Materials R&D Requirements for Fossil-Fuelled Steam Plant

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Energy materials – Meeting the Challenge
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Why is Steam Plant a key issue?

74% of the UK’s electricity demand is met by fossil-fuelled plant
- 38% coal- or oil-fired
- 36% gas-fired
  • Split between open cycle (gas turbine only) and combined cycle (gas turbine + steam turbine)

>50% of UK electricity dependent on steam plant
- Boilers
- Steam turbines
Key Drivers

• Economic
  • Improved efficiency
  • Reliability
  • Manufacturing Costs

• Environmental
  • Improved efficiency = lower emissions
  • Carbon capture
Cost of reduction in CO₂

by Replacing old Coal-Fired Power Stations

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Cost of Avoidance (€/t CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal (State of the Technology 2004)</td>
<td>20</td>
</tr>
<tr>
<td>Water</td>
<td>40</td>
</tr>
<tr>
<td>Biomass</td>
<td>50</td>
</tr>
<tr>
<td>Wind</td>
<td>100</td>
</tr>
<tr>
<td>Solar Energy</td>
<td>&gt; 120</td>
</tr>
</tbody>
</table>

Replaced by:
- New coal-fired power stations: 13 - 25 €/t CO₂
- Water < 5 MW: 40 - 50 €/t CO₂
- Biomass: 50 - 100 €/t CO₂
- Wind: 50 - 100 €/t CO₂
- Solar Energy: > 120 €/t CO₂

Ref: Stamatelopolous “Clean Combustion Technologies 2- Pulverised Fuel Technology, Brussels 2005
Approach to Efficiency Improvements

• Higher Inlet Temperatures
  - Boilers
  - Steam Turbines
    ➞ Materials with Higher Temperature Capability

• More efficient LP turbines
  - Optimise aerodynamic design
  - Increase exhaust area
    ➞ Higher Strength Materials with SCC Resistance
High Level Requirements: Implementation – 5 years

• Incremental improvements in existing materials systems
• Production/characterisation of prototype components using identified materials and processes
• Repair and improvement solutions for existing plant and materials
• Advanced manufacturing development for existing materials/processes for cost reduction/increased performance and integrity
High Level Requirements: Implementation – 10 years

• Development of new materials systems (substrate + coatings) based on existing knowledge including behaviour in realistic environments

• Development and application of process modelling to new materials to speed up introduction and help define new system solutions

• Adopting a total system approach to critical part design and life prediction with multi-material components with joints and coatings
High Level Requirements: Implementation – 20 years

• Identification of disruptive novel material systems and initial characterisation to identify most promising approaches

• Development of novel advanced technologies that will enable high overall efficiencies that will significantly reduce emissions
High Level Requirements: Generic Research

- Surface Protection Technologies
- Improved understanding and predictive modelling of degradation mechanisms
- Non-invasive inspection techniques for in situ assessment of material condition
- Existing plant refurbishment
- Similar and dissimilar materials joints
Boilers: Furnace Walls

State-of-the-Art
- Low alloy steels T23 and T24
- Designed for use without PWHT

Future Requirements
- Higher temperature capability
- Fireside Corrosion Resistance

Possible Solutions
- Ni-base alloys (IN617, IN740)
- New steels with surface protection
# Boilers: Superheater Tubes

## State-of-the-Art
- High Cr austenitic steels (NF709, HR3C, Sanicro 25)

## Future Requirements
- Higher temperature capability
- Fireside Corrosion Resistance

## Possible Solutions
- Ni-base alloys (IN740)
- Materials with properties intermediate between austenitic steels and Ni-base alloys (AC66)
Boilers: Headers and Steam Pipes

State-of-the-Art

- 9-12%Cr Martensitic Steels (P92, E911)

Future Requirements

- Higher temperature capability
- Steam Oxidation Resistance
- Eliminate Type IV Cracking

Possible Solutions

- High boron steels
- Coating of internal surfaces
- Ni-base alloys
Steam Turbines: HP/IP Rotors

State-of-the-Art

• 9-12%Cr Martensitic Steels (X13CrMoCoVNbNB 9 2 1)

Future Requirements

• Higher temperature capability
• Inspectability

Possible Solutions

• Ni-base alloys
• Cooling technology / thermal barrier coatings
Steam Turbines: Casings and Valve Chests

State-of-the-Art

- 9-12%Cr Martensitic Steels
  (G-X13CrMoCoVNbNB 9 2 1)

Future Requirements

- Higher temperature capability
- Castability / Weldability

Possible Solutions

- Ni-base alloys
Steam Turbines: HP/IP Blades

State-of-the-Art

- 9-12%Cr Martensitic Steels (X20CrMoV 12 1)
- Austenitic Steels

Future Requirements

- Higher temperature capability
- Solid Particle Erosion Resistance

Possible Solutions

- Ni-base alloys
- Erosion Resistant Coatings
Steam Turbines: Valve Internals

State-of-the-Art

- 9-12%Cr Martensitic Steels (X20CrMoV 12 1)
- ‘Stellite’ hardfacing

Future Requirements

- Higher temperature capability
- Erosion/Corrosion Resistance

Possible Solutions

- Ni-base alloys
- Abrasion Resistant Coatings
# Steam Turbines: LP Rotors

## State-of-the-Art
- NiCrMoV steels
- Surface treatment

## Future Requirements
- Higher strength
- SCC resistance

## Possible Solutions
- More highly alloyed steels
- Improved surface treatment
## Steam Turbines: LP Blades

### State-of-the-Art
- PH-stainless steels
- Surface treatment

### Future Requirements
- Higher strength
- SCC resistance

### Possible Solutions
- High strength steels with SCC resistance
- High strength steels with protective coatings
## Is success achievable?

<table>
<thead>
<tr>
<th>Issue</th>
<th>Expertise required</th>
<th>Available in UK Industry</th>
<th>Available in UK academia / research establishments</th>
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</thead>
<tbody>
<tr>
<td>Materials with increased strength at high temperature</td>
<td>Alloy development</td>
<td>Yes</td>
<td></td>
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<tr>
<td></td>
<td>Materials modelling</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Long term test capability</td>
<td>Yes</td>
<td>??</td>
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<tr>
<td>Development of coatings</td>
<td>Coating processing technology</td>
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<td></td>
<td>Compositional development of coatings</td>
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<tr>
<td></td>
<td>Long/short term test capability</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Surface Processing</td>
<td>Processing to develop residual stress profile</td>
<td>Yes</td>
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<tr>
<td></td>
<td>Understanding of residual stress development</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td></td>
<td>Long/short term test capability</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>High strength SCC resistant alloys</td>
<td>Alloy development</td>
<td>Yes?</td>
<td></td>
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<td></td>
<td>Materials modelling</td>
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Threats to success

• Materials systems approaching physical temperature limits for applicability
• Long timeframe for materials development cycle – does not fit with 3-4 year funding cycles
• Growing shortage of graduates with necessary skills
High Level Actions Required

• Development of integrated strategy for Energy Materials Development, buy-in from
  - Funding agencies
  - Industry
  - Academia

• Commitment to long-term funding to cover entire materials development cycle

• Active encouragement for pre-competitive collaboration, both national and international

• Attract and retain high quality students/graduates within the Energy Materials field