Collaboration With the U.K.
in
Cleaner Coal Technology

Overview of FE's US-UK Implementing Arrangement

Pittsburgh, PA
May 24, 2010

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Office of Fossil Energy

MOU Between US DOE and UK DTI on Collaboration in Energy R&D

- Signed by Secretary Bill Richardson in 2000
- Fossil Energy, Renewable Energy, Waste-related management, Energy end-use technologies
- Task Shared Collaborations: sharing tasks, facilities, scientific and technical information, and human resources

Implementing Arrangement between US DOE and UK DTI to Cooperate in the Field of Fossil Energy Technology

- Signed March 11, 2003 by Secretary Spencer Abraham and DTI's Secretary Patricia Hewitt

- FE's IA was first executed under MOU

- Remains the most active and robust collaboration under the MOU

Task Development Criteria

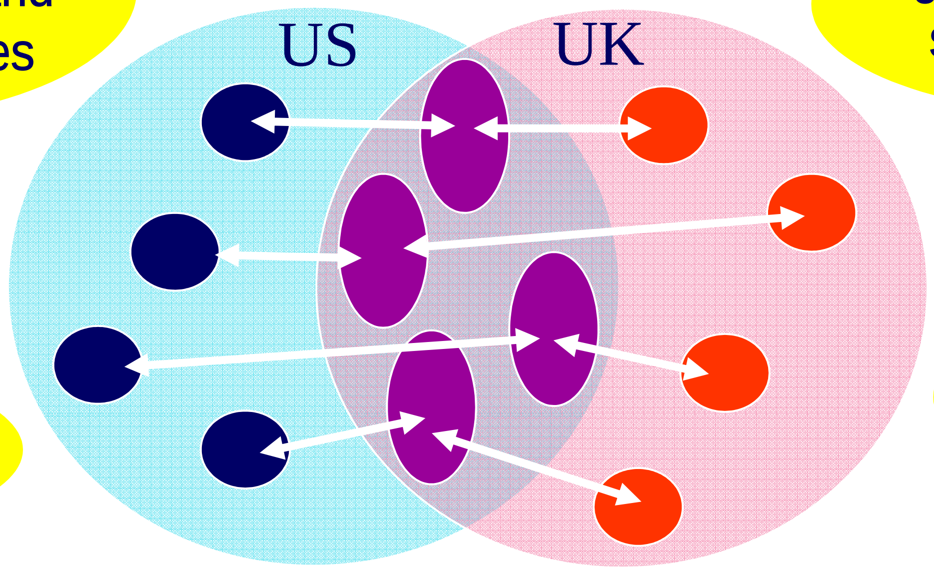
- Quid pro quo
- US tasks are drawn from currently existing research
- Task sharing based agreement
- Highest priority areas….of common interest
- Types of collaboration will include:
  - Joint project planning
  - Technical information exchange
  - Personnel exchange

Benefits of Collaboration

Increased specialist knowledge pool

Improved vision of industrial needs and national strategies

Highly cost effective - small extra cost



Critical review of methods & results

Access to unique facilities

Reduced risk of wasted effort

Improved confidence in outputs

Less time to develop design & modelling capability

Improved quantity & quality of data

PARTICIPANT SECTION
[Password Required]

JOINT COORDINATING COMMITTEE

TECHNOLOGY AREAS

- Advanced Materials
- Virtual Plant Simulation

United States - United Kingdom Collaboration on Fossil Energy Research and Development

A website supporting the Implementing Arrangement between the Department of Energy of the United States of America and the Department of Energy and Climate Change (formerly known as the Department for Business, Enterprise & Regulatory Reform) of the United Kingdom of Great Britain and Northern Ireland to cooperate in the field of fossil energy technology.

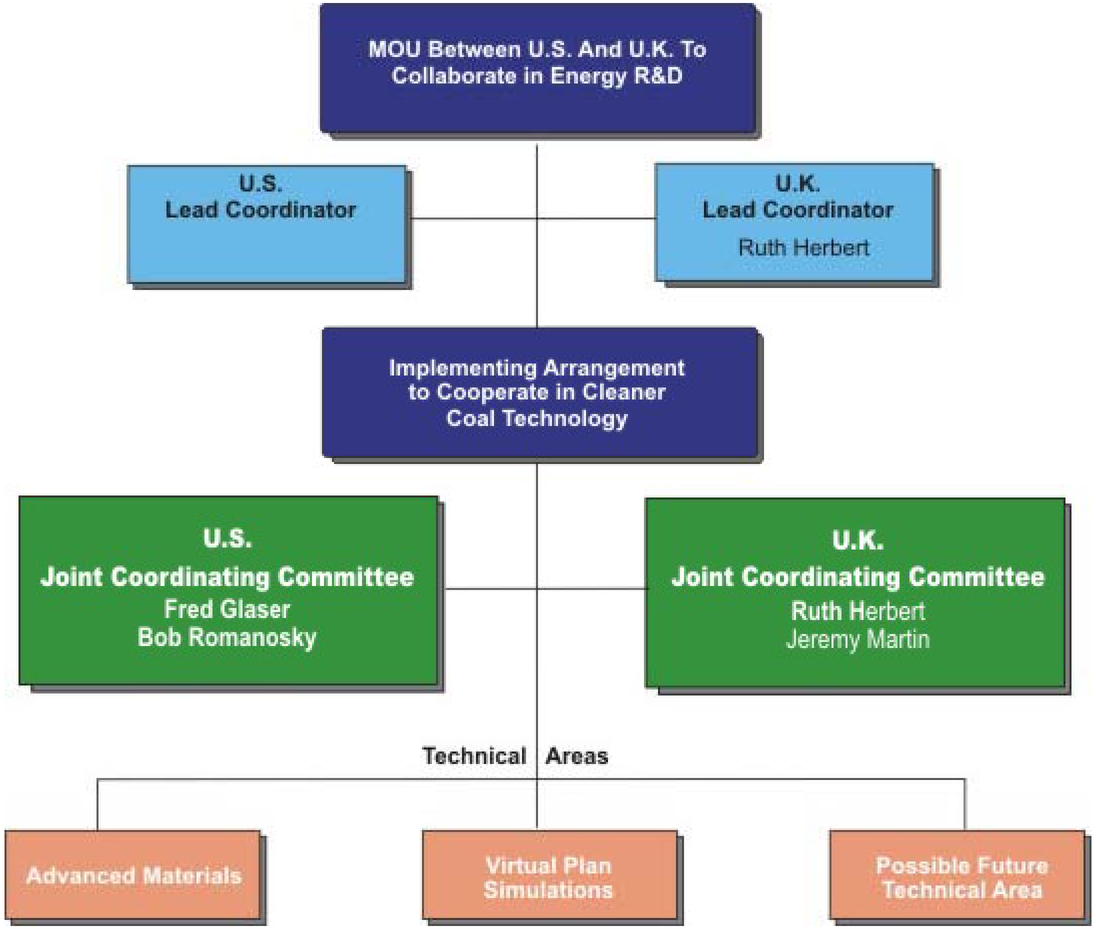
- The Memorandum of Understanding

  A framework to continue, expand, and maximize cooperation in energy research and development between the two nations signed on November 6, 2000.

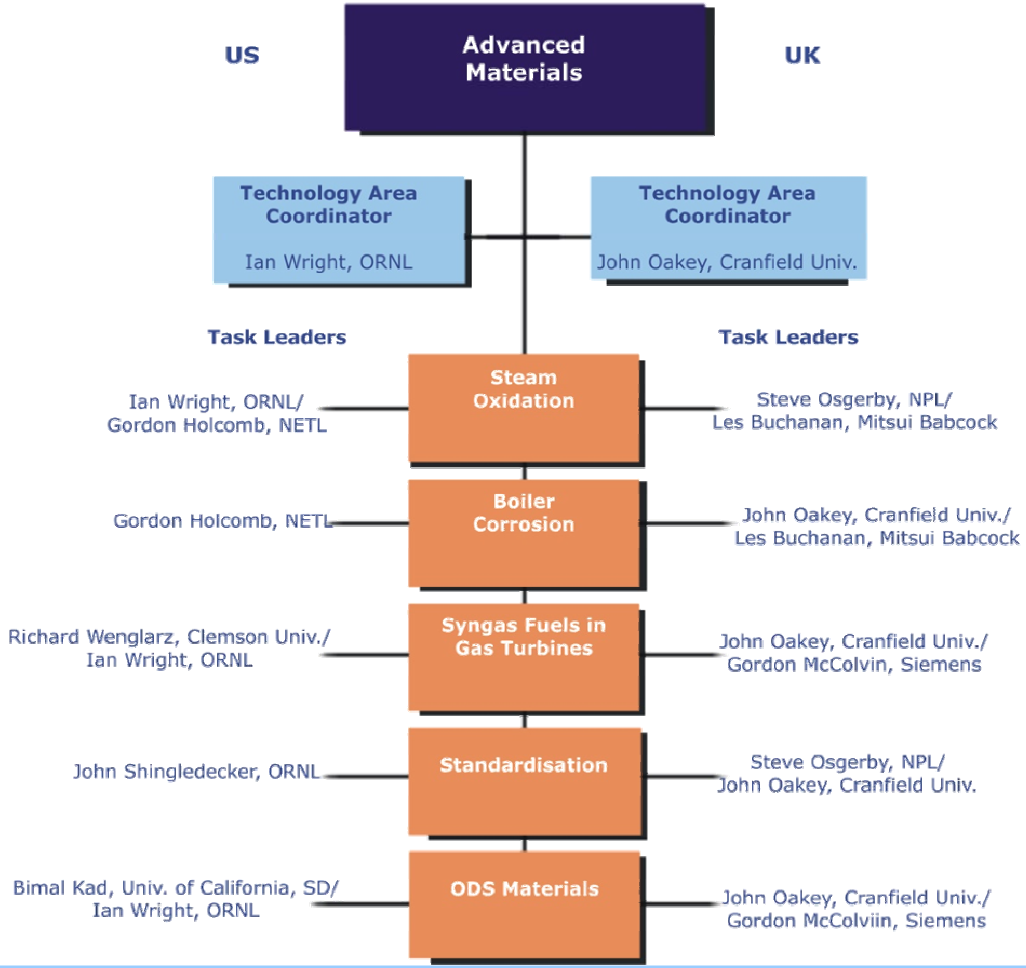
- The Implementing Arrangement

  An arrangement signed on March 10, 2003, reflecting the two nations' interest in the joint planning and exchange of information and personnel in the field of cleaner coal technology, and for exploring opportunities for expanded fossil energy utilization.

Organizational Chart for the Joint Coordinating Committee



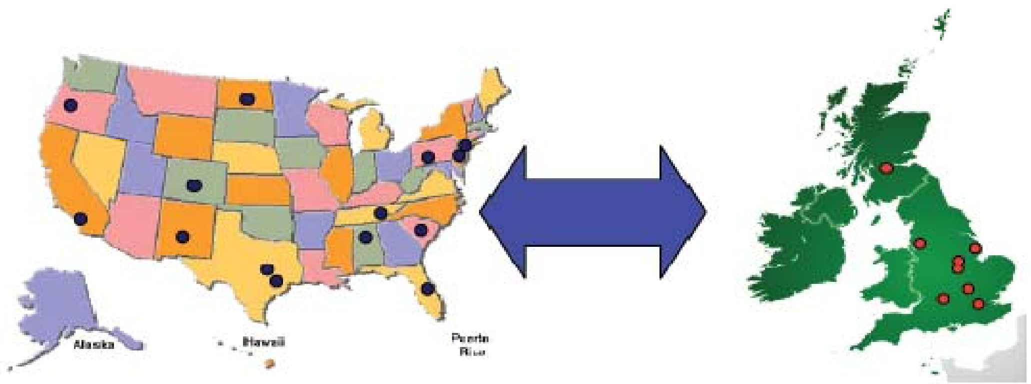
Organizational Chart for Advanced Materials – Phase I



US-UK Collaboration on Fossil Energy R&D Advanced Materials

Tasks

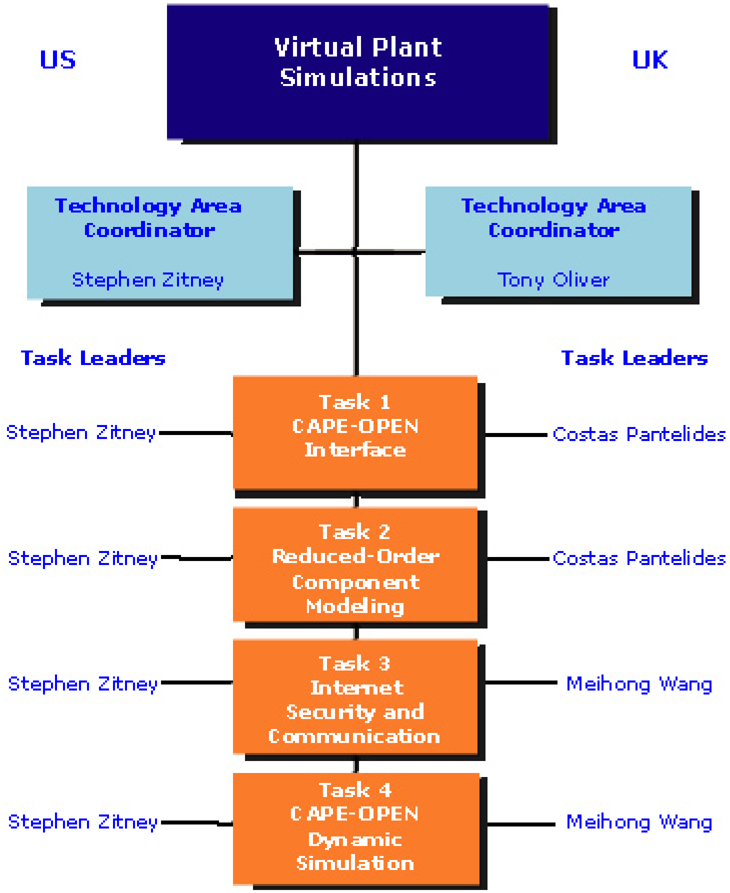
- **Steam Oxidation**
- **Boiler Corrosion & Monitoring**
- **Gas Turbines Fired on Syngas and Other Fuel Gases**
- **Oxide Dispersion-Strengthened (ODS) Alloys**
- **Standards & Databases**



Participants

- *NETL*
- *ORNL*
- *Reaction Engineering International*
- *Siemens*
- *University of North Dakota, EERC*
- *University of California, San Diego*
- *Alstom Power - UK*
- *Cranfield University - UK*
- *Doosan-Babcock Energy - UK*
- *National Physics Laboratory - UK*
- *Rwe Group - UK*
- *University of Liverpool - UK*

Organizational Chart for Virtual Plan Simulations



background

Under the auspices of the UK-US Memorandum of Understanding (MOU) and the associated Implementing Agreement for Fossil Energy Research and Technology Development, a number of organizations from the UK and US have participated in a five-year collaboration on advanced materials supported by the UK Department of Energy and Climate Change (DECC) and the US Department of Energy (DOE).

As one of the areas under the MOU, advanced materials was identified as a key underpinning technology. The development, characterization and understanding of advanced materials will help the UK and US fossil energy industries to develop new and cleaner power generation systems with lower cost, improved time-to-deployment, and reduced technical and commercial risk.

A developed understanding of advanced materials is a key prerequisite which must be satisfied in order to achieve the targets of any future energy policy. Stringent environmental and efficiency targets will necessitate the development of more advanced materials and components, systems, manufacturing methods and improved life assessment methods. The impact of changes such as; fuel type, plant operating cycles/environments and the introduction of CO_2 capture technology will also place severe demands on the materials and components used in power plant equipment.

objectives

The key objective of the UK-US collaboration was to share and develop the partners' knowledge and expertise in the key area of high-temperature materials for advanced fossil energy power plant applications.

This would be achieved through such mechanisms as: sharing of test facilities and best practices, development of common tools and methods, and industrial secondments. The opportunity to develop long-term cooperation in advanced materials from the experience gained during project collaborations was also recognized.

More specific technical objectives related to:

- Optimized test methods, data analysis and storage
- Development of life time prediction tools
- Materials evaluation techniques and ranking methodologies
- Joining and thermomechanical processing

These were to be delivered through five technical tasks, approved under the Implementing Arrangement, covering:

- Steam oxidation
- Boiler corrosion
- Gas turbines fired on syngas and other fuel gases
- Standards and databases
- Oxide Dispersion Strengthened (ODS) alloys

work programme and key results

The five technical tasks were selected as being those most appropriate for equitable collaboration, where both UK and US partners could maximise the value and benefits to their organizations. The criteria adopted in selecting these tasks included:

- Nature of the technology challenge
- Added value of collaboration
- Complementary skill sets
- Absence of any IPR issues
- Ability to share and use outputs
- Equality of inputs from both countries

1. Steam oxidation

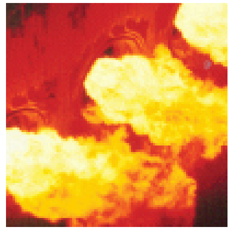
This task was driven by the need to develop and qualify materials for high efficiency ultrasupercritical (USC) steam power plant which are capable of operating at higher temperatures (up to 760°C) and pressures. The programme comprised three discrete areas.

- A state of the art review of steam oxidation data
- Steam oxidation testing to fill gaps and extend data coverage
- Development of models to simulate oxide growth and exfoliation

Key results

- Over one million hours of new steam oxidation data generated for thirty alloys
- Two new high pressure steam test facilities commissioned and fully operational
- Improved oxide growth and exfoliation models developed for use in life prediction methodologies and future power plant design

2. Boiler corrosion



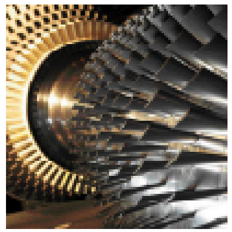
The driver for this task was to gain a better understanding of the mechanisms and the monitoring of fireside corrosion, which is a key life limiting factor in existing power plant boilers. Boiler corrosion is becoming more of an issue as a result of the more arduous operating conditions associated with current and future developments, such as NOx emission control, co-firing, USC steam technology and oxy-fuel firing. This programme focussed on two main areas:

- The development of representative laboratory scale boiler corrosion tests and the evaluation of their results
- The development, implementation and assessment of fireside corrosion probes to measure corrosion rates on-line

Key results

- Comprehensive high temperature corrosion data generation and analysis allowed ranking of the performance of boiler materials in a variety of atmospheres to be carried out
- Effects on corrosion of more novel technologies such as oxy-fuel and co-firing have been measured
- Corrosion probe technologies have been evaluated and demonstrated under real operating conditions providing important indicators for commercial probe development

3. Gas Turbines fired on syngas and other fuel gases



In moving towards higher efficiency power generation systems, the use of gasification-based combined cycle technologies have become increasingly attractive. These technologies produce fuel gases derived from a range of feedstocks including coal, biomass and waste. All of these fuel gases contain contaminants detrimental to the gas turbine system, compared to natural gas, and these effects need to be quantified to identify the best operating conditions and to aid materials selection. This task focussed on two areas:

- Assessment of future fuels and their effects on the operating environments on hot gas path components
- Ranking of a range of candidate alloys and coating systems through high velocity burner rig testing, simulating a range of operating conditions

Key results

- Materials damage and degradation mechanisms have been identified and measured which can be used in lifetime modelling of hot gas path components
- High-velocity, high-temperature burner rig tests under simulated operating environments of future gas turbine systems, combined with advanced analytical techniques, have facilitated the ranking of various alloy and coating systems. This will assist in materials selection for future components

4. Standards and databases

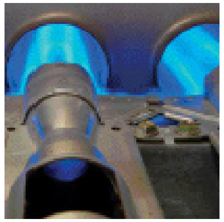
The continued drive for the development of new and improved materials and the optimum use of existing materials in a cost-effective manner is leading to a critical need to ensure data from different sources can be combined. Whilst this is highly cost effective, it is essential that such shared results and test methods are truly comparable and meaningful. To achieve this, it is vital that the methods used and the results from each source are evaluated, shared, stored and analyzed using agreed standard methods. This task recognized the fact that this collaboration would generate data from different laboratories using a range of methods. The following activities were undertaken to explore the comparability of data from these sources:

- A review of existing standards and test methods
- The development of a data exchange and storage tool, accessible by all partners
- An inter-laboratory comparison of the test methods used for boiler corrosion and steam oxidation testing

Key results

- A standard method of data collection, exchange, analysis and storage (including microstructural) has been designed and demonstrated
- Inter-laboratory tests have demonstrated the clear need for improved standardization of high-temperature corrosion and oxidation testing

5. Oxide dispersion strengthened alloys (ODS)



Due to their excellent high temperature properties, ODS alloys have potential for application in the next-generation high-temperature power plant, where good creep strength and oxidation resistance are required. However, due to the nature of the material, their use in service requires a number of challenges to be overcome, including (i) low creep strength of joints fabricated by conventional fusion welding methods and (ii) the optimization of secondary recrystallization to produce microstructures where large grains can be custom-oriented with respect to the maximum stress in service. This task set out to evaluate and overcome some of these challenges, by:

- Addressing joint strength through the evaluation of a number of different joining (friction stir, diffusion bonding) techniques
- Addressing ways to manipulate and customise secondary recrystallization through the development of techniques (eg cross-rolling, flow forming) to modify the microstructure of the material

Key results

- Joining technologies have been evaluated and the feasibility of producing joints with creep strengths comparable with the parent material demonstrated
- Thermo-mechanical methods for improving the microstructural evolution of ODS alloys have been successfully demonstrated allowing optimum strength to be aligned with the direction of maximum operating stress

benefits and future activities

The benefits of the collaboration to the UK and US fossil energy industries can be recognized through:

- The value of the collaboration through sharing data, facilities and experience, leading to reduced cost and effort
- The combination of the partners' experience to obtain better understanding of materials behavior and degradation mechanisms which may arise in future advanced fossil-fired power plant operation
- Identifying and resolving problems when comparing data from different sources and recognizing the importance of standardization
- Developing combined analysis and predictive tools (and hardware) to improve future component development and lifetime prediction methods
- Establishing a solid platform for future collaborations with agreed equitable programs

Continued UK-US collaboration on advanced materials will help accelerate the development of competitive low-emission power plant solutions with significantly reduced development costs and technical risk. These future programs will include further work on steam oxidation, boiler corrosion, syngas in gas turbines and ODS alloys. Additional programs in the area of Plant Asset Management are also being considered. It is anticipated that these programs will commence in 2009.

project duration

April 2004 - April 2009

project partners

UK:
Alstom Power
Cranfield University
Doosan Babcock Energy Ltd
Liverpool University
National Physical Laboratory
RWE
Siemens Industrial Turbomachinery Ltd

US:
Alstom Power
Covanta Energy
Honeywell Process Solutions
Intercorr International
Interface Welding Inc
MER Corporation
NETL
Oakridge National Laboratories
Reaction Engineering International
Siemens
University of California
University of North Dakota

Further information on the UK-US Collaboration on Energy Research and Development, please visit - http://us-uk.fossil.energy.gov/

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Advanced Materials

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Doosan-Babcock Energy
* National Physical Laboratory

US:
* Oak Ridge National Laboratory
National Energy Technology Laboratory

* Task Leaders

Steam Oxidation

background

In recent years interest in the development of steam-generating power plants with increased efficiencies has led to the need to develop and qualify materials capable of operating at steam temperatures and pressures significantly higher than those employed in current power plants. On-going programs in Europe and Japan envisage steam conditions increasing in stages from 600ºC to 700ºC (1112 to 1292ºF), and in the USA to 760ºC (1400ºF). The overall focus of these national programs is on using ferritic steels to the maximum possible temperature, before switching to austenitic steels or Ni-based alloys.

As a result, there has been considerable emphasis on improving the high-temperature creep properties of 9-12% Cr ferritic steels which currently appear to be capable of use up to approximately 620ºC (1148ºF) and 30 MPa (4500 psi). However, the relatively low Cr content of these alloys affects their resistance to steam oxidation at these higher temperatures. For the highest steam temperatures envisaged, only nickel-based alloys have the required strength, and for 760ºC, a precipitation-strengthened Ni-based alloy is being considered, but with a severe cost penalty.

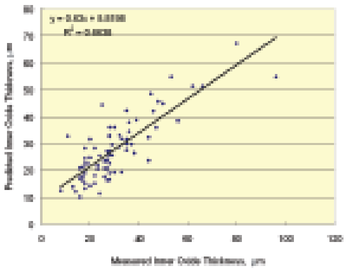

Figure 1. The predicted inward growing oxide thickness compared with the experimental values for a range of 9-12% Cr steels.

Whilst there is extensive practical experience of the behavior of 'standard' alloys in conventional steam conditions, it is not clear if the established trends in oxidation and scale exfoliation behavior will extend into the advanced steam conditions, or whether the newer alloys will follow the trends established for the conventional ferritic and austenitic steels. Further, there are few data for the steam oxidation of the higher-strength austenitic steels, and data are very sparse for Ni-base alloys in steam.

The overall intent of this task was to leverage efforts in the UK and US to provide a better insight of the steam oxidation of these classes of alloys by collaborating on (a) the evaluation of available information, and (b) the generation of data still needed to provide the basis for confident use and prediction of steam oxidation behavior.

objectives

- To establish the current state of knowledge regarding steam oxidation of materials used in fossil-fuelled power plant
- To collate and analyze existing information to identify missing critical data
- To generate critical data as required which could be used in subsequent design and life prediction of components
- To develop mechanistic models for the exfoliation of oxides grown under steam environments

work programme

The project was split into three discrete areas: the first was focussed on reviewing the current state of knowledge of steam oxidation that was pertinent to ultra-supercritical (USC) steam cycles and collating relevant and reliable steam oxidation data that already existed internationally.

The second aspect of this project was concerned with identifying where critical data were missing and then undertaking a work programme to generate these data, whilst evaluating the effect of laboratory practices on the data generated.

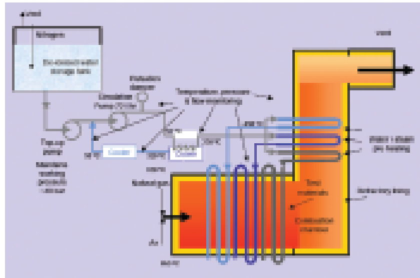

Figure 2: Schematic of the high pressure flowing steam test facilities installed at Cranfield University.

The third part of this project focussed on developing models to simulate the oxide growth and exfoliation. Figure 1 shows results from the neural network model used to predict the oxide thickness of the inward growing (Fe, Cr) spinel.

key results

- Over 1 million hours of steam oxidation data have been generated in US and UK laboratories, covering 30 alloys and a range of temperatures
- The effects of water chemistry, pressure and steam delivery method used during laboratory campaigns have been studied with water chemistry and pressure being demonstrated to affect the oxidation kinetics. Improved test methods and a unified approach can now be formulated
- An inter-comparison exercise demonstrated the difficulties in comparing steam oxidation data from different laboratories. Differences in the measured oxidation rates where observed accompanied by varying exfoliation behavior, highlighting the necessity for a standardised testing approach
- A model for estimating the reactive evaporation of protective chromia scales in ultra supercritical conditions, 760 °C (1400 °F), was developed. It appears that alloy additions of Ti may aid in reducing this type of corrosion damage
- Models based on the mechanistic behavior of oxides during the initial growth and service have been developed. These models predict the oxide growth and exfoliation behavior of alloys and provide an important tool to plant designers and operators to enable improved use of materials through less conservative design and extended component lifetimes. Accurate predictive methods will also help to avoid conditions that would lead to tube failure
- Neural network algorithms have been developed from 'pedigree' laboratory data that predict the specific mass change and oxide growth for 9-12% Cr alloys in steam environments. The kinetics from these models are available to modelers for use as a 'standard' data set in model development, within set limits of temperature, time and alloy composition
- Two high-pressure steam facilities have been developed and commissioned: Figure 2 shows a schematic of the Cranfield facility. these are now available for future test programmes

future activities

- The effect of pressure on the oxidation kinetics and scale morphology will be investigated using high-pressure laboratory tests
- Deviations in alloy composition and their impact on oxidation resistance will be examined using one material with a range of compositions, all of which fall within the specification of that alloy; thus providing a measure of the scatter which could come from different alloy melts
- Critical data will be generated on the effect of specimen geometry and heat flux, and a unified test method developed with a view to future standardization
- Development and validation of models for (a) scale exfoliation and (b) oxidation kinetics when accompanied by chromia evaporation
- A compendium of oxidation kinetics and oxide microstructures will be created for specific materials. This will provide a valuable insight into the interdependency of oxide morphology and exfoliation behavior

Further information on the UK-US Collaboration on Energy Research and Development, please visit - http://us-uk.fossil.energy.gov/

U.S. DEPARTMENT OF ENERGY

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DEPARTMENT OF ENERGY & CLIMATE CHANGE

project duration
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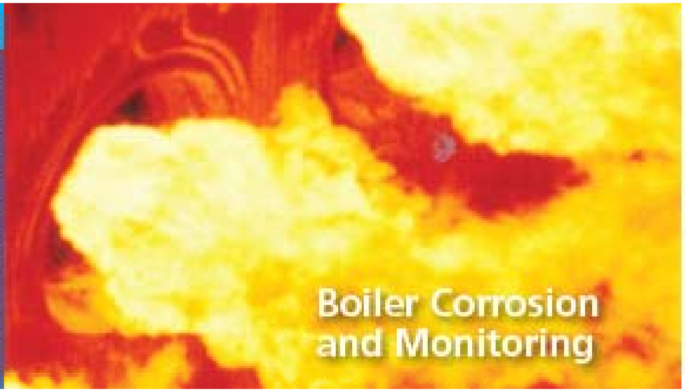
UK:
*Doosan Babcock Energy Limited
NPL
RWE
University of Cranfield

US:
*National Energy Technology Laboratory (NETL)
Reaction Engineering International
Covanta Energy
InterCorr International
Honeywell Process Solutions

* Task Leader



Boiler Corrosion and Monitoring

background

Incidence of excessive boiler tube metal wastage due to fireside corrosion has long been a significant issue for coal-fired utility boilers. Boiler design rules and features introduced in the 1950's and 1960's in response to corrosion problems at that time have proven reasonably successful with the occurrence of excessive corrosion being relatively rare.

However a number of developments are changing this position:

1. Primary NOx emission control technologies, which implement harsh furnace conditions
2. Co-firing non-conventional fuels (e.g. biomass) in coal-fired boilers, which affect ash deposits
3. Advanced coal-fired boiler operating conditions producing higher steam pressures and temperatures
4. Oxyfuel firing technology producing very high flue gas acidic species concentrations such as SO_2 / SO_3 and HCl

An ability to control fireside corrosion to acceptable levels is imperative for the successful development of advanced coal-fired boilers. This programme of work was developed to gain a better understanding of these key issues by bringing together UK & US organizations with specific expertise and interest in boiler corrosion.

objectives

- To review plant experience of furnace wall, superheater and reheater corrosion
- To develop and apply optimized in-situ monitoring and analysis techniques for applications that include biomass co-firing, oxyfuel firing and waste incineration
- To evaluate candidate alloys under accurately controlled conditions reflecting current and advanced boiler operations
- To further develop laboratory characterization of boiler corrosion processes relevant to advanced power plant and to model the extent and mechanisms of degradation involved and to develop a predictive capability relevant to real plant performance

work program

The work program was focussed on two main topics:

- The development and performance of laboratory-scale, high temperature corrosion experiments
- The development, implementation and assessment of corrosion probe techniques for the measurement of corrosion rates in utility boilers

Doosan Babcock Energy Ltd., Cranfield University, NPL and NETL were involved in laboratory experiments to assess the corrosion resistance of selected materials and provide important corrosion rate and mechanism information. Testing included exposures in simulated flue gases with deposits typical of those from boilers using world-sourced coals, with conventional and oxyfuel firing as well as biomass co-firing. The effects of heat flux and alternating atmosphere were also investigated.

work program

Figure 1 shows typical corrosion morphology for the 9% Cr alloy, T92 examined in the programme.

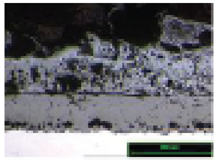


Figure 1.
T92 coupon exposed during a laboratory experiment

There were a number of approaches to corrosion probe design, from one based on the measurement of material loss of a sacrificial test specimen to various types of electrochemical devices.

Doosan Babcock Energy was involved with the further development of a simple furnace wall corrosion probe system. During an exposure campaign, probe tip temperatures are continuously monitored and periodic gas sampling is completed to assess the nature of the local environment. Probes were exposed in a 600 MWe, UK coal-fired utility boiler during two campaigns of 6,700 and 9,200 hour duration. This boiler had been converted to operate with a Boosted Over-Fire Air (BOFA) system, which requires a portion of the furnace to operate under reducing conditions.

NETL, Honeywell Process Solutions and Covanta Energy developed and tested an electrochemical corrosion probe system for application in waterwall and convective region locations. Prototypes were tested at a Waste to Energy (WTE) power plant site.

A comprehensive system involving the application of electrochemical sensor devices for monitoring waterwall corrosion in coal-fired utility boilers was developed by REI. American Electric Power assisted in this activity, providing access, resources and performance data at commercial utility sites.

Cranfield University was involved with the development of a continuous corrosion monitoring system based on electrochemical noise measurement (ECN) and heat flux. A photograph of a probe, post exposure is presented in Figure 2.

key results

General

- A review of plant experience in the field of furnace wall and superheater/reheater corrosion was conducted

Laboratory Studies:

- Corrosion test results allowed for ranking of test materials in a variety of atmospheres. The performance of candidate new materials in-service can tentatively be predicted by comparing them with materials for which in-service performance information is known
- Some potential effects of oxyfuel firing on corrosion rate were identified
- Alternating atmosphere test results indicated that changing conditions impacts on scale growth in furnace corrosion. These findings suggest that alternating conditions may be a consideration for future laboratory test work

Figure 2.
Deposit covered electrochemical noise probe sensor following exposure test

Corrosion Probe Studies:

- Comparison of corrosion rates for a furnace operating with a BOFA regime with those of the same unit pre-BOFA showed that there was no significant increase in rates at the test locations, despite harsher gas conditions
- Electrochemical noise probes were shown to be sensitive to compositional differences between alloys and environmental variances. Data from standard electrochemical techniques allowed the production of electrochemical polarization diagrams that are typical of those for actively corroding metals
- Electrochemical corrosion probe activities indicated that they can currently only be used in a semi-quantitative manner
- Electrochemical corrosion rates measure less of the corrosion reaction than measured by either dimensional or mass loss measurements.
- Field testing of prototype probes provided indicators for future design improvements in their robustness and reliability

future activities

- Develop laboratory procedures incorporating realistic conditions such as fluctuating atmospheres and temperature cycling in order to provide better links between laboratory experimentation and in-service plant operation
- Develop an improved understanding of the relationship between fuel diet and boiler operating conditions with the rate of corrosion recorded by electrochemical corrosion probes
- Use field test data to improve the reliability of probes for commercial application

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US:
Alstom Power
* Oak Ridge National Laboratory

* Task Leader

Standards and Databases

background

With the continued drive for the development of new and improved materials and the optimal use of existing materials in a cost effective manner, the ability to share and compare data and testing methods from laboratories is of increasing importance. Collaborative programmes such as this offer clear financial and technological advantages to those involved, through the sharing of resources, results and complimentary laboratory work. With the ever-increasing global partnerships and national testing sources involved in co-operative materials testing programmes, the need for comparability between results and an efficient, comprehensible method for data collection, analysis and exchange is essential.

Recognizing that the overall UK-US programme would generate a significant amount of test data using numerous different test methods within each of its tasks and in order to capture this information and evaluate any difference in results, a Standards and Databases task was established.

The overarching aim was to provide standardized tools for the entire programme that would:

- Allow transfer of data, between partners and between tasks by setting up a consistent and easily accessed data transfer format
- Ensure that the testing techniques applied by the various partners would be directly comparable
- Create a database structure suitable for storage and retrieval of materials and microstructural data

With the variety of data envisaged and the quantities that were projected to be generated, the UK-US collaboration provided a highly suitable arena in which to build and validate such tools. Within this developed structure, the methods used and the data generated in all tasks have been recorded and stored. This task's long-term goal is for future co-operative projects to adopt the tools produced and continue to populate and use them, within the limits of the collaborative agreement.

objectives

- To identify critical differences between standards for measurement of high temperature materials properties
- To identify where further standardization for measurement of high temperature materials properties is required
- To develop a common format for data exchange and use this to disseminate the results of the test work within the consortium
- To investigate the use of commercial database software for collecting and maintaining materials properties data and micrographs

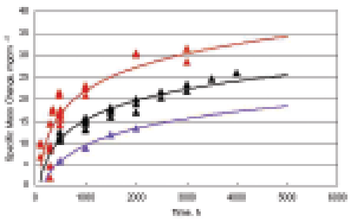


Figure 1. Comparison of mass oxidation data for T92 material at 650 °C

work programme

The task consisted of three main parts, a review of current standards, the development of a data exchange and storage tool and an inter-comparison exercise for boiler corrosion and steam oxidation testing. The review of standards was focussed on the availability or otherwise of national or international testing standards of relevance to the partners, a decision was taken to exclude "material specification" standards from this activity. Whilst it was acknowledged that many of the standards already existed a review was deemed timely to examine whether further work within the collaboration was required.

Across all tasks it was clear that a large amount of data would be produced and that a data transfer and collation method was therefore required. The data transfer method deemed most appropriate was based around spreadsheets. These were distributed to all the partners for data collation including metadata and test results and collected at the end of the collaboration and will remain available to all partners. In addition, a database was developed which acts as a repository for the data and would also enable the collation and labelling of any micrographs generated.

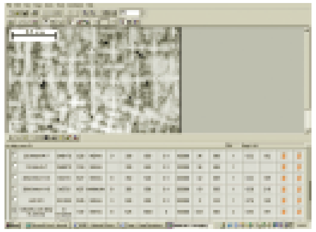


Figure 2. Typical display of a micrograph connected to the database of results.

The third part of the work program concerned running two international inter-comparison exercises. The first of these was in conjunction with the steam oxidation task and participants conducted tests following in-house practices on common materials and temperature conditions. The second inter-comparison exercise was concerned with boiler corrosion. The test procedure in this case was more prescriptive with the temperature, salt deposit and gaseous atmosphere all being well defined.

key results

- The need for additional activities to revise current or develop additional standards for high temperature mechanical testing is not required at this time
- A method of data collection and storage has been designed to allow rapid communication of test data (including detailed microstructural information) between national and international organizations
- An inter-comparison exercise clearly demonstrated the requirement for standardization of high temperature corrosion tests, in particular for steam oxidation testing. Here clear differences relating to specimen geometry, test method and specimen preparation resulted in different oxidation rates and exfoliation properties. An example of this is shown in Figure 1
- In the case of the boiler corrosion inter-comparison, which was performed under more prescribed conditions, there was generally good agreement between the laboratories for longer duration tests (1000 h), but some differences in the metal loss rate were identified for shorter duration tests. At higher temperatures these aggressive tests produced more scatter between the participating laboratories, reinforcing the need to fully quantify test methodology and the measurement and analysis techniques
- The database of the results including microstructural data (Figure 2) generated during this collaborative programme continues to be populated and made available to the participants

future activities

- Further work is recommended to address the scatter shown in the steam oxidation inter-comparison. Issues such as the effect of pressure, specimen geometry and testing procedure need to be addressed and a best practice agreed on. This should lead to future standardization for steam oxidation testing
- The boiler corrosion inter-comparison tests showed some scatter and a repeat exercise under less harsh conditions would help to develop improved methods for specimen manufacture and metal loss measurement, the two areas identified as possible causes of the scatter
- Continued use of the data collection and storage tools developed in the task should be maintained
- Whilst future activities have been identified and are worthwhile, doing these as part of a separate task is deemed to be unnecessary and so future activities around data collection, analysis and testing will be integrated into individual future tasks

Further information on the UK-US Collaboration on Energy Research and Development, please visit - http://us-uk.fossil.energy.gov/

UK-US Collaboration on Fossil Energy R&D

Advanced Materials

project duration
April 2004 - April 2009

project partners

UK:
Alstom Power Ltd
* Cranfield University
Siemens Industrial Turbomachinery Ltd

US:
Oak Ridge National Laboratory
* Siemens

*Task Leader

Gas Turbines Fired on Syngas and other Fuel Gases

background

In moving towards higher efficiency power generation systems that produce lower CO_2 emissions, the use of gasification based combined cycle technologies becomes increasingly attractive. These systems can be used to generate fuel gases from a wide range of solid fuels including coal, biomass and waste products. These fuel gases need to be cleaned before use in gas turbines, but they can also be processed to remove CO_2 and so produce fuel gases that have high hydrogen contents.

This task was focused on investigating the impact of changes expected in the future use of fuel gases in power generation gas turbines focusing in particular on the impact on hot gas path components in the power turbine such as blades, vanes and combustor cans. Enhanced corrosion, erosion and deposition on these components as a result of using gasifier derived fuel gases could reduce component lifetimes and so reduce the viability of such gas turbines. However, the correct selection of advanced materials including corrosion resistant and thermal barrier coatings provides a route to counter the effects caused by future fuel gases with higher levels of contaminants.

objectives

To quantify the major degradation effects on gas turbine materials operating with fuel gases, including coal- biomass- and waste-derived syngas, in order to improve component design and life prediction methods.

- To characterize the range of fuel gas atmospheres anticipated in solid fuel fired gasification systems
- To expose selected alloy/coating combinations in burner rig testing and determine deposition rates and the erosion and corrosion resistance of state-of-the-art gas turbine materials systems over the appropriate operating temperature ranges
- To identify candidate alloy and coating systems, that are appropriate for use in fuel gases

work programme

The work program was divided into two main activities:

- Assessment of future fuels for power generation gas turbines and their effects on the operating environments around critical components in the gas turbine hot gas path. This used thermodynamic and kinetic modelling to follow major, minor and trace elements from a fuel, through processing stages, into a gas turbine combustion chamber and through a power turbine. For example, UK/US coal and biomass fired gasification systems with differing degrees of hot gas cleaning before fuel gases combustion
- Carrying out four 1000 hour high velocity burner rig exposures at Cranfield University. Gaseous, vapor phase and solid contaminants were added adjacent to the natural gas/air flame to generate four target environments from the fuels indicated below:
    - Diesel fuel with maximum allowable contaminants
    - IGCC syngas
    - High H2 IGCC syngas
    - Pyrolysis derived gases

Siemens power generation gas turbine (F class)

work programme

The project was split into three discrete areas; the first was focussed on reviewing the current state of knowledge of steam oxidation that was pertinent to ultra-supercritical (USC) steam cycles and collating relevant and reliable steam oxidation data that already existed internationally.

The second aspect of this project was concerned with identifying where critical data were missing and then undertaking a work programme to generate these data, whilst evaluating the effect of laboratory practices on the data generated.

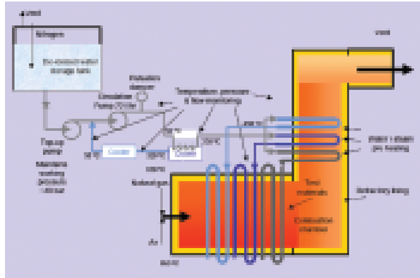


Figure 2. Schematic of the high pressure flowing steam test facilities installed at Cranfield University.

The third part of this project focussed on developing models to simulate the oxide growth and exfoliation. Figure 1 shows results from the neural network model used to predict the oxide thickness of the inward growing (Fe, Cr) spinel.

key results

- Over 1 million hours of steam oxidation data have been generated in US and UK laboratories, covering 30 alloys and a range of temperatures
- The effects of water chemistry, pressure and steam delivery method used during laboratory campaigns have been studied with water chemistry and pressure being demonstrated to affect the oxidation kinetics. Improved test methods and a unified approach can now be formulated
- An inter-comparison exercise demonstrated the difficulties in comparing steam oxidation data from different laboratories. Differences in the measured oxidation rates where observed accompanied by varying exfoliation behavior, highlighting the necessity for a standardised testing approach
- A model for estimating the reactive evaporation of protective chromia scales in ultra supercritical conditions, 760 °C (1400 °F), was developed. It appears that alloy additions of Ti may aid in reducing this type of corrosion damage
- Models based on the mechanistic behavior of oxides during the initial growth and service have been developed. These models predict the oxide growth and exfoliation behavior of alloys and provide an important tool to plant designers and operators to enable improved use of materials through less conservative design and extended component lifetimes. Accurate predictive methods will also help to avoid conditions that would lead to tube failure
- Neural network algorithms have been developed from 'pedigree' laboratory data that predict the specific mass change and oxide growth for 9-12% Cr alloys in steam environments. The kinetics from these models are available to modelers for use as a 'standard' data set in model development, within set limits of temperature, time and alloy composition
- Two high-pressure steam facilities have been developed and commissioned; Figure 2 shows a schematic of the Cranfield facility; these are now available for future test programmes

future activities

- The effect of pressure on the oxidation kinetics and scale morphology will be investigated using high-pressure laboratory tests
- Deviations in alloy composition and their impact on oxidation resistance will be examined using one material with a range of compositions, all of which fall within the specification of that alloy; thus providing a measure of the scatter which could come from different alloy melts
- Critical data will be generated on the effect of specimen geometry and heat flux, and a unified test method developed with a view to future standardization
- Development and validation of models for (a) scale exfoliation and (b) oxidation kinetics when accompanied by chromia evaporation
- A compendium of oxidation kinetics and oxide microstructures will be created for specific materials. This will provide a valuable insight into the interdependency of oxide morphology and exfoliation behavior

Further information on the UK-US Collaboration on Energy Research and Development, please visit - http://us-uk.fossil.energy.gov/

UK-US Collaboration on Fossil Energy R&D
Advanced Materials

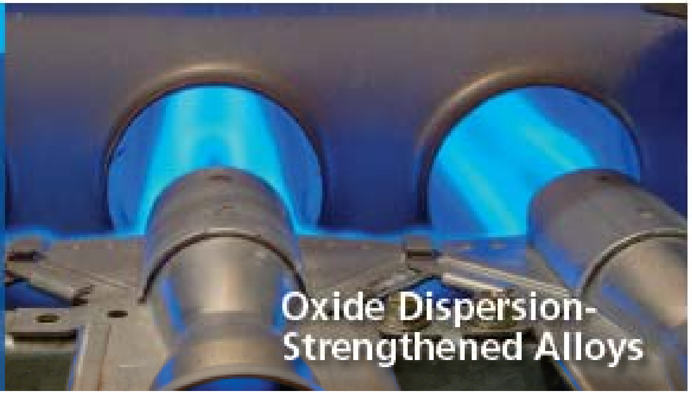
project duration
April 2004 - April 2009

project partners

UK:
*University of Liverpool
Cranfield University
Siemens Industrial Turbomachinery Ltd

US:
*University of California, San Diego
Oak Ridge National Laboratory
University of North Dakota
Interface Welding Inc
MER Corp

* Task Leader



Oxide Dispersion-Strengthened Alloys

background

The global requirement for reducing CO_2 emissions from fossil power plant is driving the design and construction of plant with higher efficiencies, along with co-firing and CO_2 capture technologies.

Gains in overall cycle efficiency generally involve increasing the maximum operating temperature of the power plant. Such improvements have and will continue to be enabled by the development of materials with increasingly high temperature capabilities. Oxide Dispersion-Strengthened (ODS) alloys have excellent potential for use in next-generation high-temperature applications where superior creep strength and oxidation resistance compared to current alloys is required. Possible applications include tubing for high-temperature heat exchangers and sheet for burners and combustion chambers.

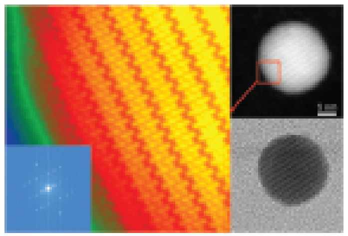
Three challenges exist that currently inhibit the use of these alloys:

- Relatively high processing costs
- Joints fabricated by conventional fusion welding techniques have low creep strength at high temperatures
- Secondary recrystallization needs to be optimized to produce microstructures where large grains can be custom oriented with respect to the principal hoop creep stress

This programme was established to address the latter two issues with the assumption that processing costs would be reduced if volume production were introduced. Hence optimized structures and joints could possibly be developed and incorporated in a demonstrator project during the next phase of this work.

objectives

- To establish and review the current state of knowledge regarding joining of (ODS) alloys
- To identify and quantify the properties of the most appropriate techniques for joining sheet and tubing, including non-fusion joining and fabrication protocols for high temperature heat exchanger components
- To establish and extend the current state of knowledge regarding the microstructural control of ODS FeCrAl alloys, especially in torsionally-orientated structures and hot-spun parts
- To establish and improve the maximum operating performance parameters of ODS alloy used in fossil-fuelled power plant including the application of coatings
- To establish and improve the critical hoop creep performance for ODS tube components by microstructural modification via thermo-mechanical processing



High resolution image of an Y-Al-oxide nanoparticle in a PM2000 alloy after heat treatment.

work program

UK Project Activities: The majority of the oxidation testing and coating production was carried out at Cranfield University, while the microstructures were evaluated at the University of Liverpool. Liverpool also characterized the friction-stir welded components which were supplied by Siemens and fabricated at The Welding Institute. Hot tube torsion trials (carried out by Forecreu SA and Kennametal Inc.) and selective laser melting were performed and evaluated by the group at the University of Liverpool.

US Project Activities: Microstructural modification and control of ODS alloy tubes (led by UCSD) was aimed at maximizing high-temperature performance under internally-pressurized service conditions. Hot rotary cross-rolling and ambient-temperature flow-forming techniques were pursued to modify and control alloy microstructural features. Identification of viable joining technologies for use in heat-exchanger fabrication focused on approaches capable of preserving specific features of the ODS microstructures. Emphasis was on non-fusion inertia welding (led by USCD) and variants of diffusion bonding (led by ORNL). The diffusion bonding work also involved MER Corp., U. North Dakota, and U. Liverpool; the UK task leader spent a three-month sabbatical leave at ORNL working on this effort.

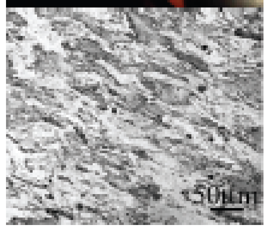
Helical grain structure in a PM2000 tube.

key results

- Friction-stir welding, inertia welding, and pulsed plasma–assisted diffusion bonding were shown to be promising methods of joining ODS alloys, with the latter producing joints with a creep strength of 75% of the parent metal. Processing parameters for similar ODS-ODS inertia joints were established, and joints fabricated by commercial vendors achieved creep performance comparable to the parent metal
- Hot tube torsion methods successfully produced a helical grain structure in PM2000 tubing, which should lead to improved hoop creep strength in pressurised tubes. Both rotary cross-rolling and flow forming of tubes induced microstructural modifications, resulting in significant improvements in high-temperature creep response
- Microstructural investigations using electron backscattered diffraction techniques were used to characterize, in detail, the influence of deformation and heat treatment on the secondary recrystallization of ODS alloys, enabling better materials properties to be achieved. After both welding and heat treatment, high resolution electron microscopy demonstrated the transformation of yttria particles
- Oxidation studies showed that 2mm thick coupons of PM2000 sheet could survive for over 2,000 hours at 1200°C without the onset of breakaway oxidation. The application of thermal barrier coatings in conjunction with a weaker bond coat were applied successfully and the coating-substrate combination survived for over 2,000 hours when tested at 1200°C
- Selective laser sintering was used successfully to fabricate thin-walled, fully-dense PM2000 component precursors from alloy powder, while retaining a critical distribution of dispersed oxide strengtheners

future activities

- The characterisation and development of a new, reproducible range of ODS alloy powders and consolidated sheets and tubes being developed by a new European supplier – this would include nanoscale characterisation of oxide dispersions and their evolution with time and temperature
- The evaluation of low-cost flow forming alternatives for microstructural modification and control of secondary recrystallization. Techniques to incorporate severe ambient temperature deformation are of particular interest
- Further secondary-recrystallization trials on sheet and torsionally-deformed tubes
- The optimization of a new set of friction-stir welded components fabricated from the new alloy.
- The fabrication of elements of a demonstrator component, such as a simple heat exchanger, and evaluation of its high-temperature performance
- The evaluation of dissimilar alloy joint fabrication of the new ODS alloy with header material candidates in the demonstrator high temperature heat exchanger, and establish required property data base
- Continued high-temperature creep data evaluation for the new alloy, all microstructure modified materials and fabricated joints



Hot rotary cross rolling trial that produced grain alignment along the tube circumference.

Further information on the UK-US Collaboration on Energy Research and Development, please visit - http://us-uk.fossil.energy.gov/

U.S. DEPARTMENT OF ENERGY

UK-US Collaboration on Fossil Energy R&D

Virtual Plant Simulations

DEPARTMENT OF ENERGY & CLIMATE CHANGE

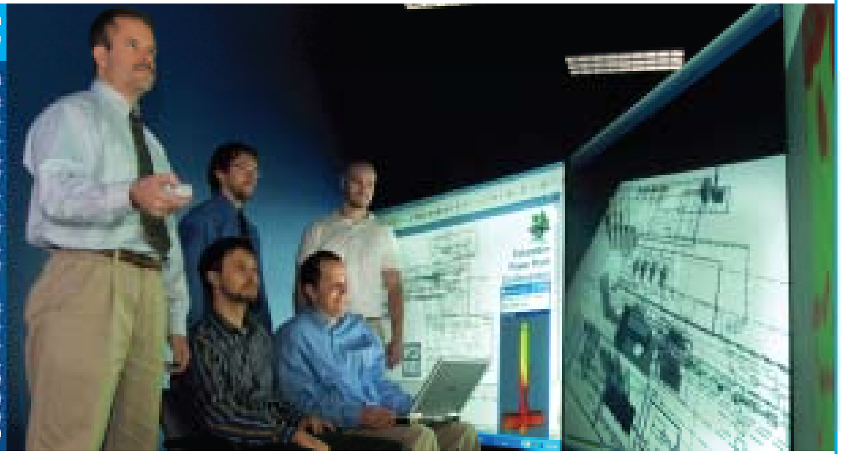
project duration

October 2004 - September 2007

project partners

UK:
K-S Technology Ltd.
Process Systems Ltd.
Enterprise Ltd.
Alstom Power
Engineous Software, Ltd.
Fluent Europe Ltd.
RWE nPower
Doosan Babcock Energy Ltd.
University of Ulster

US:
National Energy Tech. Lab.
Ansys Inc.
Aspen Technology, Inc.
Carnegie Mellon University
Iowa State University
West Virginia University
Vishwamitra Research Institute



background

Under the auspices of the U.S.-U.K. Memorandum of Understanding and Implementing Arrangement for Fossil Energy Research and Technology Development, the U.S. Department of Energy's (DOE) Office of Fossil Energy participated in a three-year collaboration on virtual plant simulation with a project team supported by the Department of Energy and Climate Change in the United Kingdom. Virtual plant simulation will help the U.S. and U.K. fossil energy industries to develop new and cleaner power generation systems with lower cost, shorter time-to-deployment, and reduced technical and commercial risk.

The U.S.-U.K. collaboration leveraged the strengths and synergies of the ongoing NETL Advanced Process Engineering Co-Simulator (APECS) project and the recently completed U.K. Virtual Plant Demonstration Model project. The R&D100 award-winning APECS system is an innovative software tool that uses the process industry CAPE-OPEN (CO) software standard to combine best-in-class process simulation, computational fluid dynamics (CFD), and virtual engineering software. At NETL, APECS provides high-fidelity process/CFD co-simulation capabilities for the design of sophisticated, highly-integrated plants such as the DOE's FutureGen power and hydrogen generation system with carbon capture and storage. Collaborative R&D partners on the APECS project include NETL; ANSYS Inc., the world's leading supplier of CFD software and services; Aspen Technology, Inc., a major supplier of process simulation software; Carnegie Mellon University; Iowa State University; West Virginia University; Vishwamitra Research Institute; and Alstom Power, a major worldwide industrial player in equipment and services for power generation.

The U.K.'s Virtual Plant Demonstration Model (VPDM) framework also exploits CO-compliant integration technology to deliver virtual plant co-simulation capabilities, with special emphasis on allowing secure web-based execution of distributed, heterogeneous equipment models. In the recently completed VPDM project, R&D partners included: Alstom Power Ltd, Engineous Software Ltd, Fluent Europe Ltd, RWE npower plc, K-S Tech Ltd, Doosan Babcock Energy Ltd, Process Systems Enterprise Ltd, and the University of Ulster.

objectives

The key objective of the U.S.-U.K. collaboration was to develop compatible virtual plant co-simulation software platforms for application to advanced fossil-energy power generation systems. Other important objectives included:

- Improving the focus and efficiency of APECS and VPDM project activities through information exchange and dissemination
- Providing plug-and-play interoperability for power plant equipment models (e.g., combustors, gasifiers, heat exchangers, gas and steam turbines, and fuel cells)
- Increasing leverage for cooperation with process simulation and CFD software vendors and open-standards organizations
- Developing potential for long-term cooperation in virtual plant simulation from experience gained during project collaborations

technical approach and accomplishments

The technical approach focused on the following four key collaborative tasks:

Task 1: Implement CAPE-OPEN software standard for interoperability of equipment models.

CAPE-OPEN (CO) is the de facto standard for plug-and-play equipment model interoperability for process simulation software. The CO standard is managed, tested, and disseminated by the internationally recognized, user-driven organization, CAPE-OPEN Laboratories Network (CO-LaN, www.colan.org), representing more than 50 member organizations from the process industries, academic institutions, research entities, and software vendors.

Accomplishments

- Adopted CO software standard for model integration in the APECS and VPDM frameworks
- Verified CO-compliant interoperability between U.S. equipment models and the VPDM framework, as well as between U.K. equipment models and NETL's APECS system
- Tested running CO-compliant FLUENT® CFD equipment models within VPDM using APECS technology
- Demonstrated a process/CFD co-simulation of RWE npower's Didcot A conventional coal-fired power station using APECS technology to couple a detailed CFD furnace simulation with a VPDM process simulation of the power plant

Task 2: Evaluate reduced-order models to enhance speed of process/CFD co-simulation

A potential barrier to the widespread use of process/CFD co-simulation is that the integration of high-fidelity equipment models may lead to unacceptable co-simulation turnaround times, especially for cases in which one or more CFD models are embedded in the iterative process flowsheet-solution procedure. One promising solution is the use of reduced-order models (ROMs) that approximate the CFD-based equipment simulations, while keeping the computational cost manageable.

Accomplishments

- Evaluated order reduction techniques for application to CFD-based equipment models
- Exchanged information on speed, accuracy, and applicability of ROMs as implemented in APECS and VPDM
- Demonstrated the use of an APECS neural network-based ROM in VPDM

Task 3: Adopt common specification for Internet security and communication

By adopting a common specification for secure, web-based execution over the Internet, virtual plant simulations can use the best equipment models available in the U.S. and U.K. while ensuring that the intellectual property contained within these models is fully protected.

Accomplishments

- Addressed issues such as model compatibility, operability over the Internet, secure communications between companies, and security of models at host sites so that companies will be comfortable in offering other parties the use of their in-house equipment models

Task 4: Define requirements for CAPE-OPEN dynamic simulation

Both the U.S. and U.K. virtual power plant simulation programs are planning to pursue dynamic co-simulation, especially for use in process control applications. The CO standard for dynamic model interoperability is under development by CO-LaN and its member organizations.

Accomplishments

- Identified the dynamic simulation requirements for power plant applications
- Worked with CO-LaN to ensure that the CAPE-OPEN standard for dynamic simulation satisfies the requirements for the APECS and VPDM projects

benefits

Virtual plant simulation benefits the U.S. and U.K. fossil energy industries in the following ways:

- Helps engineers to better understand and analyze the coupled fluid flow, heat and mass transfer, and chemical reactions that impact overall power plant design and operation
- Presents detailed equipment models in the context of plant-wide simulations, with recycle loops, heat integration, and water management
- Enables rigorous analysis and optimization of entire power plants with respect to CFD-related equipment model parameters
- Speeds technology development by reducing the pilot- and demo-scale facility design time and operating campaigns
- Offers opportunities to achieve the aggressive environmental, performance, and economic goals for advanced fossil energy power generation systems

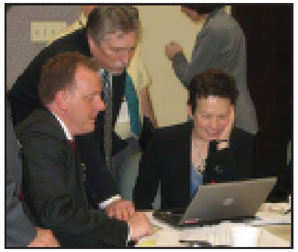
Continued U.S.-U.K. collaboration on virtual plant simulation will accelerate the development of competitive power plant solutions and ultimately zero-emission technologies with significantly reduced development costs and technical risk.

Further information on the UK-US Collaboration on Energy Research and Development, please visit - http://us-uk.fossil.energy.gov/

International Initiatives

U.S. and UK Advanced Materials Collaboration

Participants in a U.S.-UK advanced materials collaborative effort held a meeting in March 2009, in Washington, DC, to mark the fifth anniversary of the cooperative research and report on its results. The collaboration was launched in 2003 under an Implementing Arrangement (IA) between DOE's Office of Fossil Energy headquarters and the former UK Department of Trade and Industry, now the UK Department of Energy and Climate Change. The IA takes advantage of specialized research facilities and the skills of scientists in both countries, and calls for joint project planning, integrated work tasks, scientist exchange, and workshops. New and advanced materials capable of surviving high-temperature and high-pressure environments are central to next-generation power plants with high efficiency and low emissions.



L to R: Phillip Sharman of Alstom Power, NETL's Bob Romanosky, and Bronwen Northmore confer

Bronwen Northmore, Director of Cleaner Fossil Fuels Policy at the UK Department of Energy and Climate Change, heads the collaboration on the UK side. She spoke of UK policy initiatives in carbon capture and storage, policies in which ultra-efficient coal plants, constructed with advanced materials, have a definite place. DOE officials provided the equivalent U.S. picture. Technical presentations reported on team achievements in the major research areas.

Over the day's program, speakers addressed the problem of materials "creep" (deformation under stress), the behavior of materials under steam oxidation conditions, and models developed to evaluate the oxidation process. The group also noted progress in understanding boiler corrosion, developing special oxide dispersion-strengthened (ODS) alloys, and overcoming problems specific to gas turbines fired by syngas.

Material creep is a particular problem in boiler steam tubes under *steam oxidation* conditions. Thus, understanding oxidation mechanisms of conventional and candidate new materials in steam environments is critical. Oxide scales build up and form an insulating layer on the inside of the boiler steam tubes. This acts to increase the local temperature of the metal, as the heat from the boiler can no longer be effectively transferred to the cooling steam. The material then creeps at a faster rate and component life is shortened. The oxide can also spall away from the waterwall side of the tube, exposing fresh materials to oxidize. As this continues, the wall thickness is reduced, leading to further reductions in component life.

One of the important results of U.S.-UK work has been the development of models based on the mechanistic behavior of oxides to help forecast how oxidation will progress over the service life of the materials. Oxidation research is taking place at several high-pressure steam test facilities in the U.S. and the UK. In total, over 1 million hours of steam oxidation data have been accumulated in these laboratory tests, with some 30 alloys tested at varying temperatures.

U.S.-UK researchers are also studying *boiler corrosion* in cases where a range of fuels (e.g. waste and biomass) are combined with coal. New fuels added to the feed coal expose tube surfaces to different particulates and gaseous compounds that can shorten boiler tube life. Work has emphasized oxidation kinetics and accumulation of scale on boiler tubes exposed to steam, air, and water vapor. Electrochemical techniques are being used for on-line monitoring at high temperatures. Laboratory studies have also investigated potential effects of oxyfuel firing on corrosion rates.

Progress has also been made in field testing of prototype corrosion probes, with the goal of improving durability and reliability in harsh environments. Probes allow measurements of tube corrosion in-situ, avoiding the need for unplanned, costly shutdowns.

In terms of *gas turbines fired by syngas*, contaminants from coal, waste products and biomass necessitate corrosion-resistant, thermal barrier coatings for blades, vanes, and combustor cans. Turbine materials also have to be optimized for specific gas streams using different gasifiers, syngas systems, and pre-combustion CO_2 capture/H_2 enriched syngas production. Researchers have worked to quantify the effects of contaminants and rank alloys and coatings that could be used in future high-temperature power plants. Four 1000-hour burner rig tests have been carried out on candidate materials, including single crystal and conventionally cast materials.

Oxide dispersion-strengthened (ODS) alloys have excellent creep strength, but cannot be effectively joined by conventional welding techniques. Work has focused on developing non-fusion joining methodologies, evaluating tube-to-tube, butt- and flanged-joint welding configurations as required for the high temperature sections of the boiler. Friction-stir welding, inertia welding, and plasma-assisted diffusion bonding were shown to be promising methods of joining ODS alloys, with the latter producing joints with creep strength of 75 percent of the parent metal. Another joining method, hot tube torsion welding, also showed promise.

Collaborative efforts will continue in these same materials study areas, developing data to improve understanding of degradation mechanisms, improving predictive models, and establishing standardized test methods to make more effective use of research data.

the ENERGY lab

PROJECT FACTS

Advanced Research

U.S.-U.K. Collaboration on Virtual Plant Simulation

Background

Under the auspices of the U.S.-U.K. Memorandum of Understanding and Implementing Agreement for Fossil Energy Research and Technology Development, the U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) participated in a three-year collaboration on virtual plant simulation with a project team supported by the Department for Business, Enterprise & Regulatory Reform in the United Kingdom. Virtual plant simulation will help the U.S. and U.K. fossil energy industries to develop new and cleaner power generation systems with lower cost, improved time-to-deployment, and reduced technical and commercial risk.

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PROJECT DURATION

Start Date
10/01/2004

End Date
09/30/2007

U.S. DEPARTMENT OF ENERGY

Objectives

The key objective of the U.S.-U.K. collaboration was to develop compatible virtual plant co-simulation software platforms for application to advanced fossil-energy power generation systems. Other important objectives included:

- Improving the focus and efficiency of APECS and VPDM project activities through information exchange and dissemination
- Providing plug-and-play interoperability for power plant equipment models (e.g., combustors, gasifiers, heat exchangers, gas and steam turbines, and fuel cells)
- Increasing leverage for cooperation with process simulation and CFD software vendors and open-standards organizations
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Technical Approach and Accomplishments

The technical approach focused on the following four key collaborative tasks:

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Accomplishments

- Adopted CO software standard for model integration in the APECS and VPDM frameworks
- Verified CO-compliant interoperability between U.S. equipment models and the VPDM framework, as well as between U.K. equipment models and NETL's APECS system
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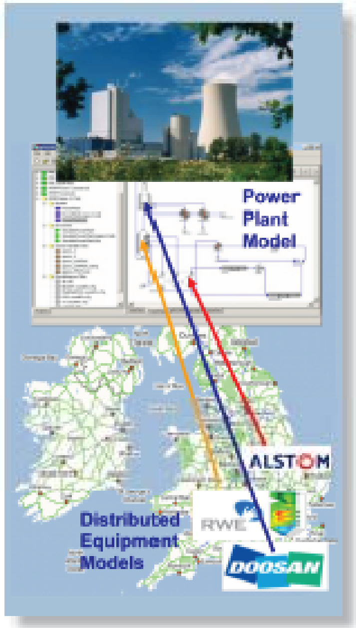

- **Task 2: Evaluate reduced-order models to enhance speed of process/CFD co-simulation**

  A potential barrier to the widespread use of process/CFD co-simulation is that the integration of high-fidelity equipment models may lead to unacceptable co-simulation turnaround times, especially for cases in which one or more CFD models are embedded in the iterative process flowsheet-solution procedure. One promising solution is the use of reduced-order models (ROMs) that approximate the CFD-based equipment simulations, while keeping the computational cost manageable.

Accomplishments

- Evaluated order reduction techniques for application to CFD-based equipment models
- Exchanged information on speed, accuracy, and applicability of ROMs as implemented in APECS and VPDM
- Demonstrated the use of an APECS neural network-based ROM in VPDM

- **Task 3: Adopt common specification for Internet security and communication**

  By adopting a common specification for secure, web-based execution over the Internet, virtual plant simulations can use the best equipment models available in the U.S. and U.K. while ensuring that the intellectual property contained within these models is fully protected.

  Accomplishments

  – Addressed issues such as model compatibility, operability over the Internet, secure communications between companies, and security of models at host sites so that companies will be comfortable in offering other parties the use of their in-house equipment models

- **Task 4: Define requirements for CAPE-OPEN dynamic simulation**

  Both the U.S. and U.K. virtual power plant simulation programs are planning to pursue dynamic co-simulation, especially for use in process control applications. The CO standard for dynamic model interoperability is under development by CO-LaN and its member organizations.

  Accomplishments

  – Identified the dynamic simulation requirements for power plant applications

  – Worked with CO-LaN to ensure that the CAPE-OPEN standard for dynamic simulation satisfies the requirements for the APECS and VPDM projects

Benefits

Virtual plant simulation benefits the U.S. and U.K. fossil energy industries in the following ways:

- Helps engineers to better understand and analyze the coupled fluid flow, heat and mass transfer, and chemical reactions that impact overall power plant design and operation
- Presents detailed equipment models in the context of plant-wide simulations, with recycle loops, heat integration, and water management
- Enables rigorous analysis and optimization of entire power plants with respect to CFD-related equipment model parameters
- Speeds technology development by reducing the pilot- and demo-scale facility design time and operating campaigns
- Offers opportunities to achieve the aggressive environmental, performance, and economic goals for advanced fossil energy power generation systems

Continued U.S.–U.K. collaboration on virtual plant simulation will accelerate the development of competitive power plant solutions and ultimately zero-emission technologies with significantly reduced development costs and technical risk.

United States-United Kingdom Collaboration on Fossil Energy R&D

The United States and the United Kingdom are participating in a multi-year collaboration on advanced materials supported by the UK Department of Energy and Climate Change (DECC) and the U.S. Department of Energy (DOE).

The collaboration is an outgrowth of the US-UK Memorandum of Understanding and the associated Implementing Arrangement for Fossil Energy Research and Technology Development.

The MOU, signed on November 6, 2000, provides a framework to continue, expand, and maximize cooperation in energy research and development between the two nations.

The Implementing Arrangement, signed on March 10, 2003, reflects the two nations' interest in the joint planning and exchange of information and personnel in the field of cleaner coal technology, and for exploring opportunities for expanded fossil energy utilization.

MORE INFO
- Read the Memorandum of Understanding
- Read the Implementing Arrangement

Objectives

The key objective of the UK-US collaboration is to share and develop the partners' knowledge and expertise in the key area of high-temperature materials for advanced fossil energy power plant applications.

This is achieved through such mechanisms as: sharing of test facilities and best practices, development of common tools and methods, and industrial secondments. The opportunity to develop long-term cooperation in advanced materials from the experience gained during project collaborations is also recognized.

More specific technical objectives related to:

- Optimized test methods, data analysis and storage;
- Development of life time prediction tools;
- Materials evaluation techniques and ranking methodologies; and
- Joining and thermomechanical processing.

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FOSSIL ENERGY TECHLINE

Techlines provide updates of specific interest to the fossil fuel community. Some Techlines may be issued by the Department of Energy Office of Public Affairs as agency news announcements.

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DOE Lauds Successful U.S.-U.K. Collaborative Effort

Five-Year R&D Partnership Leads to Numerous Accomplishments

Washington, D.C. – The U.S. Department of Energy (DOE) has announced numerous accomplishments coming out of a multi-year collaboration in the area of advanced materials research between the United States and the United Kingdom.

Researchers from DOE's Office of Fossil Energy, the United Kingdom's Department of Energy and Climate Change, and representatives from academia and industry have been collaborating over the past five years in an attempt to develop a better understanding of advanced materials, a key prerequisite to achieving the targets of any future energy policy.

MORE INFO
- Learn more about the US-UK Collaboration

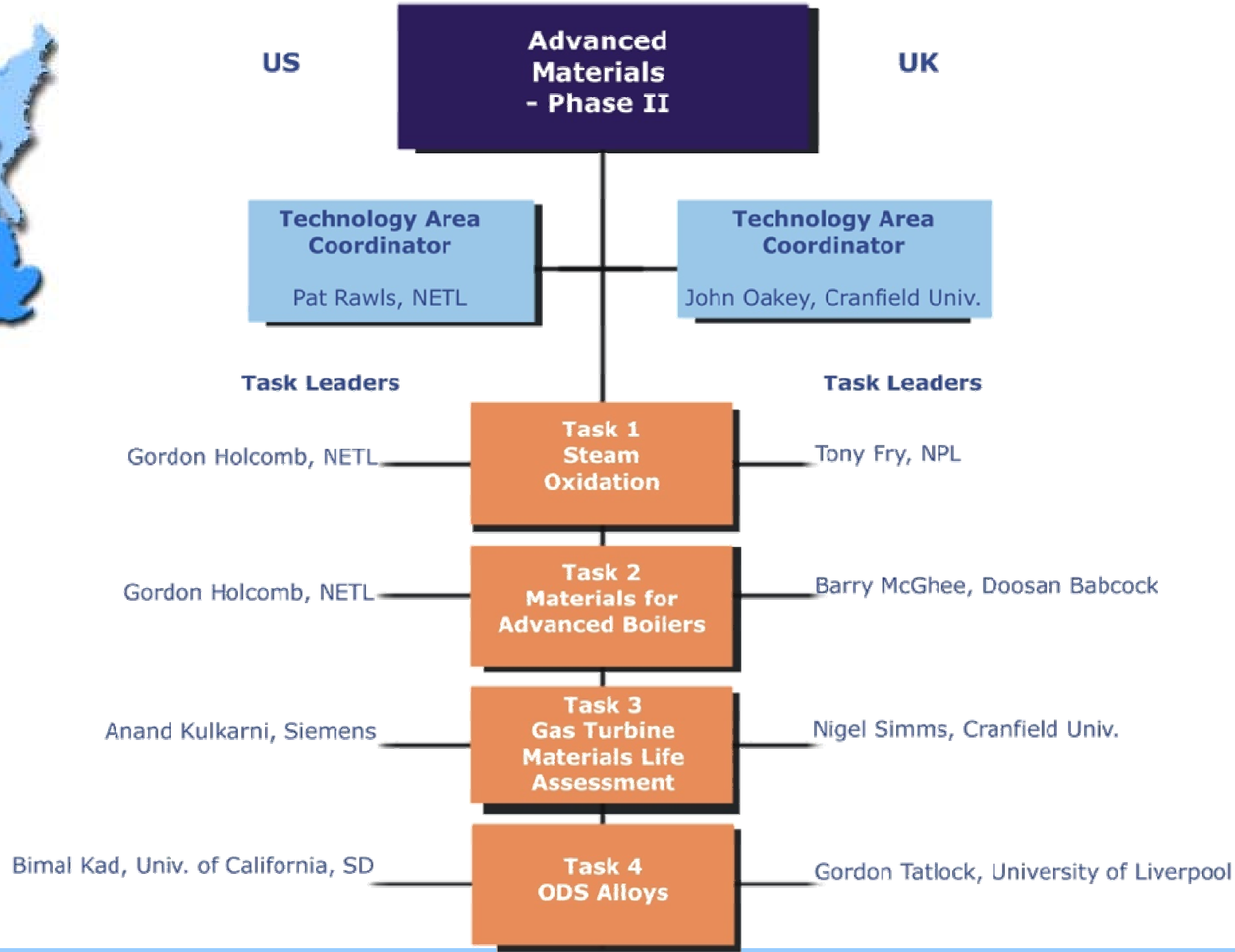
"The success of the US-UK collaboration demonstrates the power of international cooperation in energy research and development," said Dr. Victor K. Der, Acting Assistant Secretary for Fossil Energy. "Sharing data, facilities, and experiences has accelerated the development of high-temperature materials solutions, paving the way for advanced coal power generation."

Highlights of the multi-year collaboration include:

- Formation of new steam oxidation testing facilities and models;
- Development of comprehensive high-temperature corrosion data and technology evaluation fo boilers;
- Quantification of the effects of contaminants on gas turbines and the ranking of alloy and coatings that could be used in future gas turbine systems;
- Development of standardized data collection, exchange, analysis and storage methods to facilitate the effective use of research data;
- Evaluation and demonstration of methods and technologies for the use of oxide dispersion strengthened alloys in future high-temperature power plants; and
- Demonstration of virtual plant simulation technology to aid in the design and effectiveness of advanced fossil energy power generation systems.

Stringent environmental and efficiency targets will necessitate the development of more advanced materials and components, systems, manufacturing methods, and improved life assessment methods

Organizational Chart for Advanced Materials – Phase II



Upcoming Activities

- Renewal of MOU
- Potential areas for additional collaboration
  - Sequestration (Plasynski)
    - CO_2 storage/capacity assessments
    - Develop tracers to detect leakage
    - Share “best practices” with respect to public outreach
    - Share info on geologic storage from site selection to well closure
  - Computational fluid dynamics and modeling (Zitney)
    - Control of IGCC systems with CO_2 capture
    - Develop a common visual representation for CFD designs

Upcoming Activities - continued

– High temp turbine materials (Dennis)
  - Hi temp materials for TBCs
  - Advanced materials for use in hydrogen turbines
– Fuel Cells (Shultz)
– Plant Asset Mgmt (Romanosky)
  - On-line monitoring workshop
  - Sensor development
  - Wireless communication for diagnostics and component monitoring

10 TSB Projects (sensors, instrumentation, advanced materials, lifetime assessments, CO_2 capture)