STEEL
IN HIGH TEMPERATURE POWER PLANT

David Allen

IMPACT PowerTech Ltd

METEC & 2nd ESTAD: European Steel Technology and Application Days

16th June 2015, Düsseldorf

Biography – Dr David Allen

- 37 years experience in the electric power industry – R&D and technical support

- 1990-2014 – at E.ON (formerly PowerGen) Technology Centre, Ratcliffe-on-Soar, UK

- UK and European collaborative R&D, testing and performance of high temperature power plant materials

- Weld “Type IV” cracking, power plant support, “GENSIP” P91 project, advanced “MARBN” materials, Chairman ECCC (European Creep Collaborative Committee)

- From April 2014 – Independent materials consultant – IMPACT PowerTech Ltd

Presentation overview

- Climate change and the energy scene today
- High temperature power plant – Past, present and future
- Steel manufacture – Promises and performance
- Materials for the future – Superalloys – or steels?
- European R&D – Has the EU got it right?

Steel´s Contribution to a Low-Carbon Europe 2050

- ESTAD 2014 Plenary Session
- Joint Study - Boston Consulting Group and Steel Institute VDEh

- EC Roadmap 2011 – CO_2 reduction goal of 83-87% by 2050

- Is this feasible for the steel industry?

- Study conclusion – Almost 60% reduction is feasible – but greater reductions only achievable by making less steel

- However – Steel can also act as CO_2 mitigation enabler

  Weight reduction in cars - 166 MT/a

  More efficient fossil power plants – 102 MT/a

  Renewable energy e.g. wind turbines - 92 MT/a

Global energy – In transition

- Coal – Our dirtiest fuel – but usually the cheapest. Environmental and market drivers in competition.

- Gas – Cheap in the US (fracking), less cheap / secure elsewhere, low capital cost, less CO_2 than coal

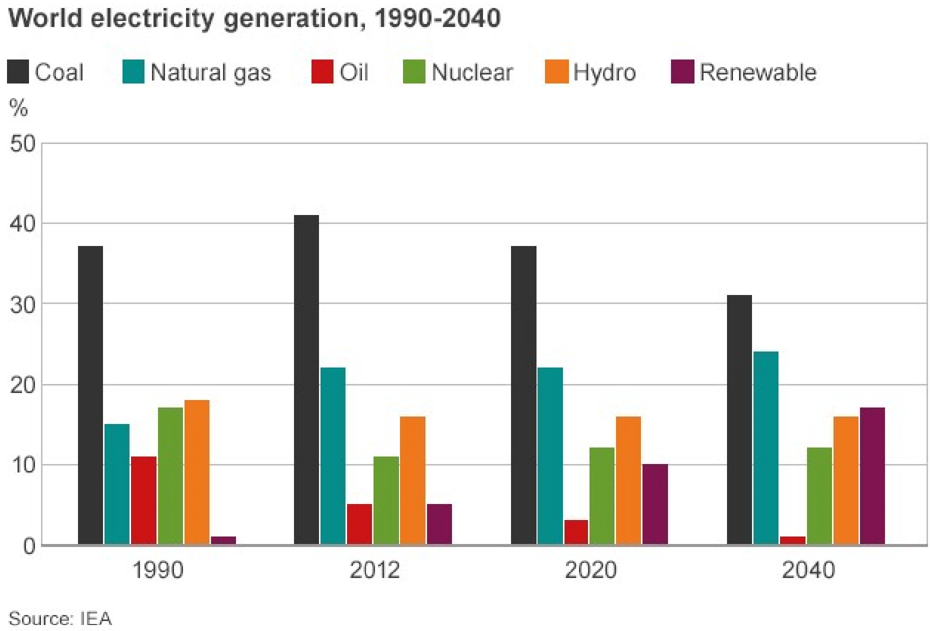
- Nuclear – Low CO_2 but expensive, high risk

- Renewables – Solar photovoltaic, wind energy - Rapid expansion – Intermittent and unpredictable – Expensive but costs falling

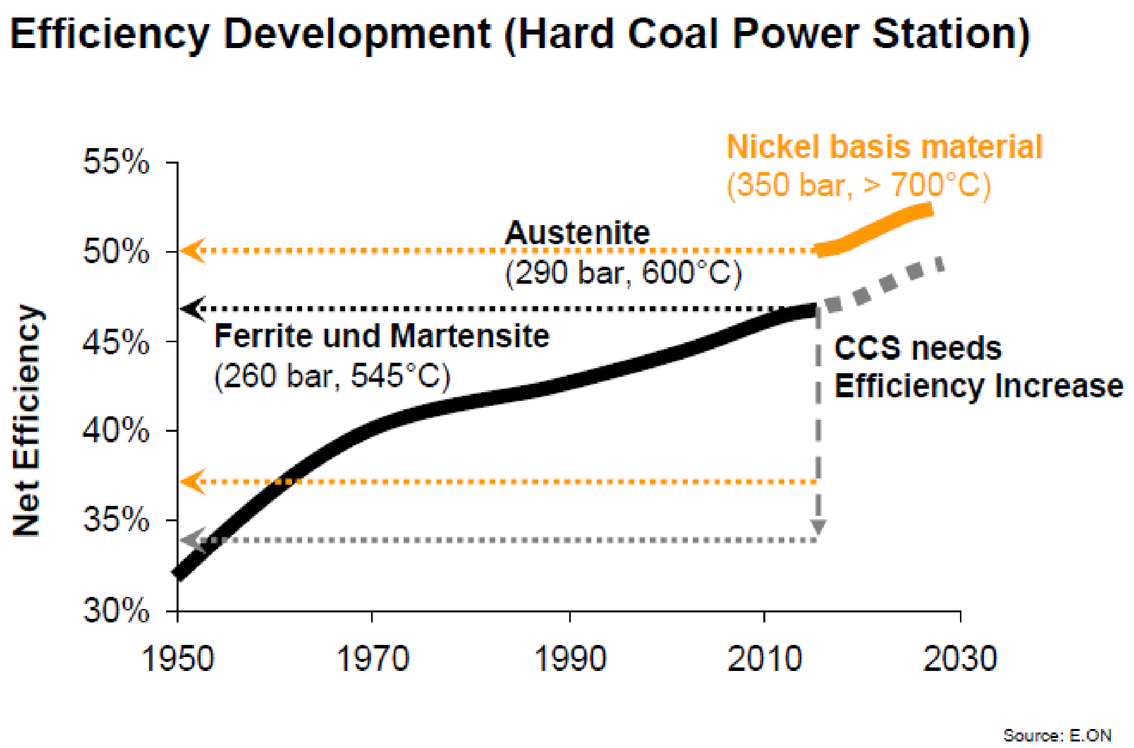
- Challenges for the large scale energy supplier – To operate coal and gas plant with unprecedented flexibility alongside renewables – and make a profit!

Global energy – In transition

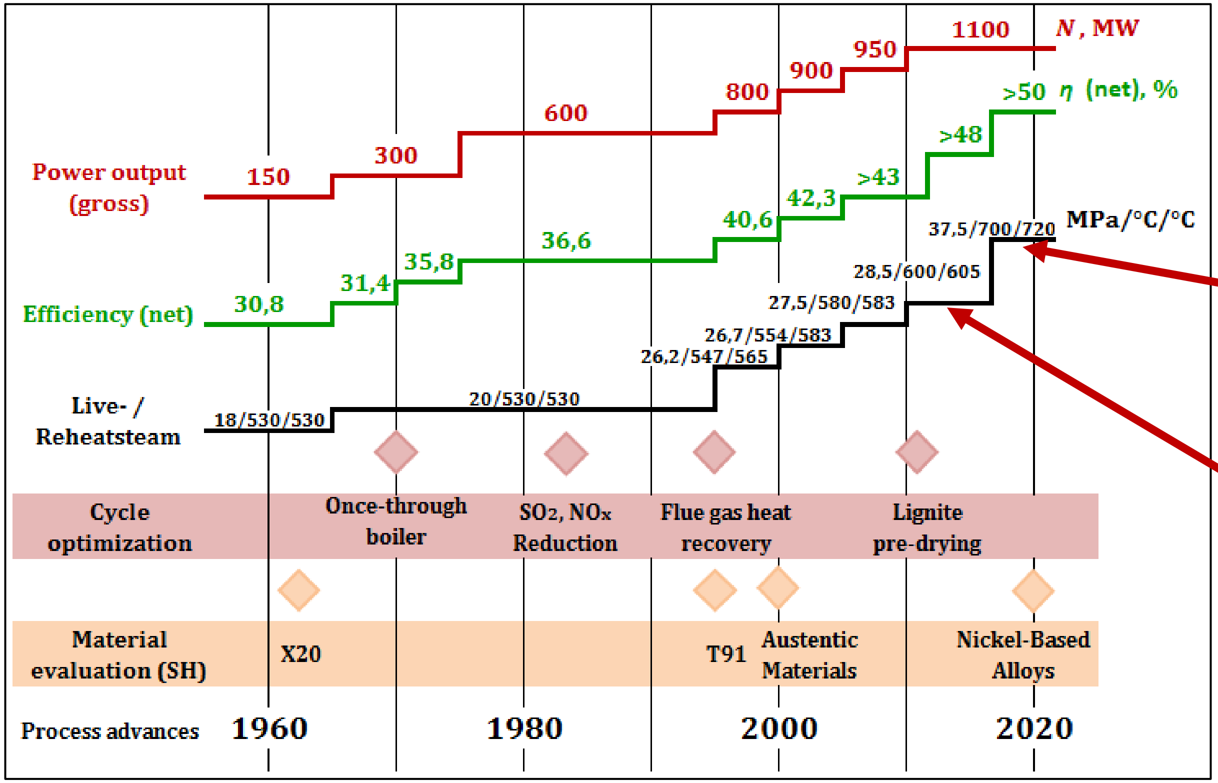
- IEA predict – Market share for coal will fall gradually
- Declining in OECD but growing in Asia and worldwide
- Major contributor to CO_2 emissions – Efficiency matters



Steam power plant efficiency



Steam power plant efficiency



Future ambition

Superalloy plant

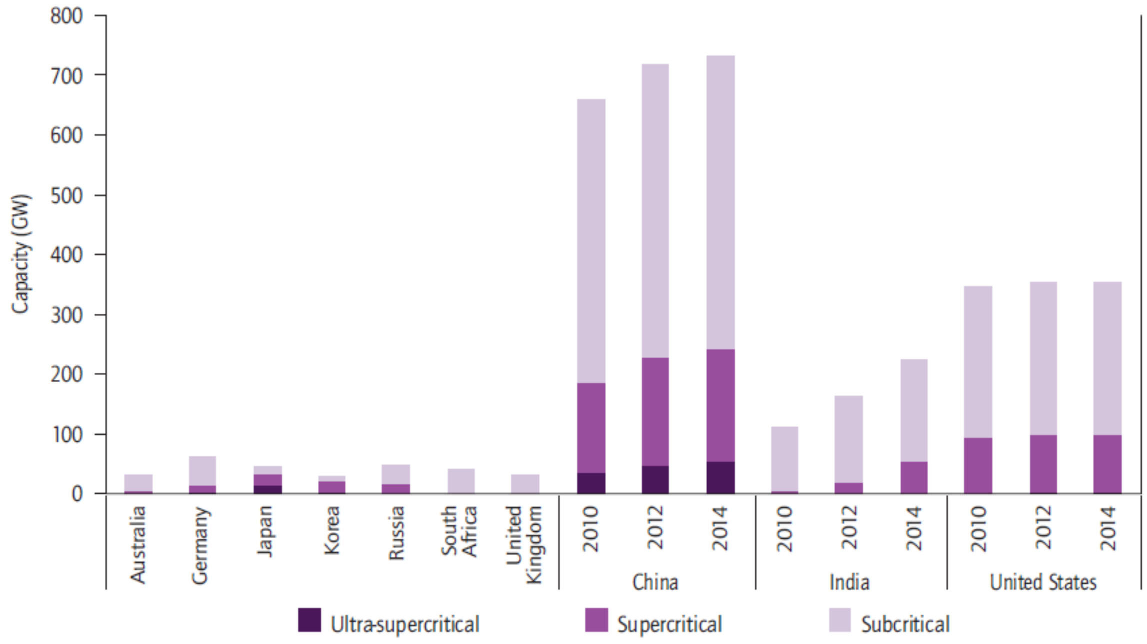
Best next step?

Current technology

High alloy steels, austenitic tubing

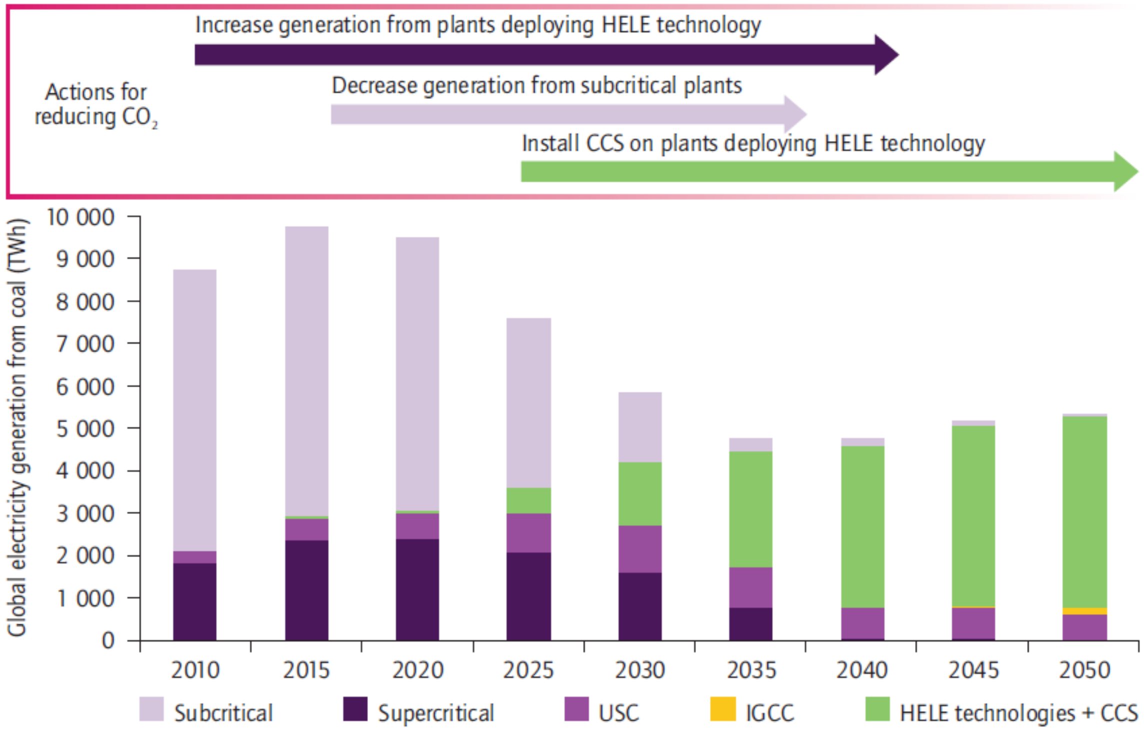
Steam power plant efficiency

- In reality - Older, less efficient plant is predominant
- Only a minority of current plant is higher efficiency "supercritical" or "ultrasupercritical" (USC)



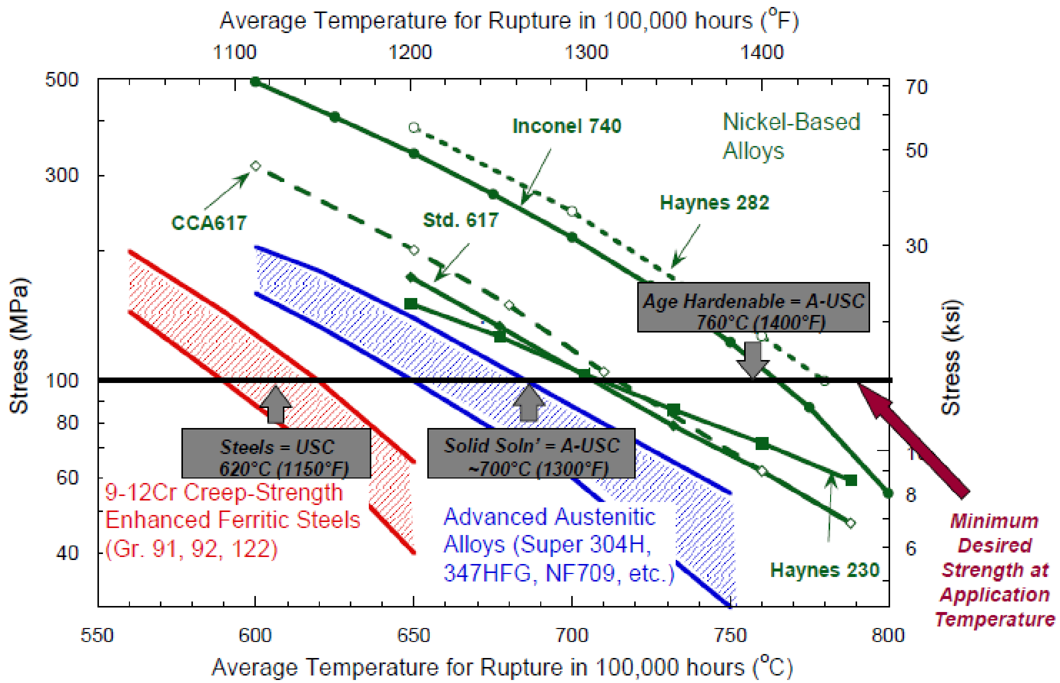
Steam power plant efficiency

- One vision of the future (IEA) – Inefficient subcritical coal plant to be replaced by USC and then by "HELE" (high efficiency low emission) plant with CCS (carbon capture and storage)



Steam power plant efficiency

- Materials development - crucial to maximise efficiency



- Stainless steels and nickel alloys – Used now in boiler tubing – But issues with cost, thermal expansion, low conductivity, poor inspectability, weld relaxation cracking and creep-fatigue performance may be barriers to wider deployment and the goal of a 700°C+ steam power plant
- What about improved ferritic / martensitic steels?

Martensitic power plant steels – P91

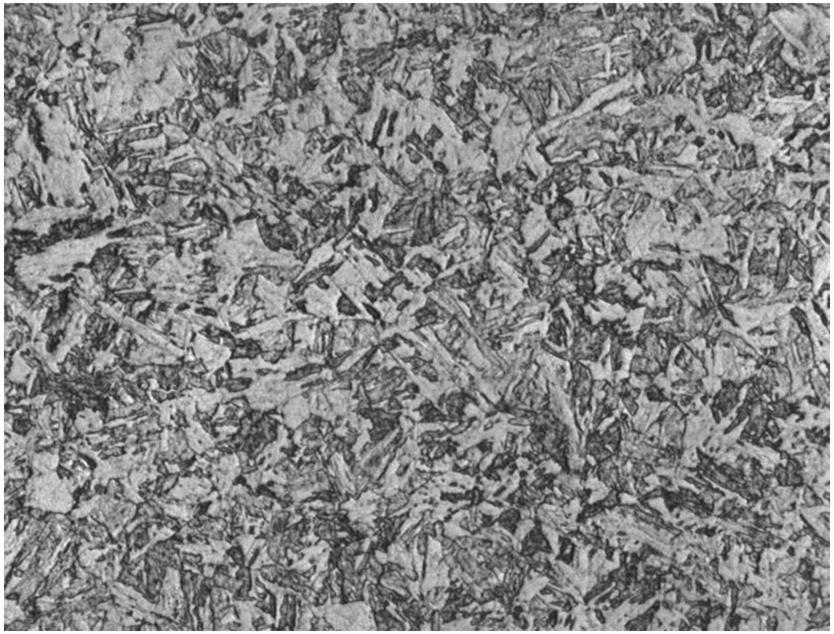
- Much current subcritical steam power plant
  - uses traditional low alloy steels (US P11 / P22, UK CrMoV steel, German X20)
  - operates at e.g. 550-570°C

- From ≈1990 – Modified 9Cr (“P91”) – X10CrMoVNb9-1 martensitic steel available for retrofit components and new plant, capable of operating up to 580-600°C

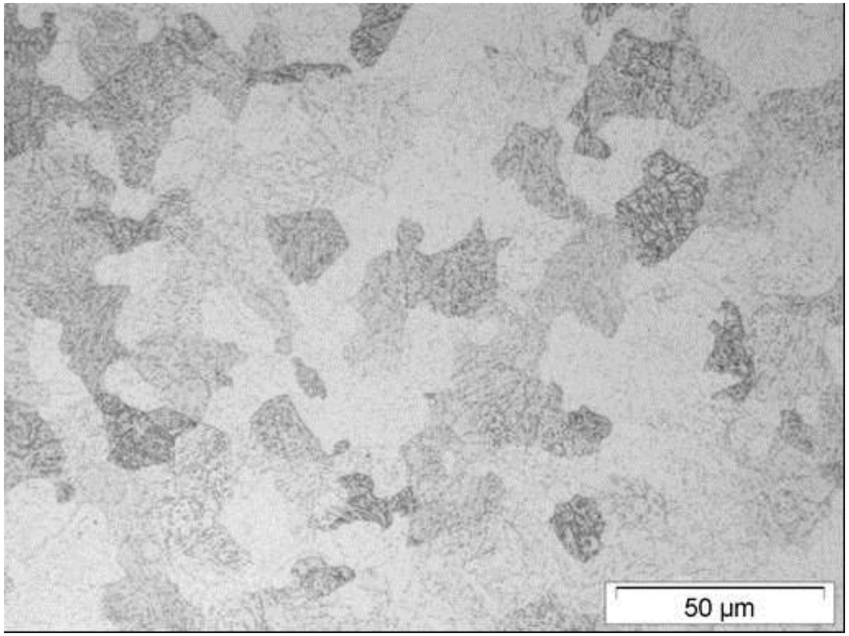
- Used extensively e.g. in UK for retrofit headers – thinner hence less susceptible to thermal fatigue

- Yet when CrMoV pipework had to be replaced, most end users chose simple like-for-like replacement with CrMoV, even though P91 would have been cheaper. Why?

P91 steel – Risk of faulty heat treatment



Normal martensitic P91 – 203HV



Aberrant ferritic P91 – 151HV

With old low alloy steels, deviations from correct heat treatment may have little effect on performance. P91 is much less forgiving!

Conservative end users may prefer "tried-and-trusted" materials.

IMPACT PowerTech

P91 Steel – Risk of Weld “Type IV” Cracking

- Design codes do not make proper allowance for welds
- Early HAZ cracking – Avoidable by better design
- Current debate (EPRI) – Instead use very high purity specs?

Martensitic Steels – The Future?

- P91 – Today's leading boiler and HRSG high temperature plant steel – Generally accepted despite quality and design / performance issues – Limited to ≈580-600°C max.

- P92 (X10CrWMoVNb9-2) – A stronger, more recent alternative – Proven capability up to ≈600-620°C – Not always favoured for new plant – Concerns relating to low creep ductility, possible consequent risk of creep-fatigue failure in flexible operation.

- "**MARBN**" (**MAR**tensitic **B**oron-**N**itrogen) steel – 9Cr3W3CoVNbB(N) – Originated in Japan (Prof. Abe). Developed in the UK ("IMPACT" project) and Austria (TU Graz / Voestalpine) – Now being taken forward within the European "KMM-VIN*" research framework **http://www.kmm-vin.info/**

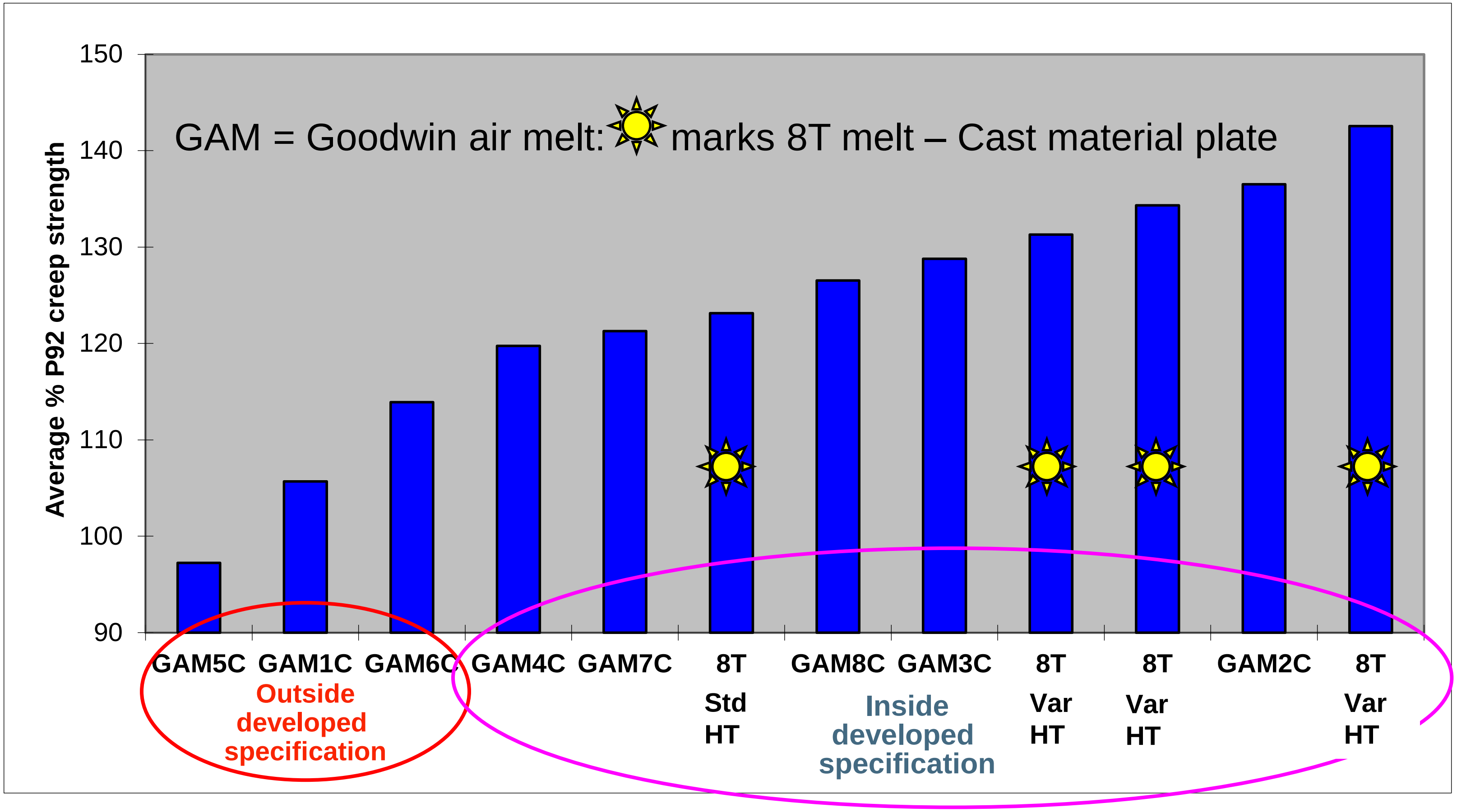
- A faster, surer way toward improved fossil plant efficiency than the superalloy plant option?

MARBN – The UK “IMPACT” project

- UK Government (TSB) part-funded industry-led collaboration
- 4 years – 2010 to end 2013
- Development of advanced welded MARBN steels for USC power plant
- tners
- E.ON, Ratcliffe (Nottingham), UK – plant user
- Doosan Power, Renfrew (Glasgow), UK – boilers / welding
- Alstom, Rugby, UK – turbines
- Goodwin Steel Castings, Stoke-on-Trent, UK – cast materials supplier
- National Physical Laboratory, Teddington, UK – monitoring technology
- Loughborough Univ., UK – microstructural characterisation and modelling

Alstom, Doosan, E.ON, Goodwin and Loughborough, with IMPACT PowerTech, subsequently agreed an ongoing self-funded collaboration, “IMPEL”, within KMM-VIN

IMPACT - creep data on MARBN variants



Within wide specification range, MARBN showed 20-40% greater creep strength than P92, indicating ≈ 25°C higher capability, saving ≈2% in fuel costs and CO_2 (much more vs. older plant)

IMPACT 8 Tonne Melt Production – May 2012

- The Melt being Poured from the AOD Vessel

- The Pouring of the Bonnet Casting

3,500Kg Ingot

Cast Material
Test Plates
(≈30-60mm thickness)

Courtesy of Goodwin Steel Castings Ltd

Photographs by Ryan McLachlan and Letian Li, Loughborough University

MARBN – Next steps

- Ongoing development in KMM-VIN
- Microstructure studies (TU Graz, Loughborough Univ) – Optimised heat treatment – IMPACT showed that normalising at 1200°C is optimal for BN control and creep performance, but other factors may suggest a lower temnperature
- Long term creep data generation on cast MARBN – TU Darmstadt, TU Graz, Alstom UK
- LCF and creep-fatigue – IfW Freiburg, Univ of Galway
- Welding development – TU Chemnitz, Doosan Babcock
- Manufacture of pipe and tube – UK “IMPULSE” project

ECCC and COST – A need for EU R&D funding?

- **ECCC** – Launched with EU funding – 1993-2005

Europe's forum for collaborative high temperature testing and data assessment to generate reliable design strength values

- 2005–2011 – Unfunded, reduced effort
- 2011 to date – Relaunched as an industry-sponsored "JIP" (Joint Industrial Programme) organised by CSM, Italy
- **COST 501/522/ 536 –** Launched with EU funding – 1980-2010

Europe's forum for collaborative development of advanced high temperature steels

- 2010 – Unfunded, reduced effort
- 2012 to date – Relaunched as an industry-organised working group within KMM-VIN
- Reduced EU support for power plant materials R&D – Wise?

ECCC and COST – A case for EU funding?

- ECCC (performance) and "COST" (development) – Both European materials collaborations launched but abandoned by European R&D funding (NB, predated EU R&D shift away from fossil power)
- Successfully relaunched – ECCC JIP, KMM-VIN WG2 – But:
- **Does Europe make good decisions on R&D?**

Look outside Europe

- US – "Military-industrial complex" – State / industry partnership
- Japan – Companies, academia, and state closely linked
- South Korea and others believe – Strong state, strong industry

All these nations show commitment to industrial strength through the long term development of powerful institutions in partnership between the private and public sectors

ECCC and COST – A case for EU funding?

Look inside Europe

- Private enterprise v State power – Seen as political opposites
- Overlapping levels of national and supranational government
- R&D is primarily funded on a short term competitive basis
- Companies form temporary ad-hoc alliances to spend public funds on limited-term one-off projects
- Materials development takes decades – but we do not get funded unless we pretend otherwise
- R&D – Governed by political goals (but NB, hence Europe leads on climate change)
- Does it work? Or, should Europe do more to boost long term collaborations like ECCC and "COST" advanced materials?
- Improved fossil plant efficiency – Now gets far less funding than renewables – but paradoxically, could save more CO_2!