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UK-US Collaboration in Fossil Energy Technology

Task 3: Gas turbines fired on syngas and other fuel gases

14 May, 2009
Pittsburgh

Overview

- **Partners**
- **Background**
- **Objectives**
- **Work program**
- **Results / achievements**
- **Benefits of collaboration**
- **Future activities**

UK:

Alstom Power Ltd

Cranfield University*

Siemens Industrial Turbomachinery Ltd

US:

Oak Ridge National Laboratory

Siemens Energy Inc*

**Task Leaders*

Background – Novel Environments

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Advanced Turbine Operating Conditions

	Syngas Turbine 2010	Hydrogen Turbine 2015-2020	Oxy-Fuel Turbine 2010	Oxy-Fuel Turbine 2015-2020
Combustor Exhaust Temp, °F (°C)	~ +2700 (~ +1480)	~ +2700 (~ +1480)		
Turbine Inlet Temp, °F (°C)	~2500 (~1370)	~2600 (~1425)	~1150 (~620)	~1400 (~760) (HP) ~3200 (~1760) (IP)
Turbine Exhaust Temp, °F (°C)	~1100 (~595)	~1100 (~595)		
Turbine Inlet Pressure, psig	~265	~300	~450	~1500 (HP) ~625 (IP)
Combustor Exhaust Composition, %	CO_2 (9.27) H_2O (8.5) N_2 (72.8) Ar (0.8) O_2 (8.6)	CO_2 (1.4) H_2O (17.3) N_2 (72.2) Ar (0.9) O_2 (8.2)	H_2O (82) CO_2 (17) O_2 (0.1) N_2 (1.1) Ar (1)	H_2O (75-90) CO_2 (25-10) O_2, N_2, Ar (1.7)

NETL

R.A.Dennis, "FE Research Direction – Thermal Barrier Coatings and Health Monitoring Techniques," Workshop on Advanced Coating Materials and Technology for Extreme Environments, Pennsylvania State University, State College, PA, September 12 - 13, 2006

N:/Turbine/MAA/vin UTSR Materials DOE Perspective 102507

Current engines with fuel flexibility (Crude oil, Diesel, Dirty contaminants)

Background – Target Areas

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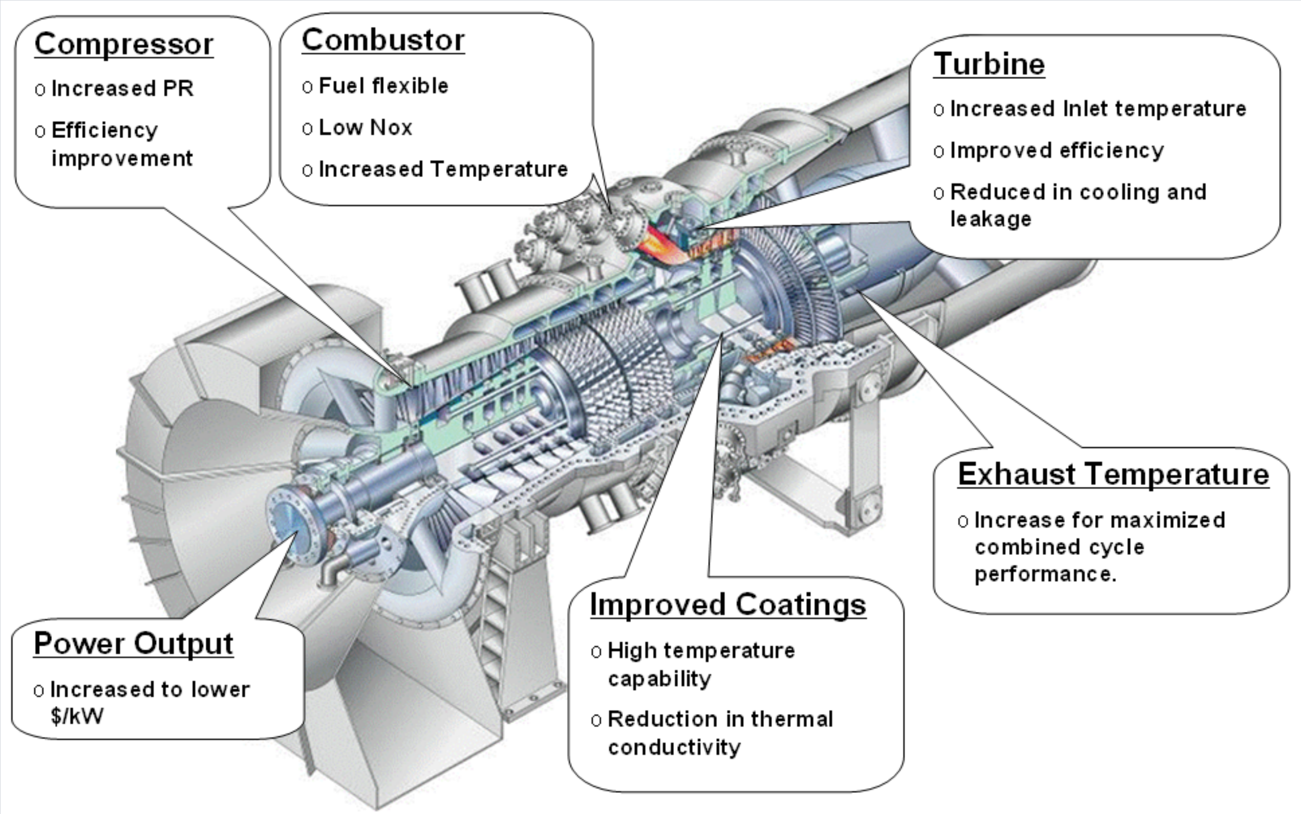
IGCC Plant

- Improved Efficiency
- Fuel Flexibility NG,Syngas,H_2
- Low Emissions
- Reduction in Plant Cost $/KW
- CO_2 Sequestration Ready



Program Development and Major Activities are Driven by Plant Level Goals

Background – Task Focus

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Task focused on:

- changes expected in the future fuel gases
- impact on hot gas path components in the power turbine
  - blades, vanes and combustor cans
  - enhanced corrosion, erosion and deposition
  - reduced component lifetimes
  - reduced viability of gas turbines
- correct selection of advanced materials
  - corrosion resistant coatings
  - thermal barrier coatings (TBCs)
  - route to counter higher levels of contaminants

IGCC Materials Behavior - 1

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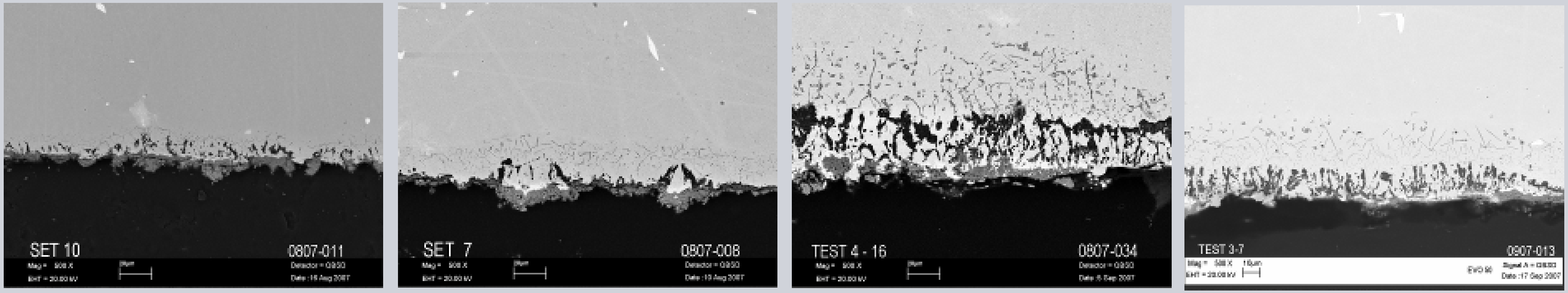
Fuel Composition

NG	IGCC #1	IGCC #2	High H_2



- **Alloy degradation depends on gas composition.**
- **A set of boundary conditions needs to be established for each working fluid.**
- **An evaluation into the effect of corrosion species and degradation mechanisms is ongoing**

IGCC Materials Behavior - 2

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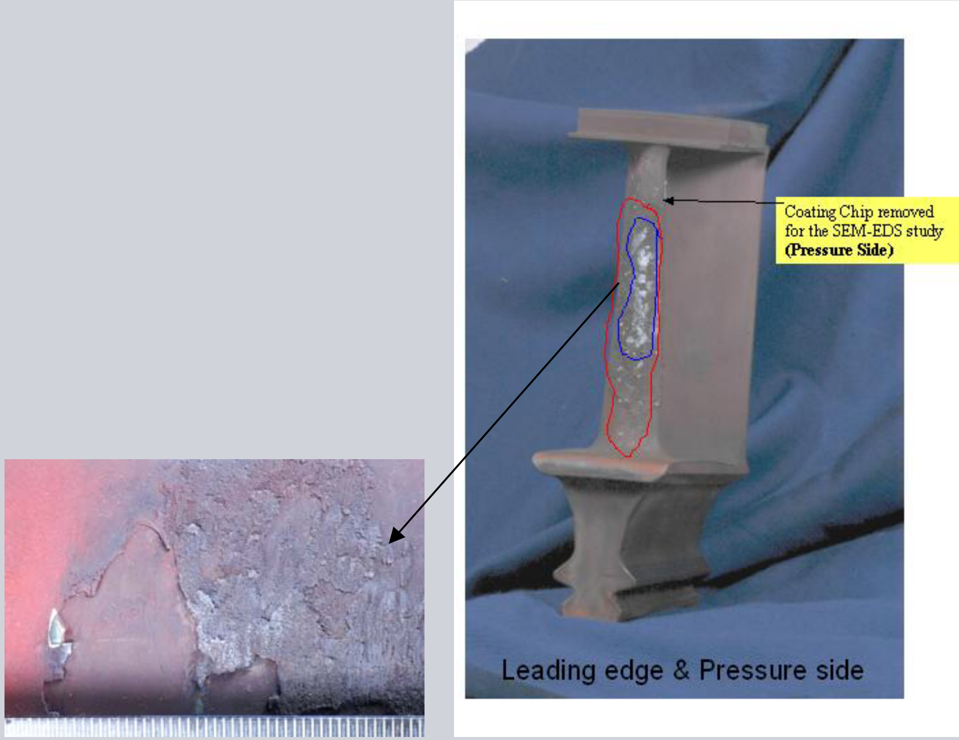
Effect of Fly Ash

Ash type	SiO_2	Fe_2O_3	Al_2O_3	CaO	Na_2O	K_2O
Typical coal	40	17	24	5·8	0·8	2·4
Forest residue	17·8	1·6	3·6	45·5	2·1	8·5
Wheat straw	37·1	0·8	2·7	4·9	9·7	21·7
Synthetic coal	55	10	25	5	1	1
Synthetic coal + 30 wt-% wood	45	0	20	2·5	4	10
Synthetic straw	37	1	3	5	10	12
Fly ash (SCA)	14·1	2·7	2·9	20·7	1·0	8·1



Deposition of molten reactants from the ash creates the aggressive environment. Molten salts cause initial rapid hot corrosion via fluxing reactions between planar interlamellar porosity resulting in debonding of the surface lenticular splats

Formation of red deposit on the blade, deposit formation similar to the one observed due to Fly Ash

Post combustion concentration vary from above concentrations

Fuel Compositions for Varied Coal/Biomass Feedstocks

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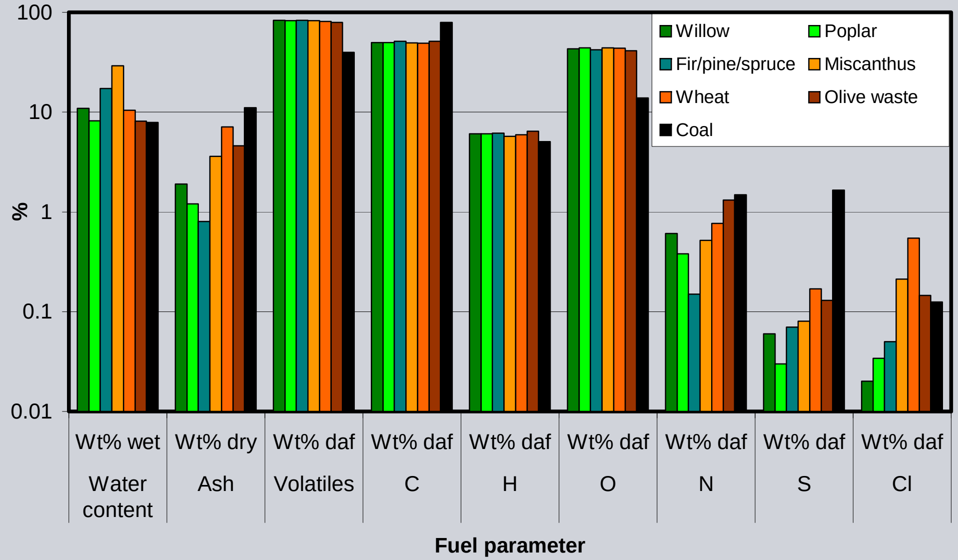

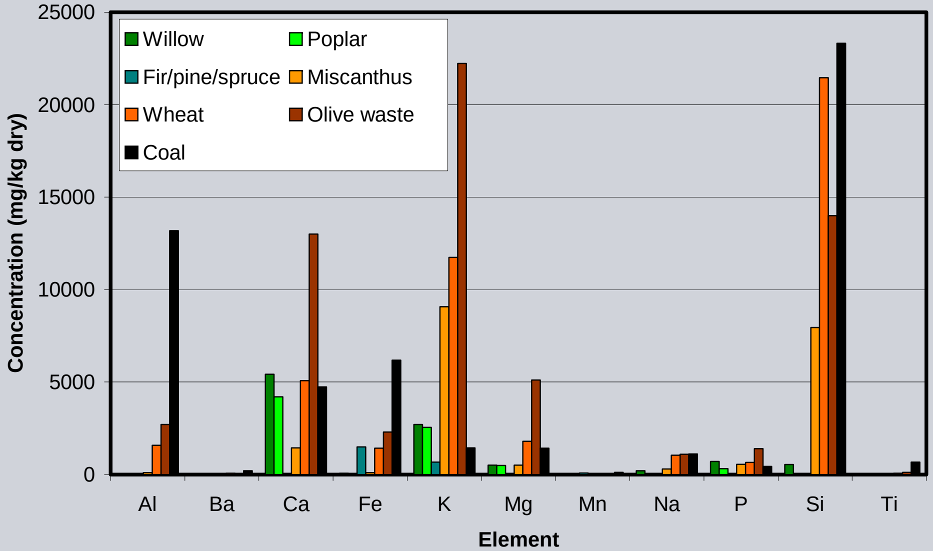

Varied concentration of contaminants can results in varied materials behavior

Fate of Gasified Fuel Particle

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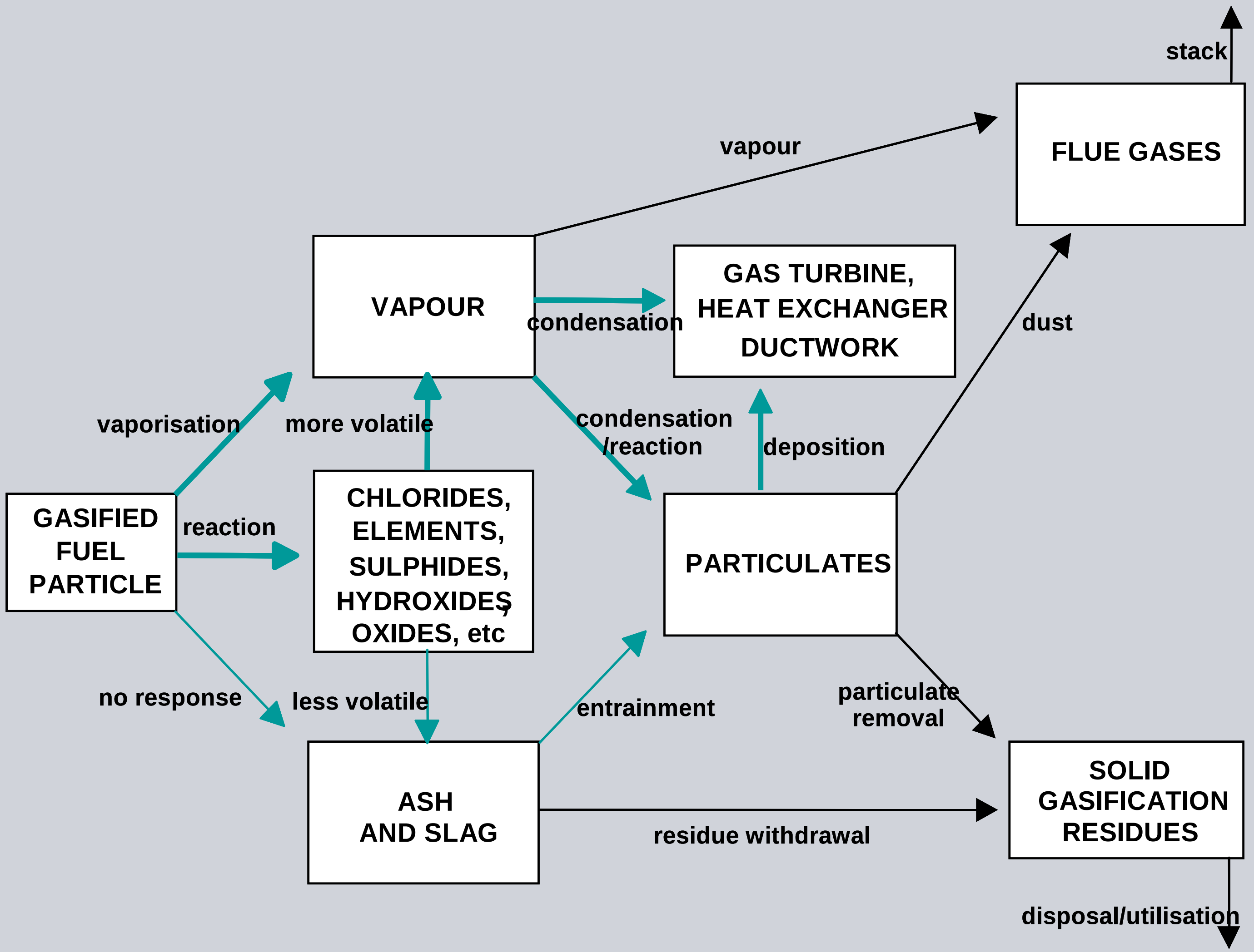

Volatility of Trace Species in Gasification

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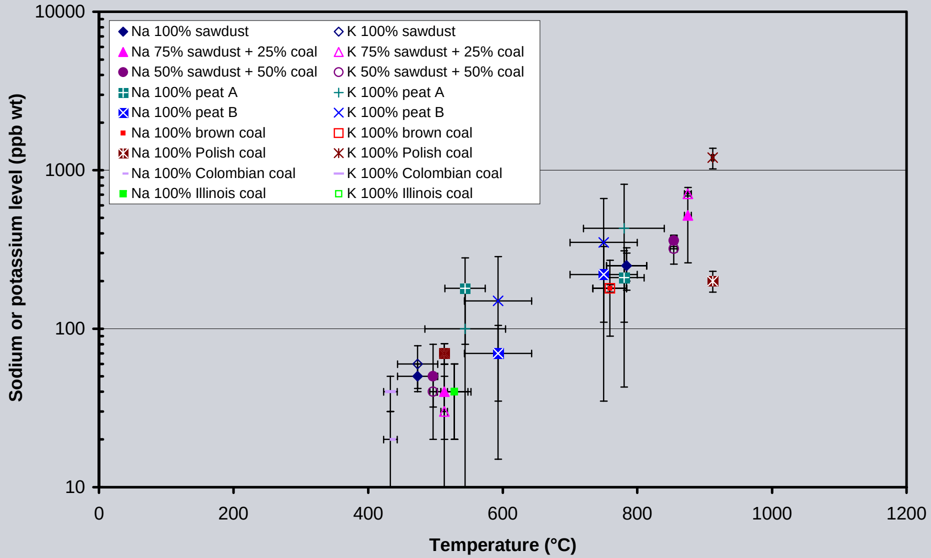
Increasing Volatility	Element
	Hg, Sb, Se (As, V, B)
	Cd, Pb, Sn, Zn (As, B)
	Co, Cu, K, Mn, Mo, Na
	As, Ba, Be
	Ca (V, As, B)

( ) sensitive to air vs oxygen gasification



Effect of Hot Gas Filtration on Alkali Levels in Gasification Gases

Gas Contaminant Levels in Combusted Gasifier-derived Fuel Gases

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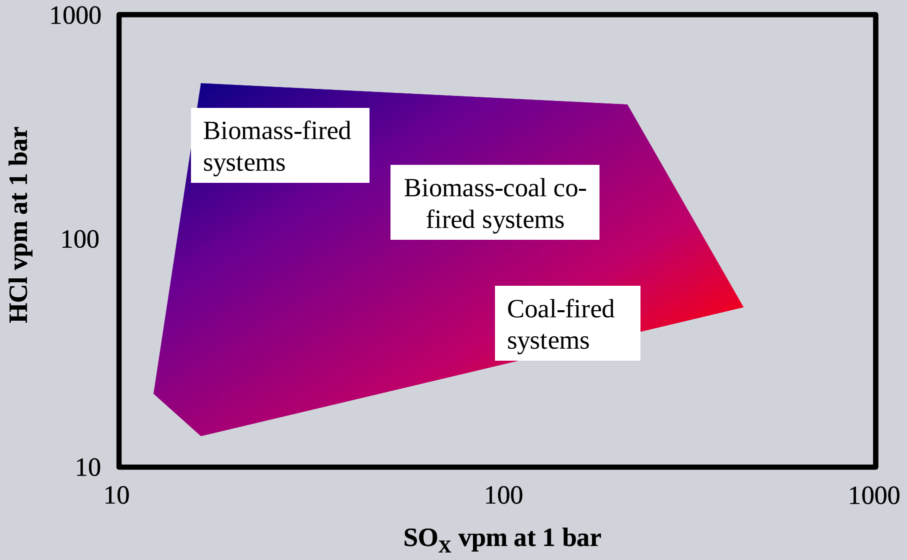

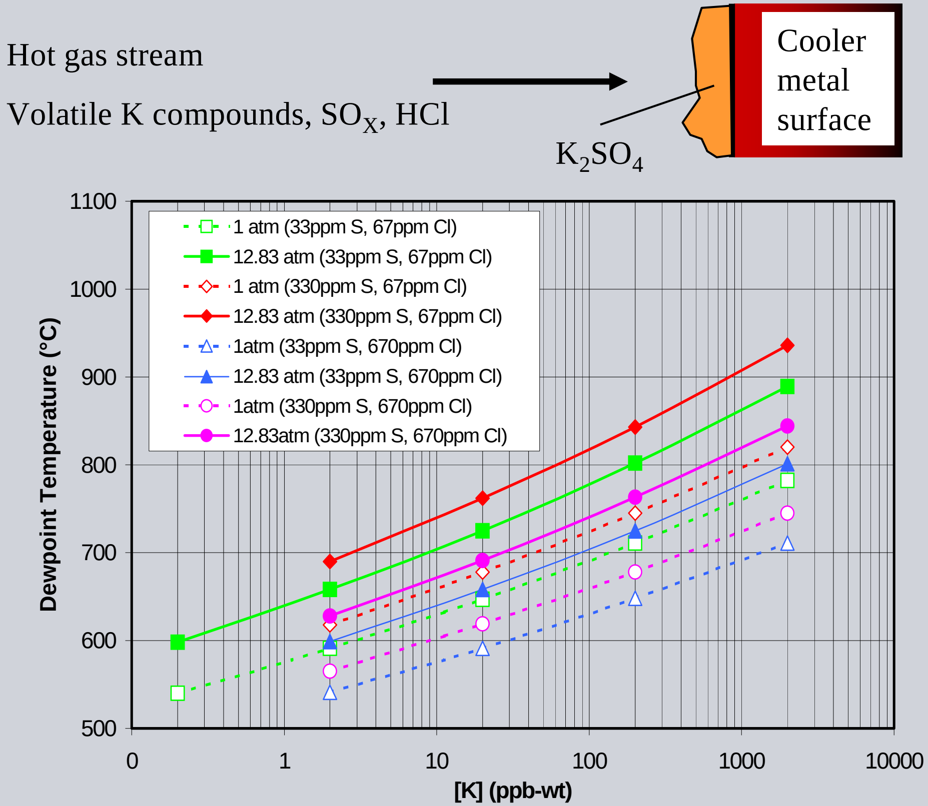

IGCC Materials Behavior – 3
Bond coat Behavior in Combusted Environments

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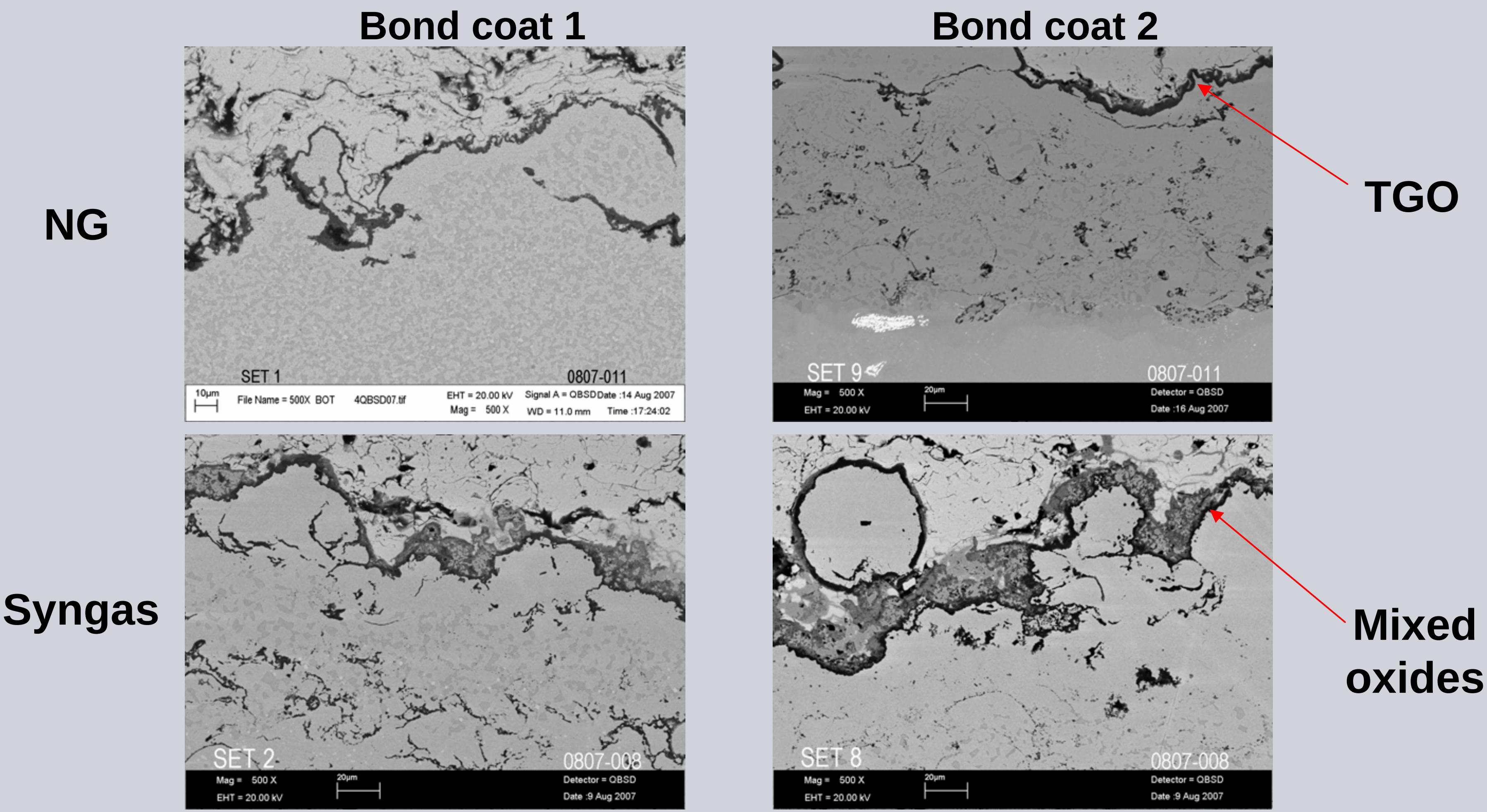

Need to investigate the kinetics of mixed oxide formation as TGO

Task 3: Objectives

- To quantify the major effects of low calorie value (LCV) fuels, including coal, biomass and waste derived syngas, on gas turbine materials to support component design and life prediction.

- To characterize the range of fuel gas atmospheres anticipated in coal and biomass gasification systems.

- To model the range of gases and expose selected alloy/coating combinations to burner rig testing and determine deposition rates and the erosion / corrosion resistance of state-of-the-art material systems over the appropriate temperature range.

- To identify the fuel/operating conditions and the candidate alloy and coating combinations which are most appropriate to the gas turbine power generating systems under consideration.

Task 3: Major Deliverables

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- Characterization maps showing the range of gas turbine atmospheres likely to result from the gasification of various coal, biomass and waste sources.
- Quantification and ranking of critical alloys and coatings in terms of their erosion and corrosion resistance and the provision of data on selected alloys and alloy/coating combinations exposed under burner rig test conditions in a range of simulated industrial gas turbine syngas atmospheres (in progress).
- Definition of fuel/operating combinations leading to service problems, consideration of avoidance strategies and the development of lifing procedures (Phase 2).

Task 3: Test Conditions

Burner rig tests based on:

Diesel fired (Alstom Power, UK);

- equivalent to 4 ppm Na, 4 ppm K, 1 wt% S in liquid fuel

IGCC derived syngas plus coal-ash loading (Siemens, USA)

H_2 enriched IGCC derived syngas plus coal-ash loading (Siemens, USA)

Pyrolysis based fuel gas (Siemens, UK)

Burner rig test conditions defined in terms of inputs to rig or targets in exposure section, remembering:

Natural gas fired

Atmospheric pressure (need to compensate for difference to maintain dewpoints)

Add contaminants to combustion chamber

Burner rig – Schematic Diagram

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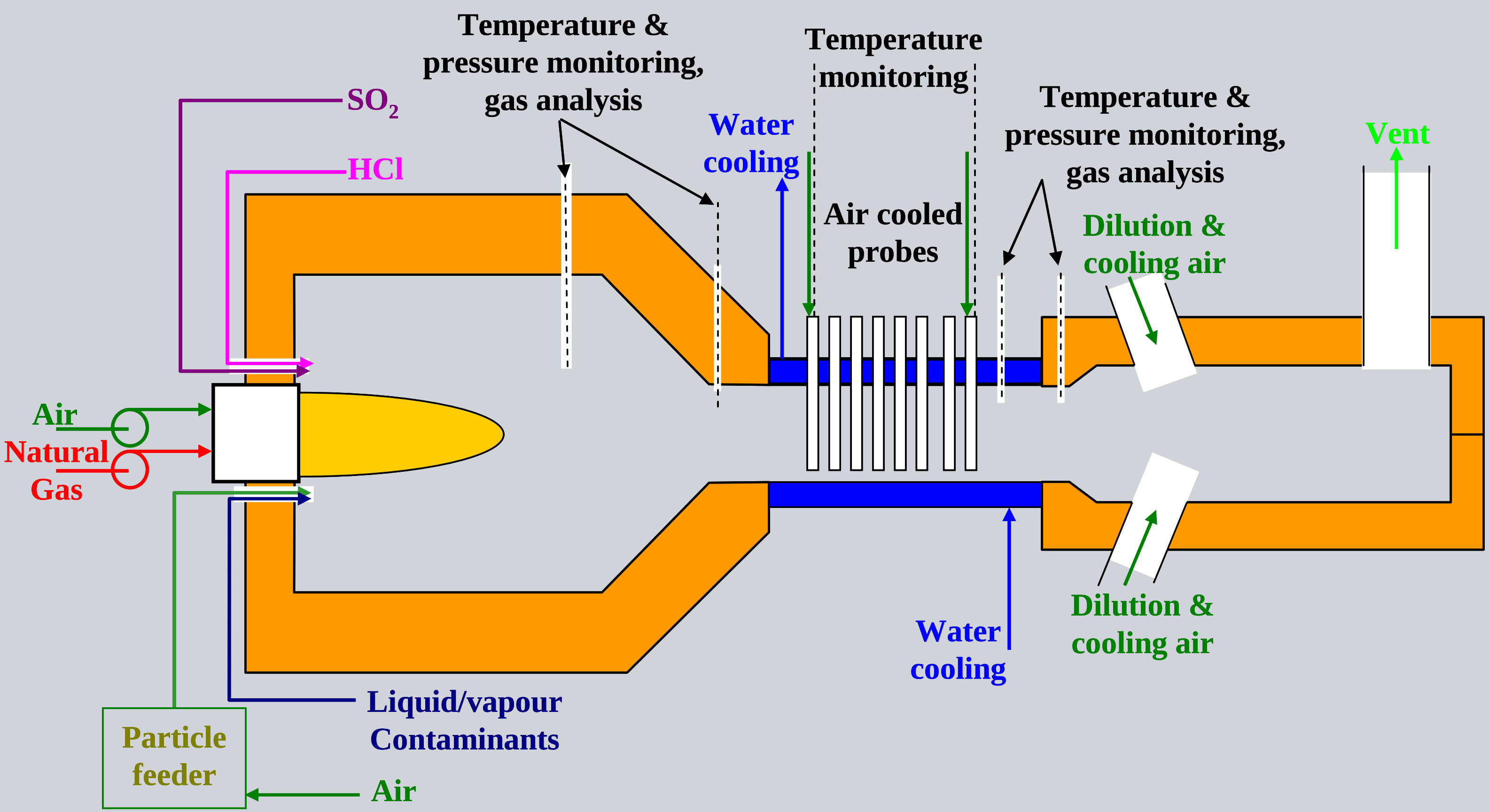

Burner rig – Test Conditions

Parameter to set	Units	Test 1	Test 2	Test 3	Test 4
UK / US		UK	US	US	UK
Gas temperature at entry to exp. section	°C	1180	1180	1250	1180
Gas velocity	m/s	50	50	50	50
Dust (type)		-	pf fly ash (sieved)	-	-
Dust loading	ppm or mg/h	-	2	-	-
SO_x	vppm	300	300	300	300
HCl	vppm	-	-	-	-
H_2O	% vol	8.7	8.7	~20	9.7
Na	ppb or mg/h	125 ppb	125 ppb	125 ppb	80
K	ppb or mg/h	125 ppb	125 ppb	125 ppb	80

Burner rig – Materials Systems

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24 materials systems selected

12 UK

12 US

Base alloys (UK+US)

CMSX4
IN738LC
Haynes 230
MarM247
IN939
CM247LC
Hastelloy X
PWA1483

Coatings (UK+US)

Corrosion resistant or bond coatings

- HVOF ‘LCO22’
- EB MCrAlY (PWP 286)
- HVOF SV21
- APS SL30
- CERAL 10
- Amdry 995
- 2464
- 2231
- 2453

Thermal barrier coatings (TBCs)

- EB-PVD
- APS
- Porous APS

Cranfield Burner Rig: Diesel Oil + Contaminants

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Bond coated HastX

Alloy (CM)247LC

IN939

300 hours

1000 hours

Diesel Oil
nominal contaminant levels
125 ppb Na (weight)
125 ppb K (weight)
625 ppm SO_2 (weight)
Water content 11.3% vol.

Nominal inlet gas temperature = 1180 °C

Nominal outlet gas temperature = 930°C

Nominal external probe temperature = 950 °C

Probe temperatures measured at the mid-point. 60-70°C variation along probe length.

Preliminary Results Confirm the Need for an Increased Integrity of Coated Substrates

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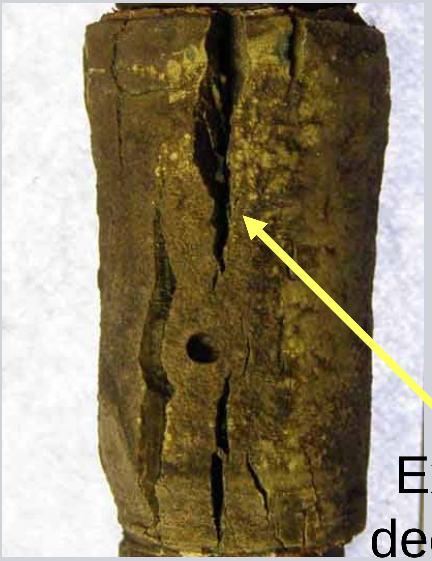
Uncoated substrate

Overlay coated substrate

Bond coat & TBC coated substrate



Extensive degradation

Failure initiation

Less severe damage of coated specimens compared to bare alloys

Materials Comparison: 1000 hrs / T_{metal} 750 °C

Diesel oil w impurities

Bond coated IN939

Bond coated (CM)247LC

Bond coated PWA1483

Corrosion

Syngas w impurities + Dust

Bond coated IN939

Bond coated (CM)247LC

Bond coated PWA1483

Corrosion / erosion

High H2 w impurities

Bond coated IN939

Bond coated (CM)247LC

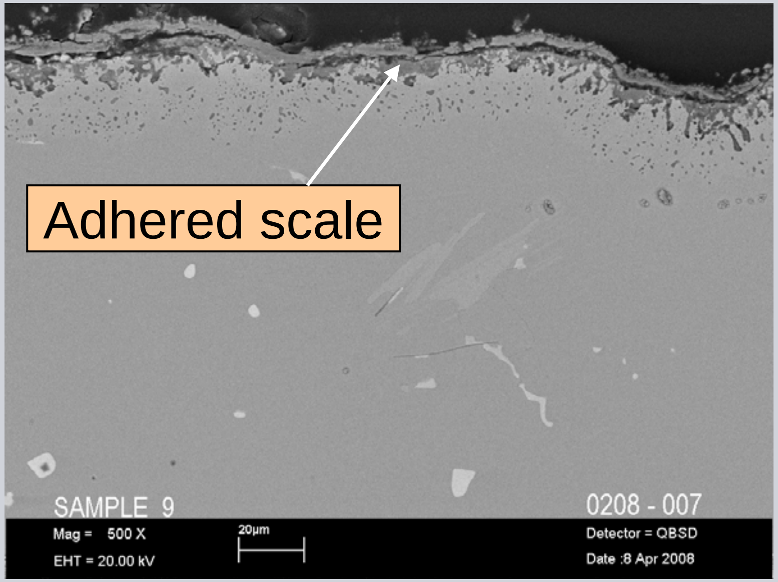
Bond coated PWA1483

Corrosion & moisture

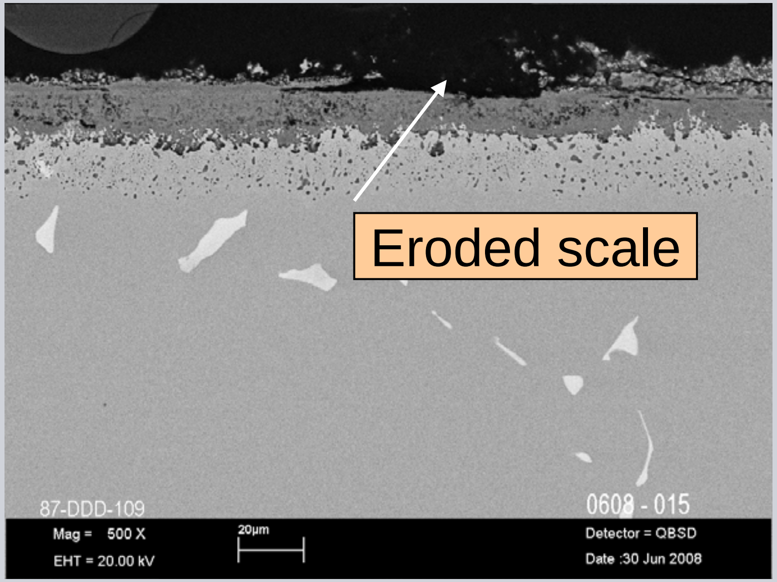
Alloy Performance Comparison

(T_{gas} = 1180 °C / T_{metal} = 950 °C)

IN939 (Diesel oil)
1000 h (Test 1)



IN939 (Syngas)
1000 h (Test 2)



Increased oxide thickness and depth of degradation in IGCC environments

Ongoing Work

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- Complete the characterization to test samples from burner rig test 3 (high hydrogen) and 4 (biomass) to determine extent of damage compared to first two tests.
- Quantification and ranking of critical alloys and coatings in terms of their corrosion resistance exposed under burner rig test conditions in a range of simulated industrial gas turbine syngas atmospheres.
- Definition of fuel/operating combinations leading to service problems, consideration of avoidance strategies and the development of lifing procedures.

Increase confidence in materials data in multi-fuel operation, specifically driven by the engine requirements.

Potential Activities

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- Evaluation of material performance under multiple drive gas conditions to evaluate impact of fuel flexibility.
- Determining the degradation of state-of-the-art materials/coatings under such IGCC/CCS operating conditions – covering oxidation, corrosion, erosion, thermal cycling (including interactions with mechanical properties).
- Provide novel concepts for better oxidation/corrosion resistance alloys and coatings.
- Development and validation of life prediction methods and extrapolation to high pressure/high velocity environments.
- Assessment of current limitations of the Cranfield burner rig to test high temperature/high velocity conditions for IGCC/CCS environments - potential to upgrade the rig capability for testing DOE 2010 goals (T_{gas} combustor exhaust ~1500 °C) with corrosive and ash loading for simulation of IGCC/CCS environments.