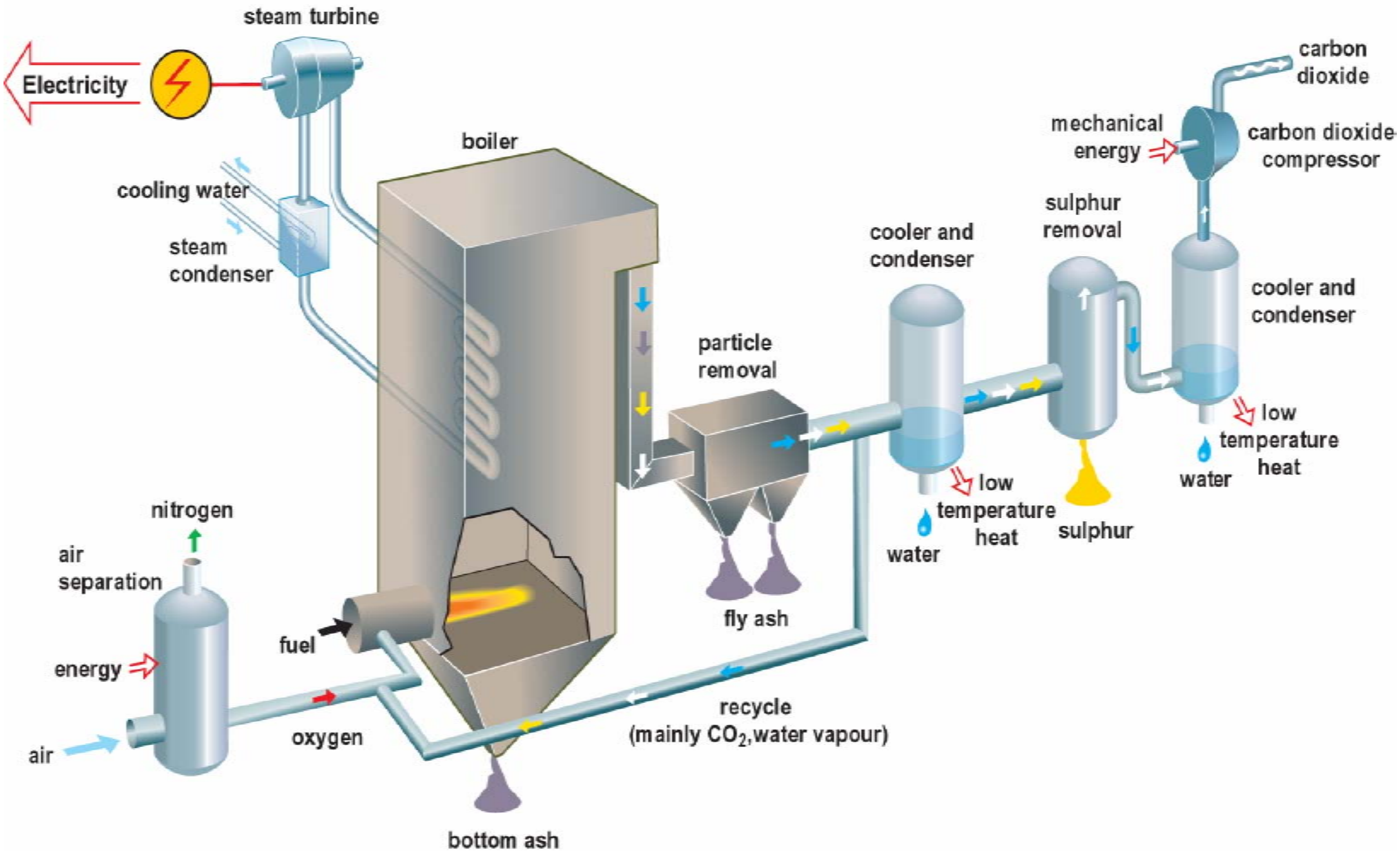


Plant options:

- Purity of oxygen
- Location of flue gas recycle take-off point
    - Before any gas clean-up
    - After particle removal
    - After flue gas desulphurisation
- Further gas clean-up before recycle
    - Dry primary combustion gas stream
    - Dry secondary or tertiary combustion gas streams

Have direct effect on component operating conditions

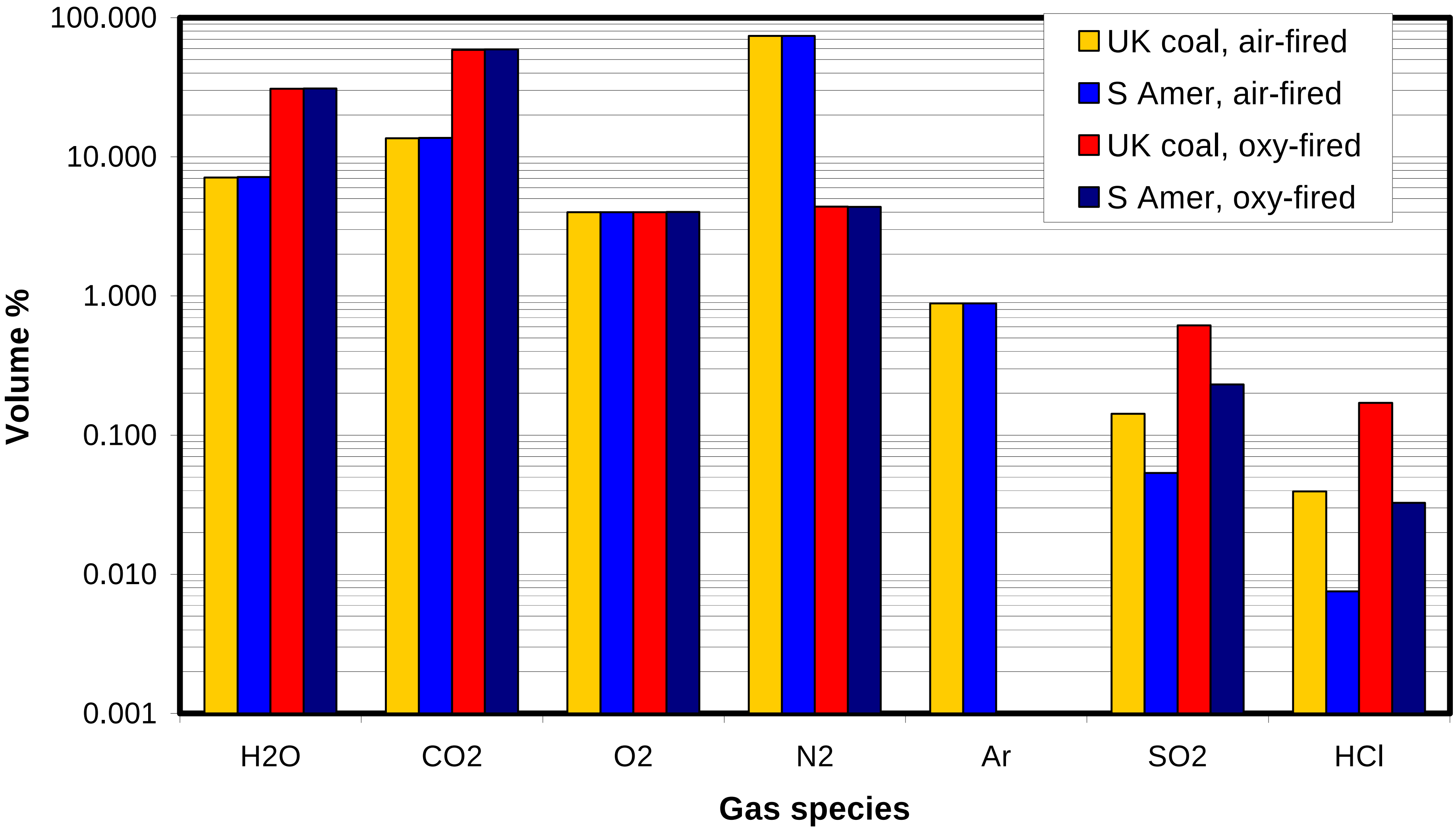
Schematic diagram of Oxy-fired combustion system



Source: Vattenfall

Gas compositions

- UK vs S American coals
- air vs oxy-fired with fuel gas recycle taken before FGD



Oxy-firing: fireside materials issues

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- Gas composition
  - Much higher SOx and HCl than conventional plants possible
    - ~4-5 times higher if recycle before FGD system
  - High CO_2 and steam levels (at same O_2 levels as conventional plants)
- Higher metal operating temperatures of heat exchangers
  - Higher efficiencies needed to counter CO_2 capture penalties
- Deposition
  - Compositions and formation rates changed by
    - gas compositions
    - metal surface temperatures
- Fireside corrosion rates – depend on:
  - Gas composition
  - Deposit composition and formation rate
  - Metal temperatures
  - Enough differences to cause mechanism change ?
- Dewpoint (aqueous) corrosion
  - Changes in gas composition can significantly increase dewpoint temperatures

SUMMARY

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- Many materials issues are being raised by the on-going developments of solid fuel fired power systems as a result of the use of:
  - Wider range of fuels with higher contaminant levels
  - Higher component operating temperatures
  - Novel component operating environments
- Novel environments resulting from fuel and/or oxidant changes have a particular affect on the fireside corrosion of components
- Increased operating temperatures and plant cycling affect mechanical requirements, as well as fireside corrosion and steamside oxidation
- Current materials R&D activities focused on:
  - Materials selection – alloys and/or coatings
  - Component lives / reliability

Thank you for your attention