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Energy Materials
(Power Generation)

Energy at Birmingham

July 8th 2011

Reducing CO2 emissions

In the UK: Climate Act 2008

34% reduction* by 2020

80% reduction* by 2050

Coal Power:
26,900,000 tonnes of CO_2 in 2009

* based on 1990 baseline

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Increasing Efficiency

Steam operating conditions for coal power plants*

Type of thermal power plant	Steam operating temperature	Steam operating pressure	Efficiency HHV(%)
Sub-critical	~540ºC	~16.5 MPa	~38
Supercritical	540-600ºC	≥22.1 MPa	~41 - 44
Ultra-supercritical	≥600ºC	≥30 MPa	46+

World-wide research efforts

AD-700 (EU)

Clean Coal Power Initiative (USA)

THERMIE (EU)

COST programs (EU)

Boiler Materials for Ultrasupercritical Coal Power Plants (USA)

*Source: P. Lako, *Coal-fired power technologies: Coal-fired power options on the brink of climate policies*, 2004.

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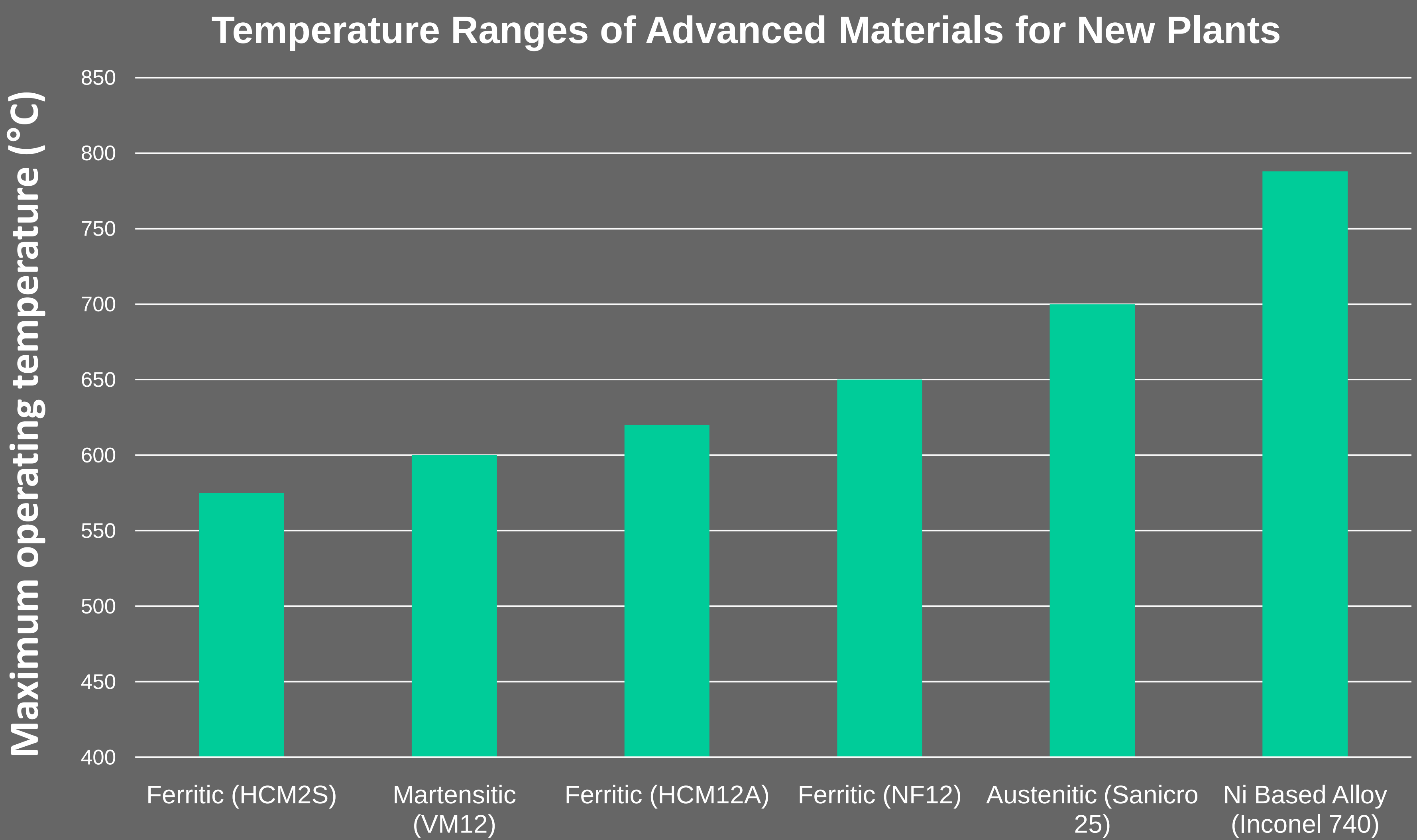

Data from Viswanathan, R., J. Sarver & J. M. Tanzosh (2006) Boiler materials for ultra-supercritical coal power plants-steamside oxidation. *Journal of Materials Engineering and Performance,* 15**,** 255-274.

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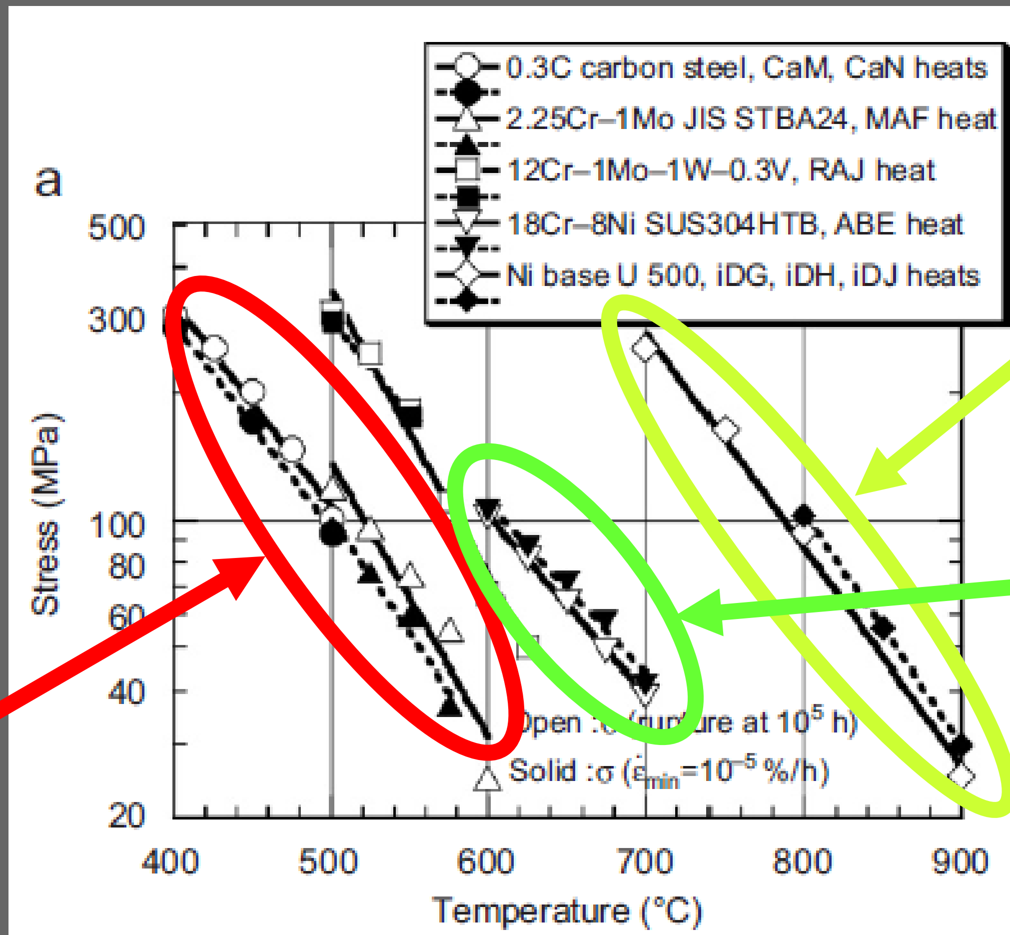
Material Creep Strength



Nickel-based
Super alloys
e.g. Incolnel 625

Austenitic Steels
e.g. S304H

Ferritic &
Martensitic
Steel
e.g. P91

Figure 1(a) from Abe, F. (2008). Stress to produce a minimum creep rate of 10^{-5}%/h and stress to cause rupture at 10^5h for ferritic and austenitic steels and superalloys. *International Journal of Pressure Vessels and Piping*, ***85***(1-2), pp99-107

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NDE of Power Plant Steel
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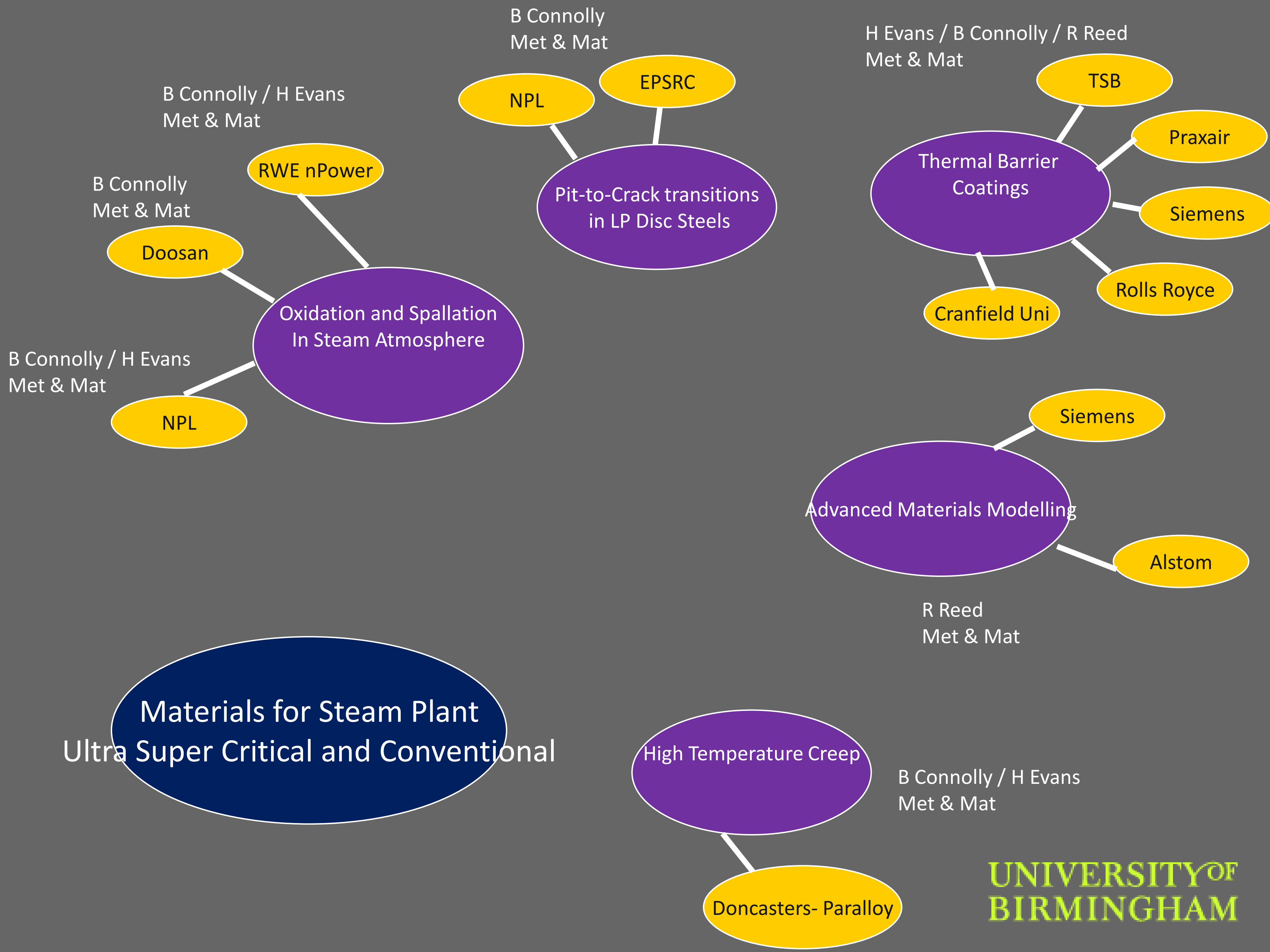

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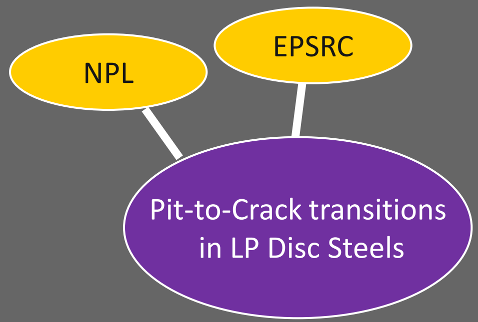
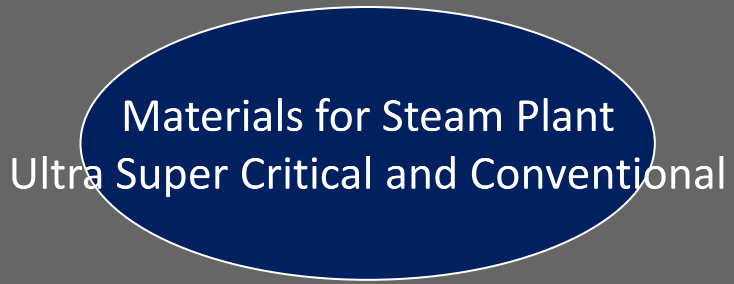
B Connolly
Met & Mat





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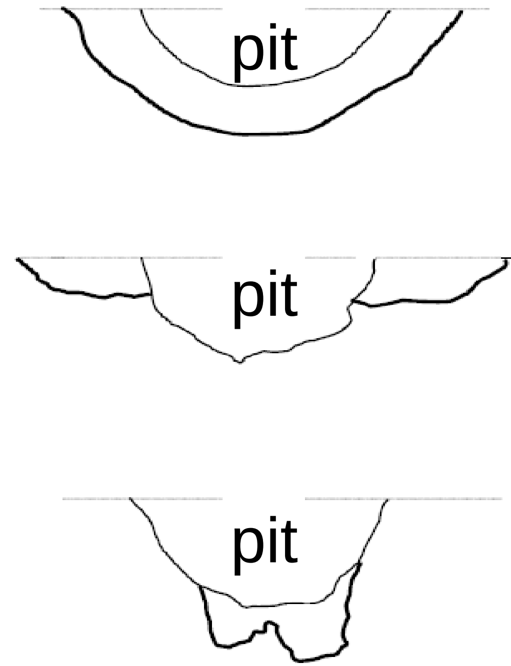
Pit to Crack Transitions in Low Pressure Steam Turbines

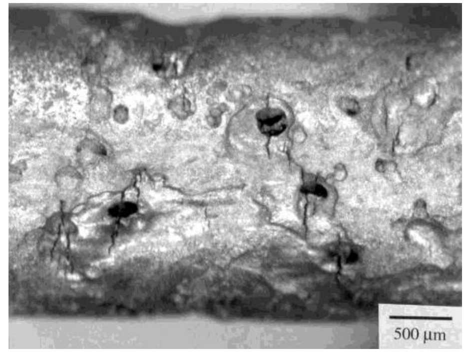


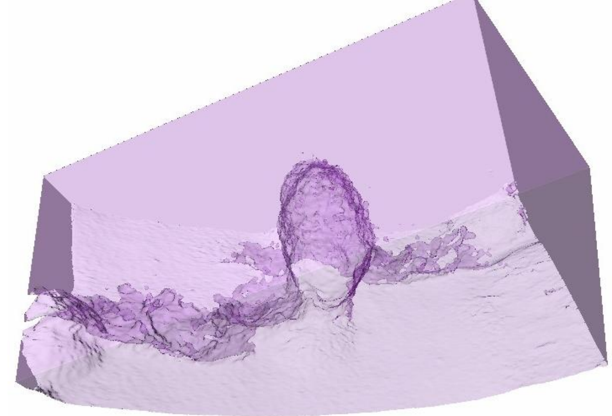
*** NPL Report MATC (A) 95**

Pit to Crack Transitions in Turbine Disc Steels

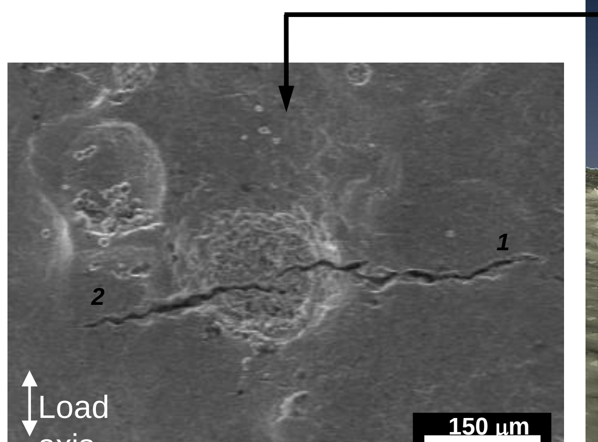
- **X-ray tomography** results indicating nucleation of stress corrosion cracks at pit sides is consistent with finite element analysis data indicating that localised plastic strain occurs just below the pit mouth.

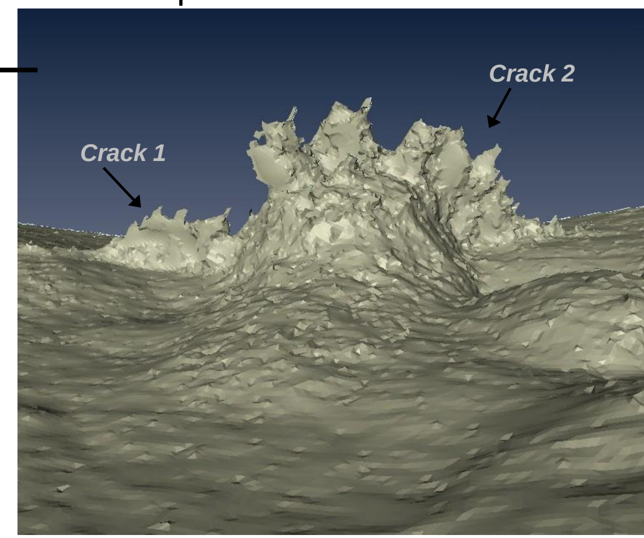
- Observations of pit-to-crack transitions made in this study indicate that existing steam turbine disc steel SCC **predictive models** that are based on criteria defined by Kondo should be reassessed.

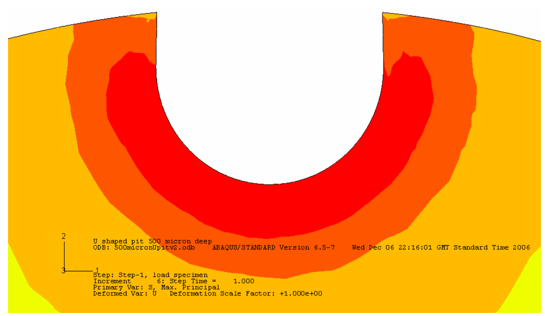




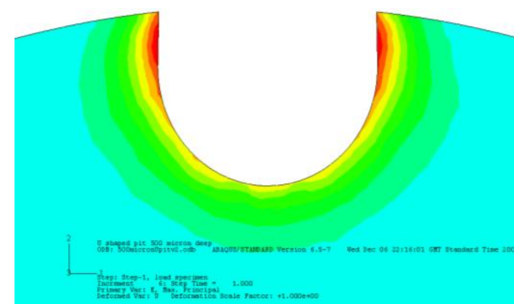
X-ray tomographic images of pit-to-crack transition





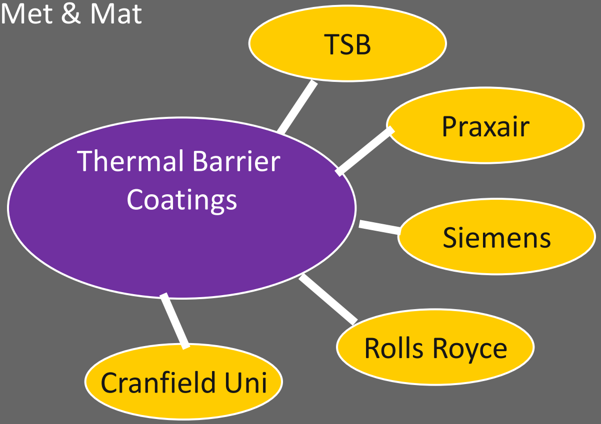


Stress distribution



Strain distribution

H Evans / B Connolly / R Reed
Met & Mat



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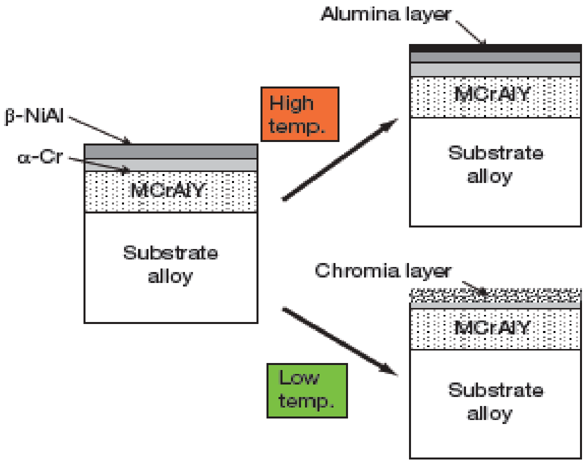
CASET – Carbon Abatement Surface Engineering Technologies

Peter Smith, Mary Taylor and Hugh Evans

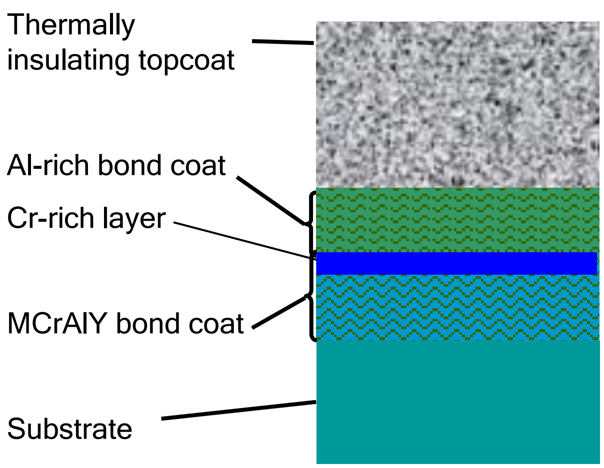
- A set of coatings developed to improve industrial gas turbine efficiency by allowing higher operating temperatures and dirtier fuels to be burnt (including biofuels) for power generation.
- The multilayer coatings have excellent oxidation and corrosion resistant properties.
- The project partners are Siemens PLC, Praxair Surface Technologies, Cranfield University and funded by the Technology Strategy Board.

Coating Schematics

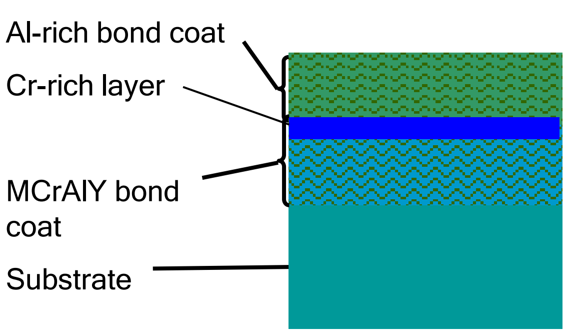
- The ERC thermal barrier coating (TBC) is designed to be used in the hottest part of the gas turbine.
- The Sheila TBC is used in cooler parts of the gas turbine where molten corrosive material is deposited.
- An alumina thermally grown oxide (TGO) gives the best protection against oxidation.
- A chromia TGO is very resistant to attack from corrosive material.
- The multilayers allow the coatings to react should they be required to, for example, if the Sheila coating loses its topcoat and the surface temperature exceeds 1000°C the chromia TGO will fail and an alumina TGO will eventually take its place.



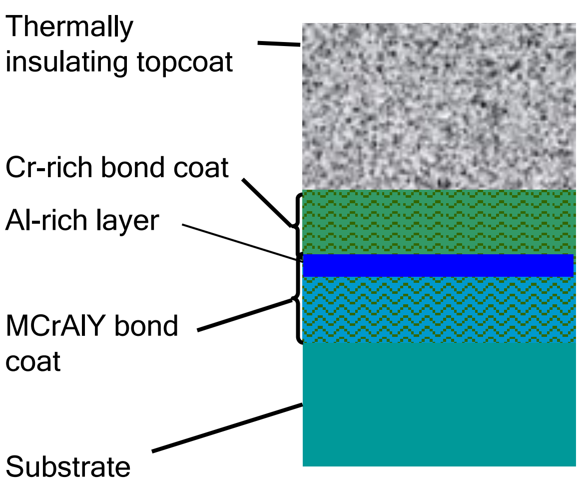
ERC TBC



ERC Overlay Coating



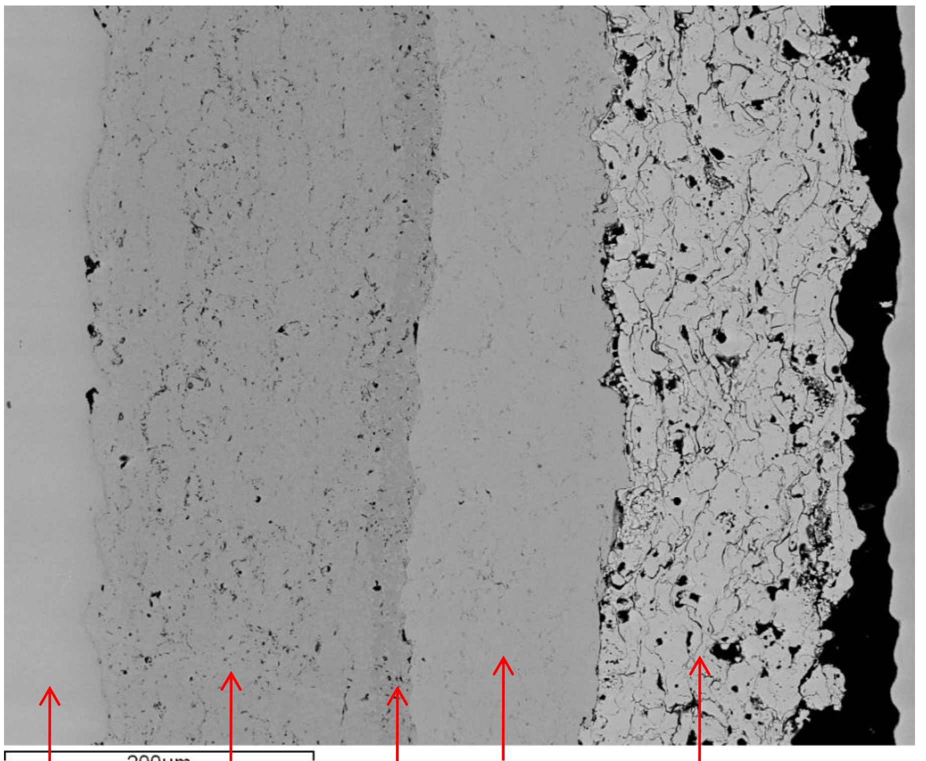
Sheila TBC



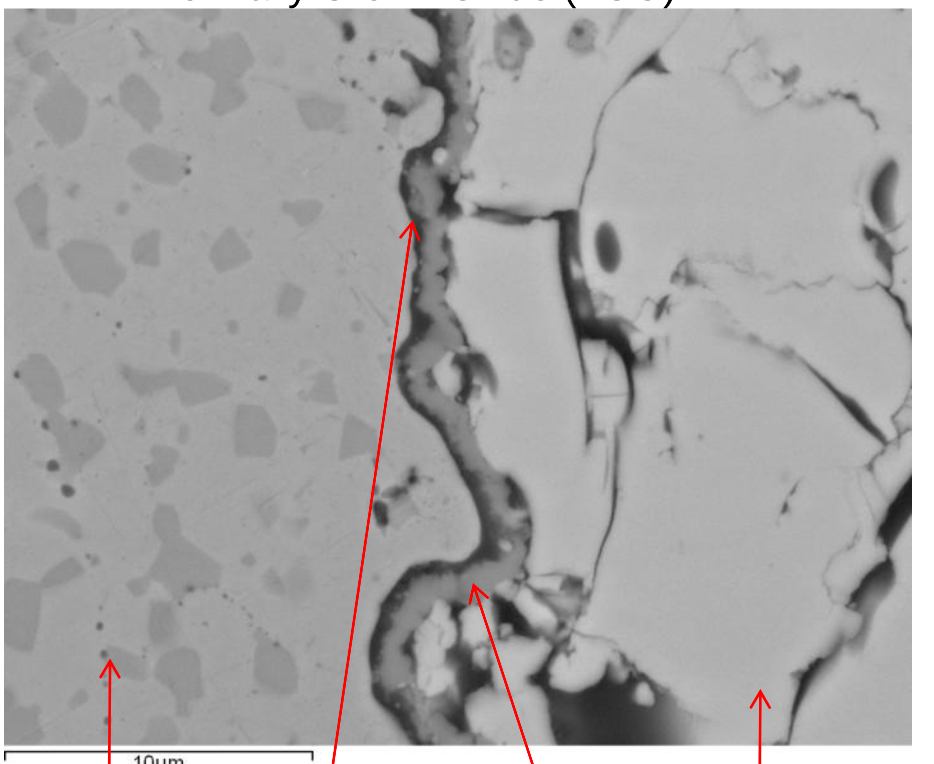
Sheila

- The lower temperature coating. Designed to be applied to gas turbine regions that operate below 900°C.
- At operating temperatures corrosive salts will be deposited on the surface of coating and a chromia thermally grown oxide (TGO) is more protective against this type of corrosion than an alumina TGO.
- Small amounts of silicon are added to NiCr as it has been found that a silica TGO beneath slows the growth of the chromia TGO.

- As received structure.

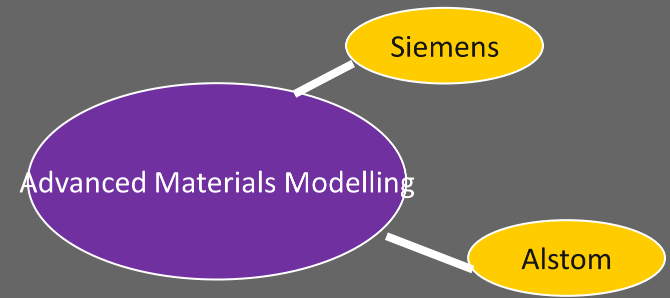


- Thermally Grown Oxide (TGO)



Project Aims

- To establish production routes for all three coatings.
- To establish coating lifetimes by testing at high temperature in air, SO_x and with corrosive salts.
- To understand how the coatings fail in different testing conditions.
- To predict interdiffusion between the metallic multilayers over the lifetime of the coating (20000 hours).



R Reed
Met & Mat

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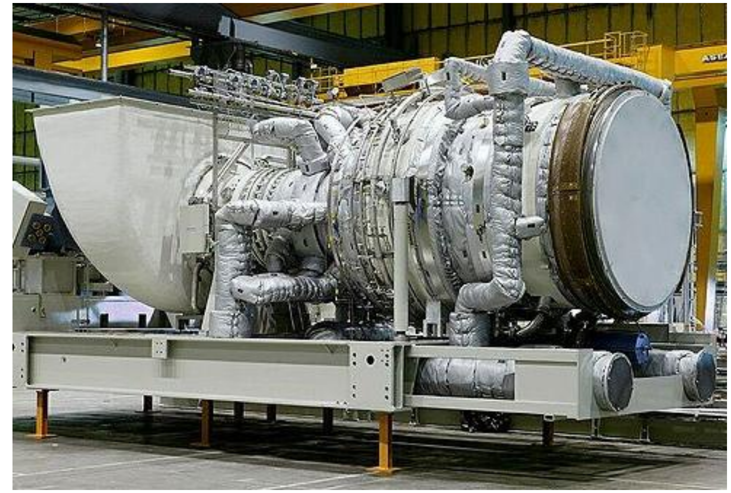
Development / Modelling of Next-generation Alloys for Power Generation Applications



SIEMENS SGT-800

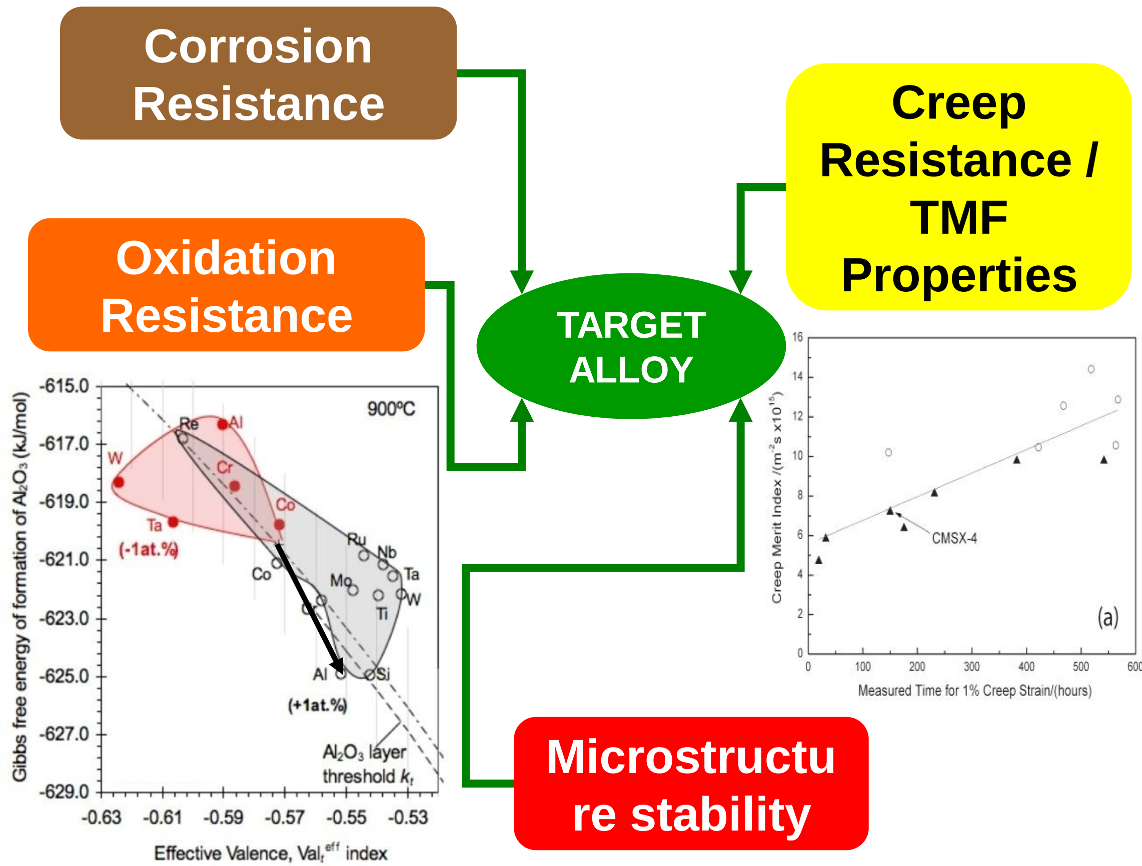
An Alloys-By-Design approach has been proposed; application of it allows compositions of single crystal superalloys to be identified using modelling methods.

First order estimates of important characteristics (creep resistance, oxidation resistance, castability…..) are made for alloys in a chosen compositional space. From it are eliminated those compositions which do not satisfy design constraints.

The methods are being applied to design various new alloy systems against minimum property targets.

Any success depends upon accuracy of underlying sub-models and databases (*e.g.* CALPHAD); these need to be further improved.

Still many challenges: *e.g.* corrosion, thermal-mechanical fatigue for which quantitative models are still needed.



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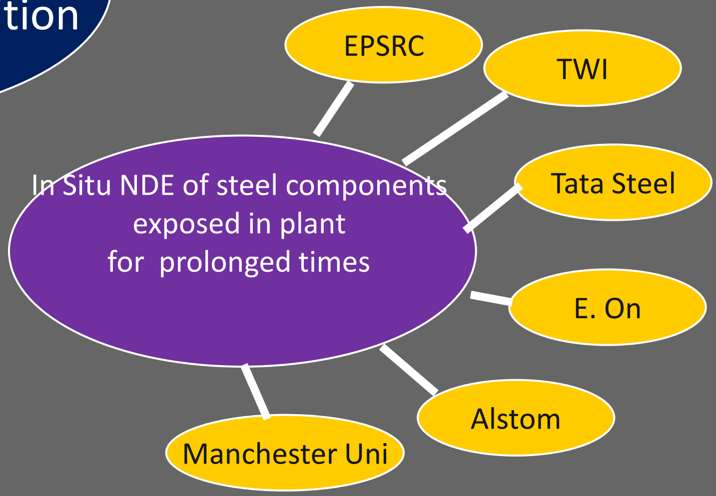

C Davis / M Strangwood
Met & Mat

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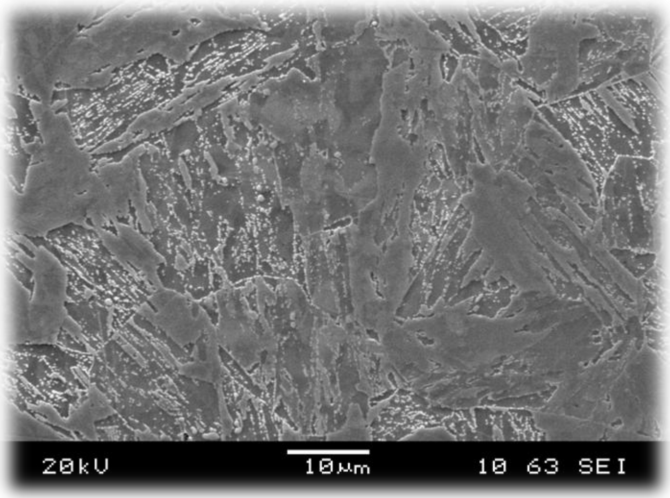
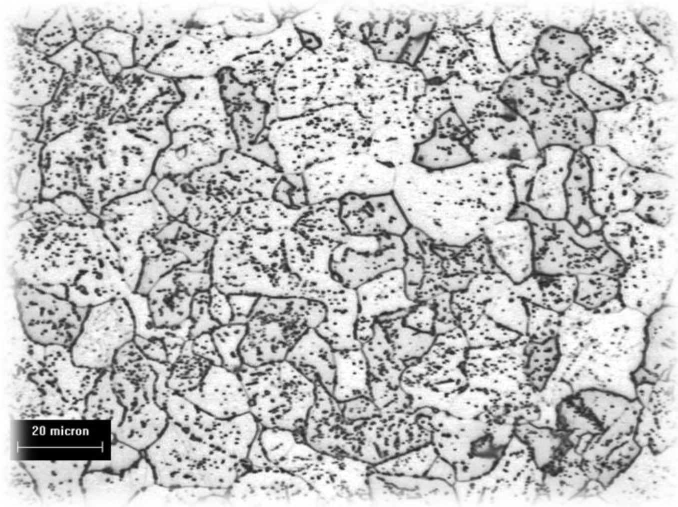
Non-destructive evaluation of power plant steel microstructural condition

Steel used in power plant components experience prolonged time at high temperature with or without external stresses. During this time the microstructure and precipitates change. Example given below for P91 (8.5Cr1Mo steel).



Microstructure entering service



Microstructure on removal from service

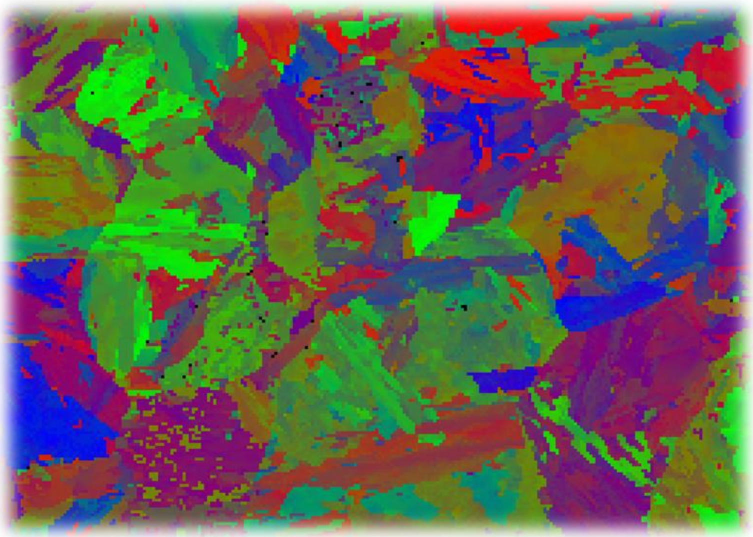
Prof Claire Davis, Drs Martin Strangwood, Xinjiang Hao and Jun Liu, and Frank Zhou (Birmingham Univ)

Prof Tony Peyton and Dr Wuliang Yin (Manchester Univ)

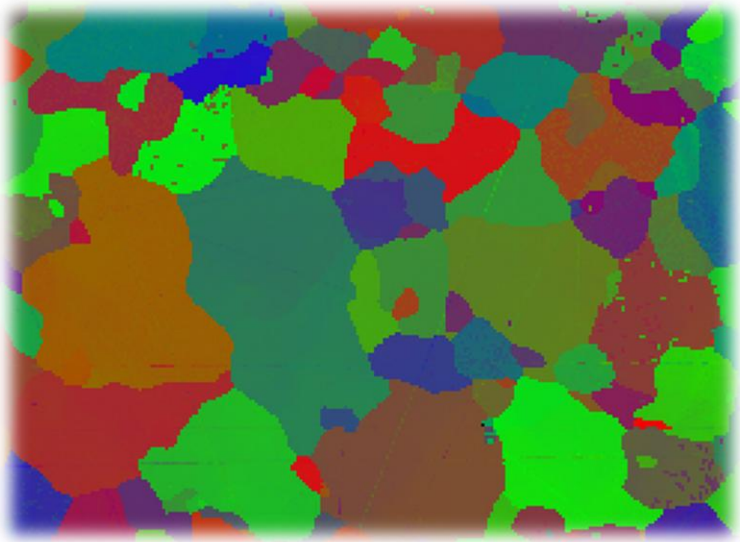
EPSRC research programme supported by Tata Steel Europe, E.ON, Alstom and TWI

Non-destructive evaluation of power plant steel microstructural condition

Change in structure (EBSD maps shown below showing change in microstructural unit size) results in a change in electrical and magnetic (relative permeability) properties. These can be detected using an appropriate electro-magnetic (EM) sensor.



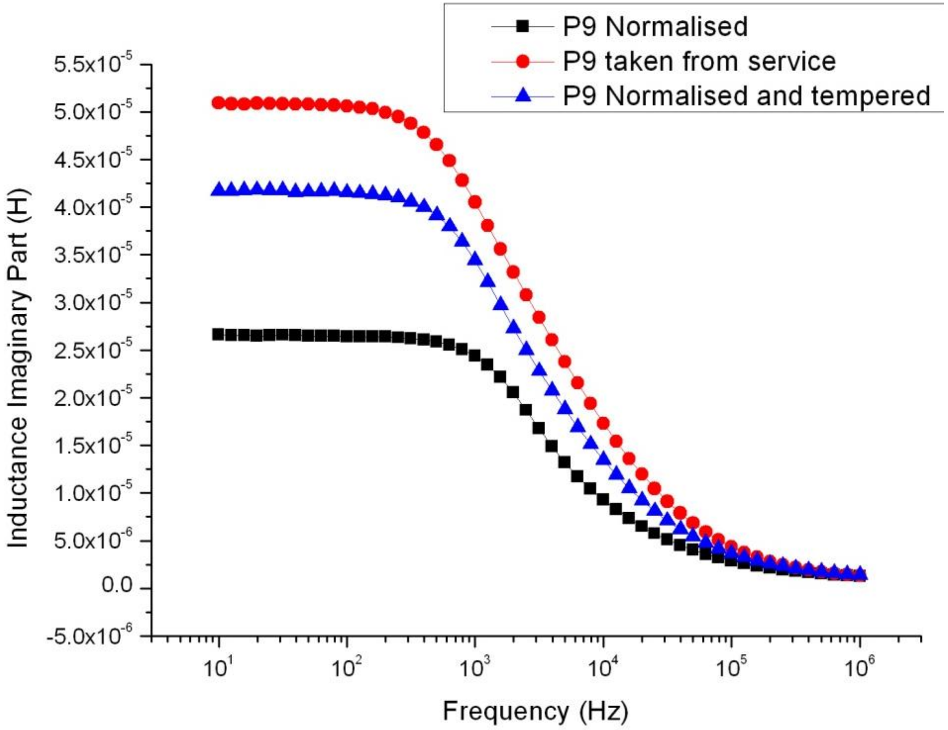
Entering service - normalised and tempered (950°C for 1 hour followed by 760°C for 1 hour)



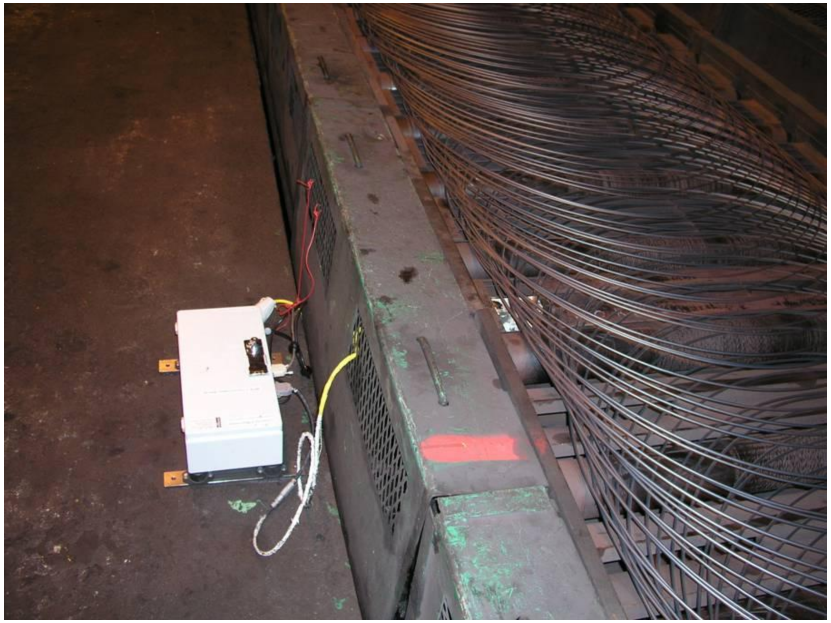
Removed from service – 11 years at approx 520°C

Non-destructive evaluation of power plant steel microstructural condition

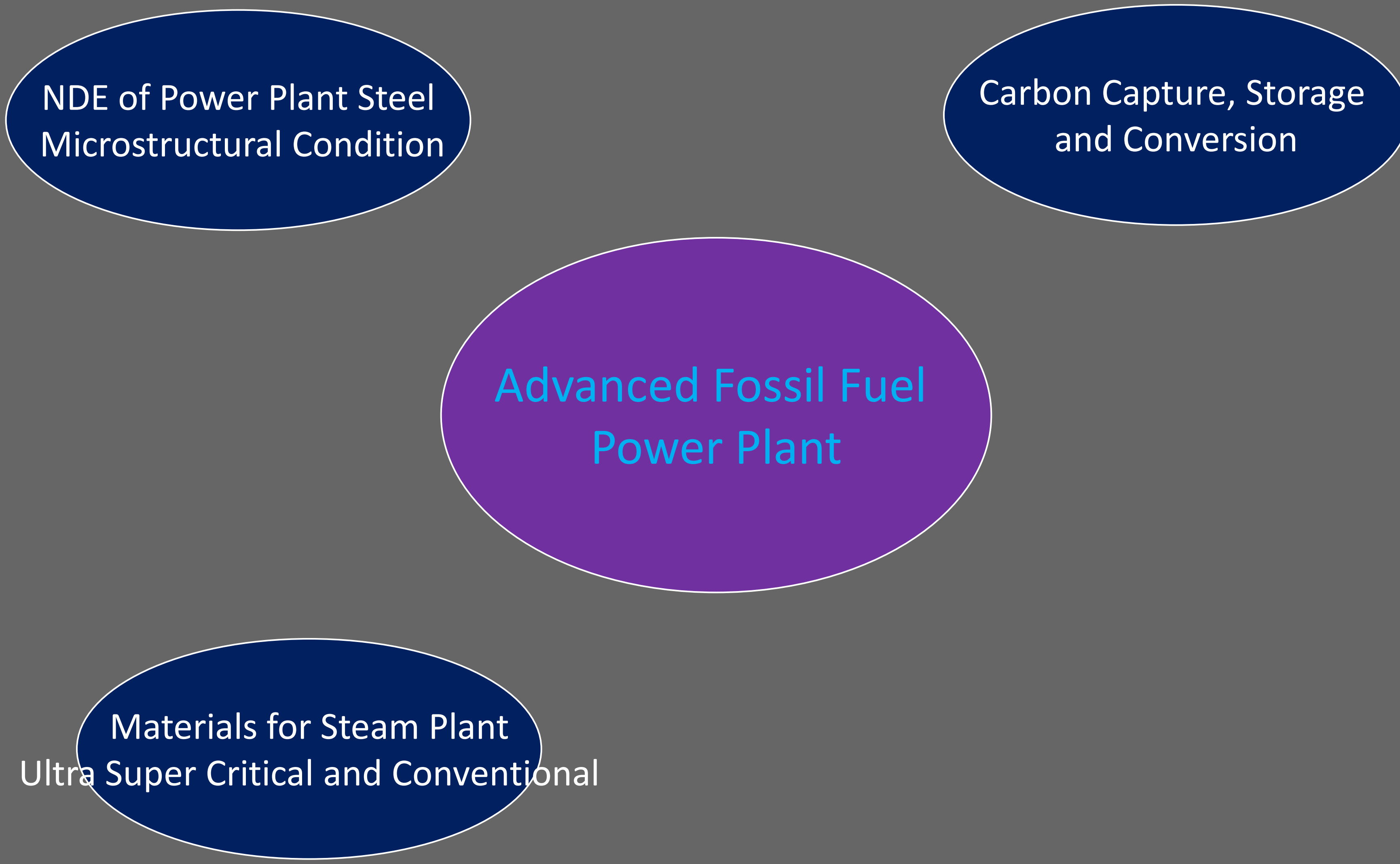
EM sensor scans the material across a range of frequencies. The low frequency inductance value is sensitive to changes in relative permeability allowing the microstructural state of the material to be determined.



EM sensor results showing the different microstructural states can be distinguished.



Prototype EM sensor system for phase transformation in steel installed on a hot rod mill illustrating industrial application. Trials currently being conducted.



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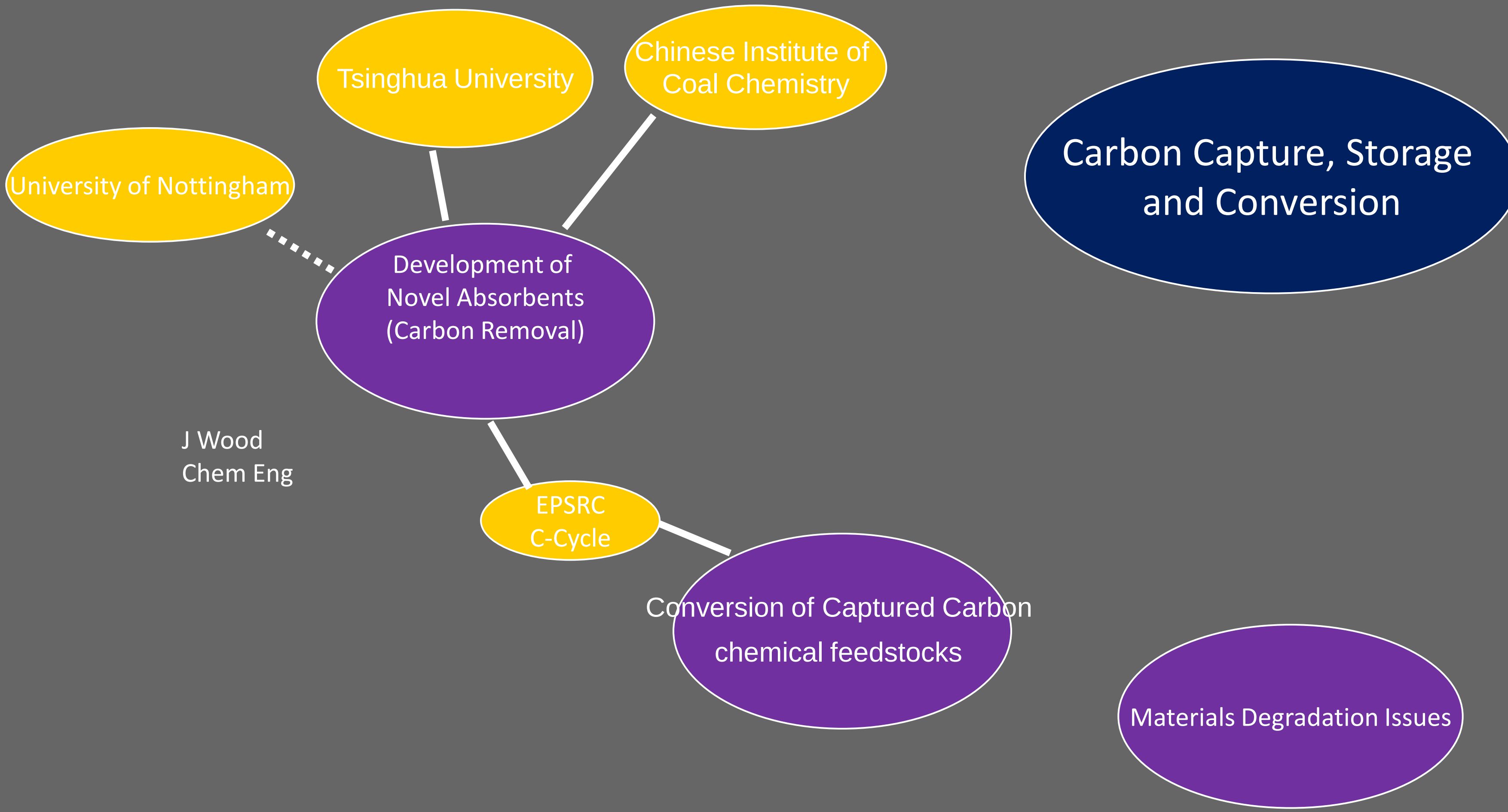

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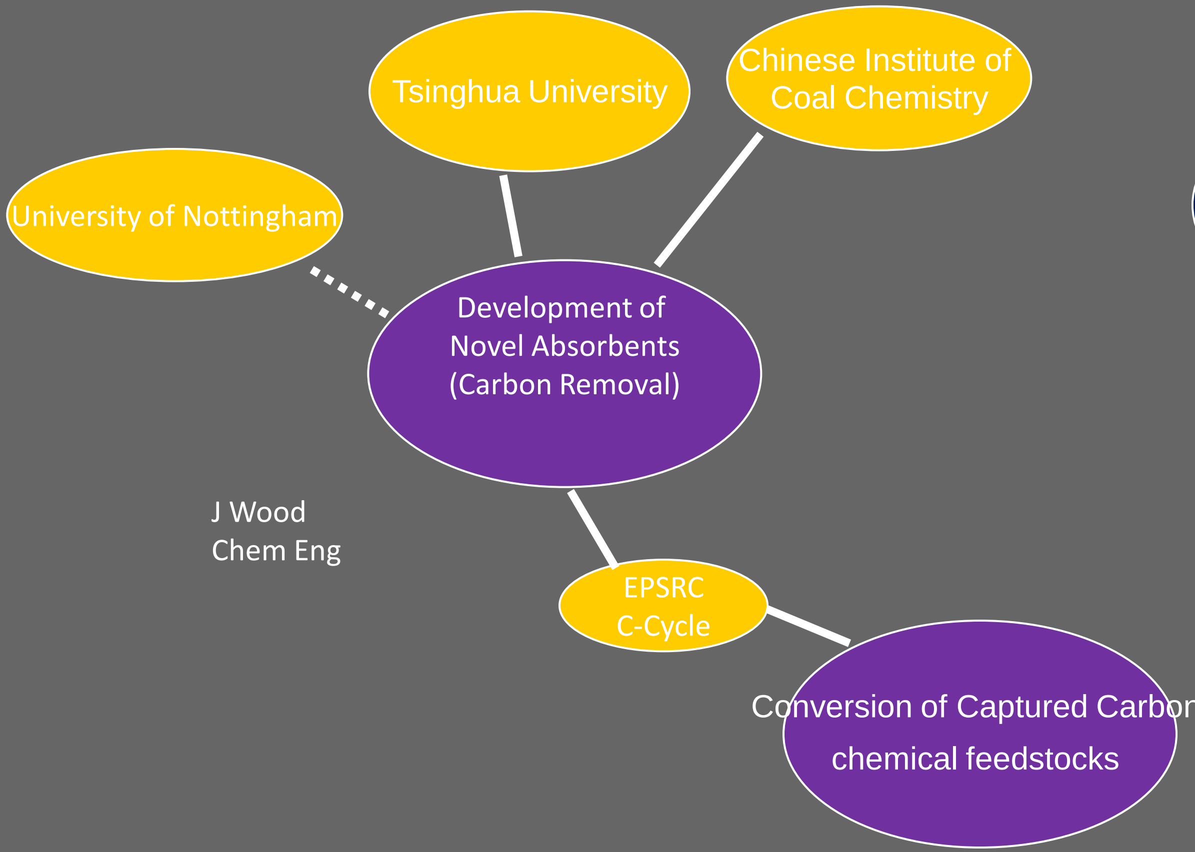
Carbon Capture, Storage and Conversion



J Wood
Chem Eng

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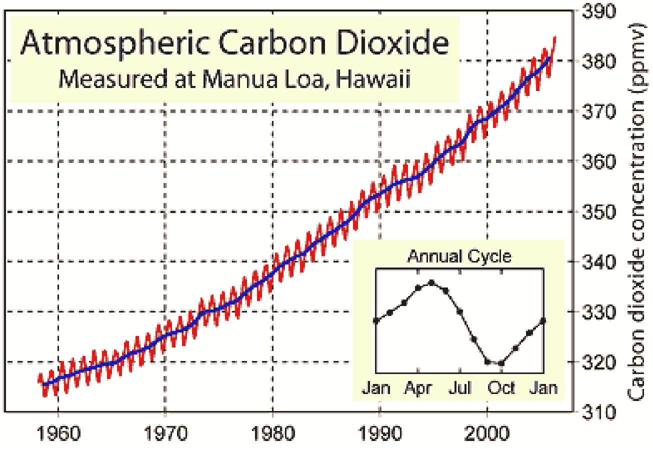
Carbon Dioxide Capture

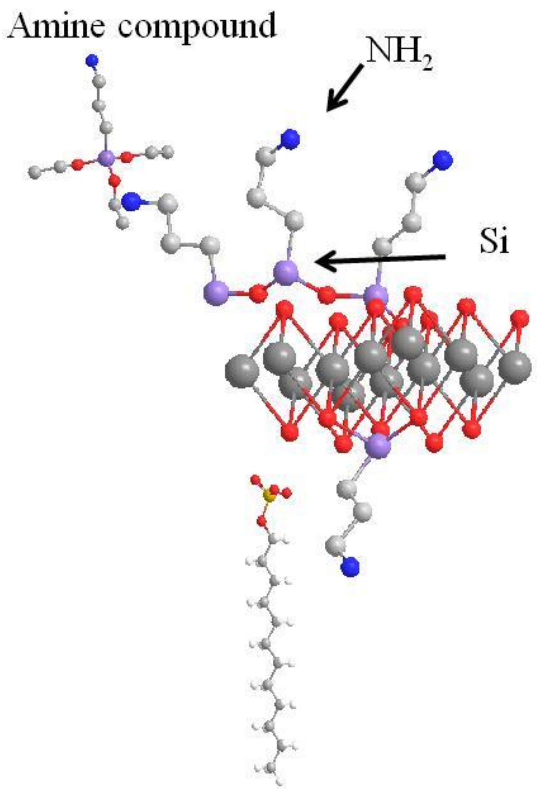
- Need to decrease CO_2 emissions at point source such as power stations
- Introduce carbon capture plants
  - Develop technology
  - Increase efficiency
  - Reduce costs
- Capture by liquid absorbents or solid adsorbents
- Lower energy penalty and ease of regeneration to be considered.



Projects at Birmingham

- STEPCAP – Development of next generation adsorbents for CO_2 based on amine modified hydrotalcites
- Basic amine groups grafted to surface of clay like material to increase affinity for CO2
- Researcher: Dr Jiawei Wang. Collaborators Universities of Nottingham, UCL, Liverpool.

Schematic of amine modified hydrotalcite adsorbent for CO_2 capture

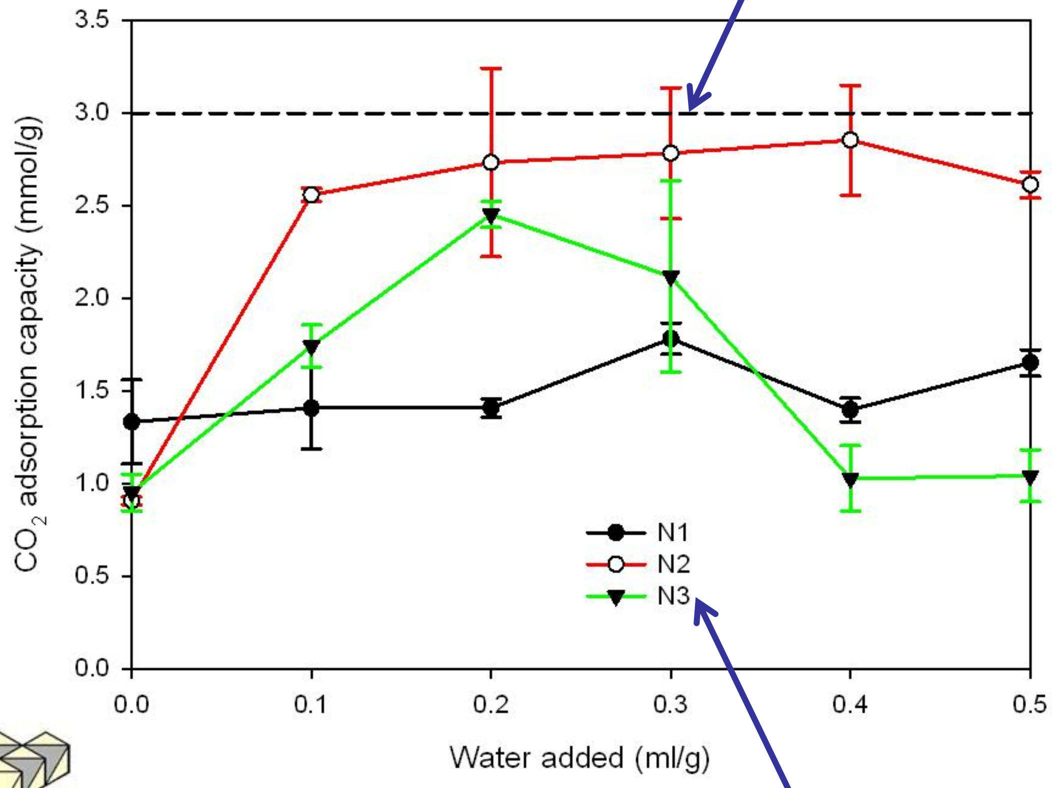


Typical Carbon Capture Results

- Measured in the laboratory by Thermogravimetric Analysis

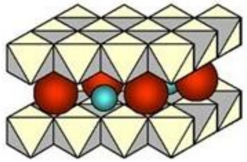
3 mmol / g adsorbent is a desirable target

CO_2 uptake



Temp: 60 °C

CO_2 uptake was peaked with 0.2-0.4 ml/g water added for NiMgAl N2.



Number of amine groups in molecule

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Thank you for your attention

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