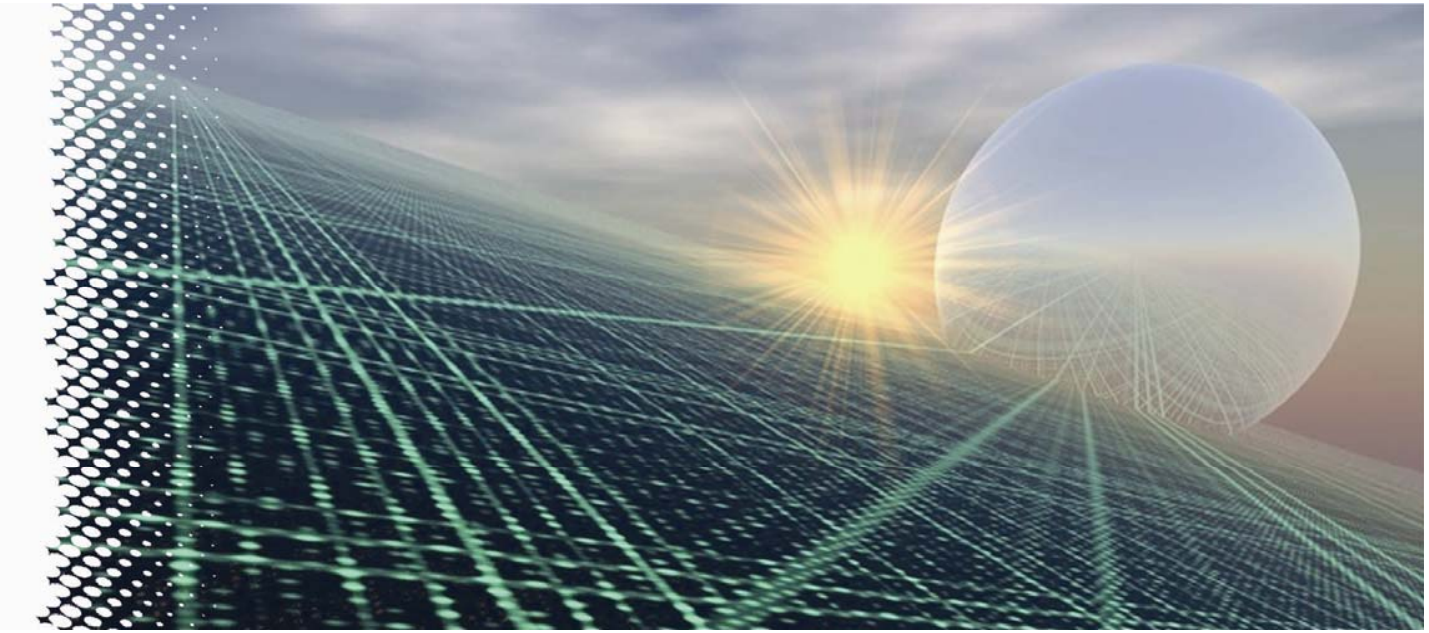
NATIONAL ENERGY TECHNOLOGY LABORATORY



US/UK Collaboration on Energy RTD
Fast response Gas Turbine Temperature Sensor
Harsh Environment Sensing Technology

Susan Maley, Project Manager

May 24, 2010
Workshop on US-UK Collaboration on Energy RTD

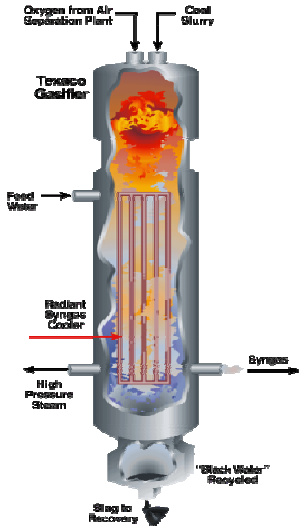
Harsh Environments

Solid Oxide Fuel Cells

- Utilizes Hydrogen from gaseous fuels and Oxygen from air
- 650 – 1000 °C temperature
- Atmospheric pressure

Advanced Combustion Turbines

- Gaseous Fuel (Natural Gas to High Hydrogen Fuels)
- Up to 1300 °C combustion temperatures
- Pressure ratios of 30:1



UltraSupercritical Boilers

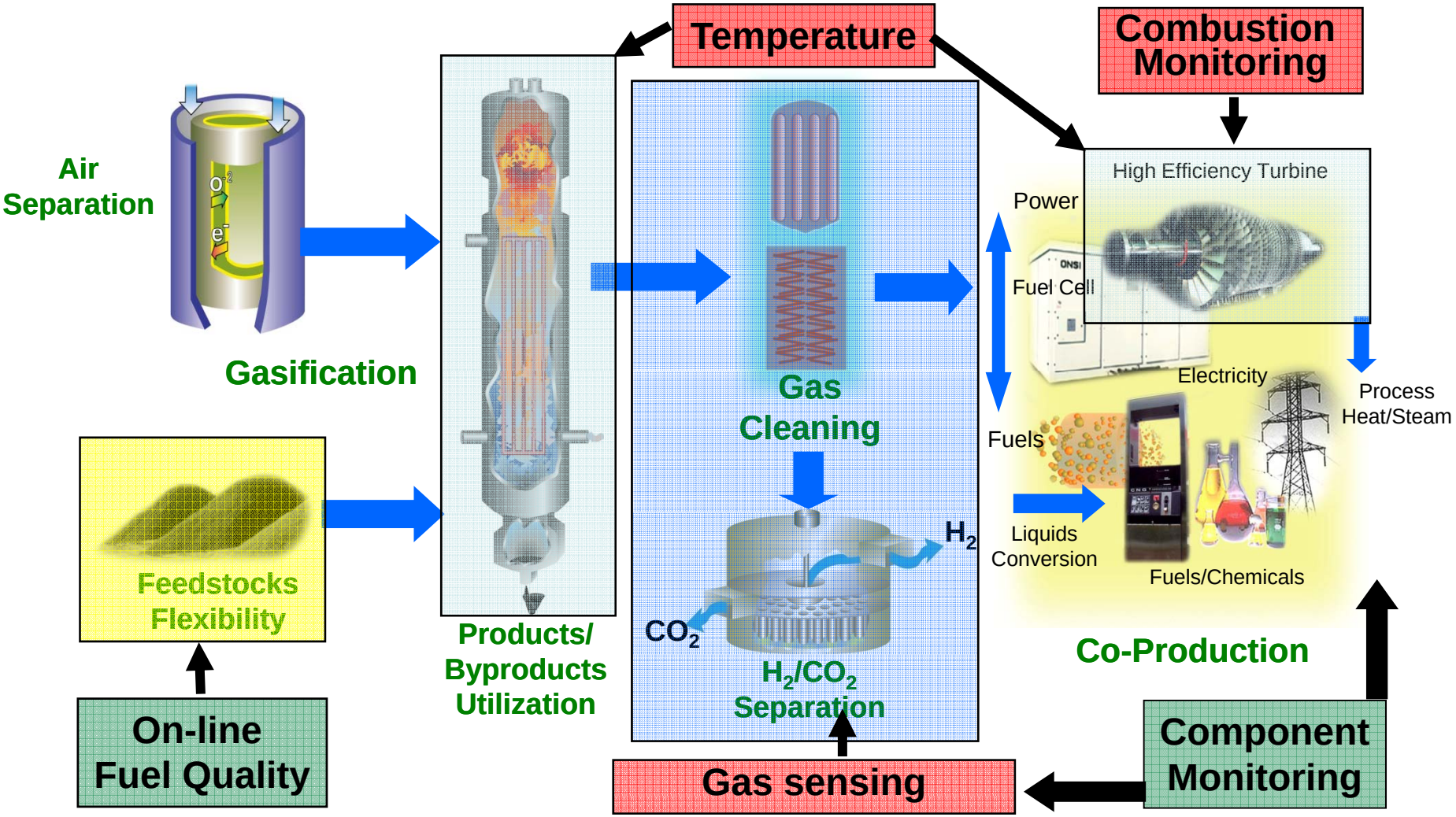
- Development of ferritic, austenitic, and nickel-based alloy materials for USC boiler conditions
- Up to 760 °C temperature
- Up to 5000 PSI pressure

Gasifiers

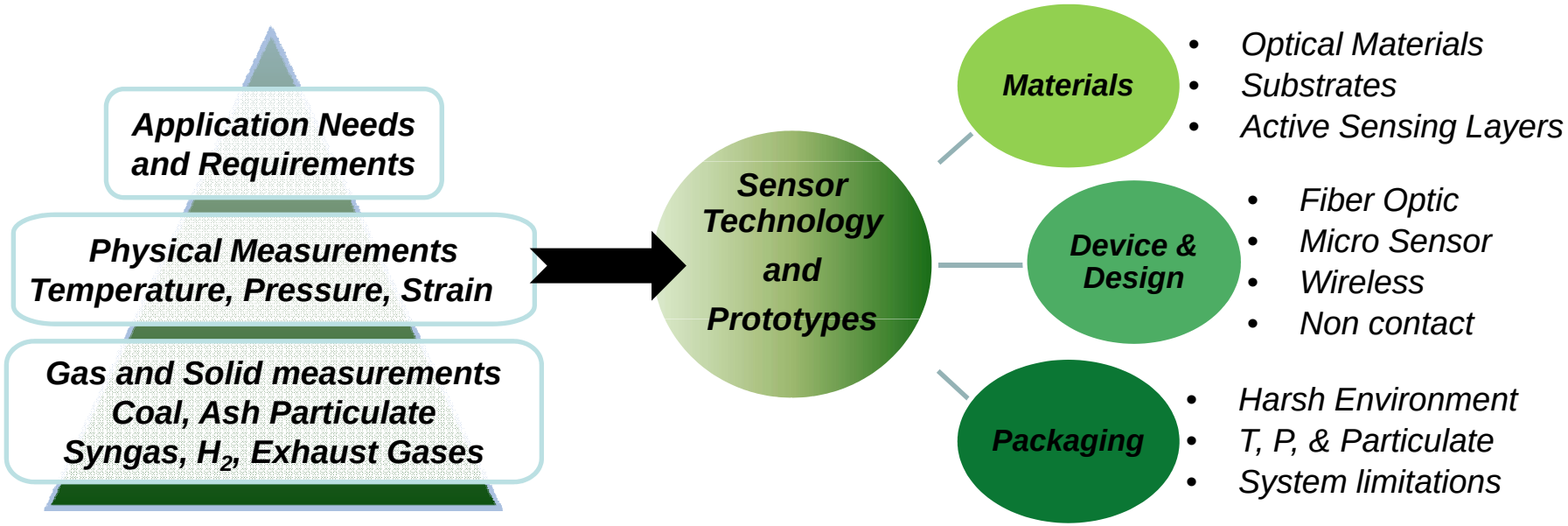
- Up to 1600 C, and 1000 PSI (slagging gasifiers)
- Erosive, corrosive, highly reducing environment
- Physical shifting of refractory brick, vibration, shifting “hot zones”

Prioritized Sensing Needs

IGCC based Near Zero Emission Cogeneration Plant

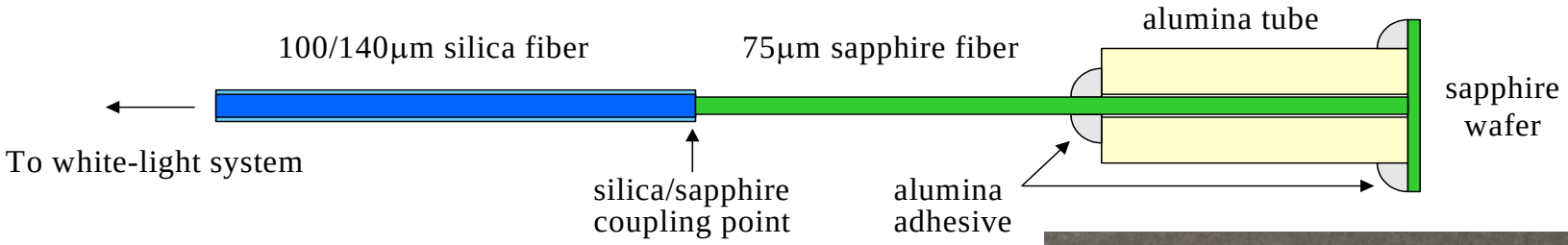


Delineation of Sensor Development

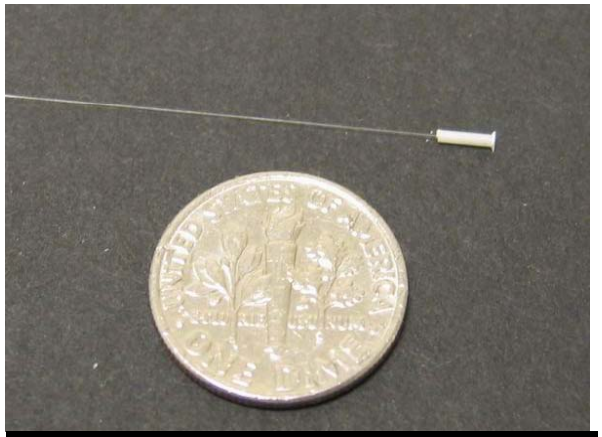


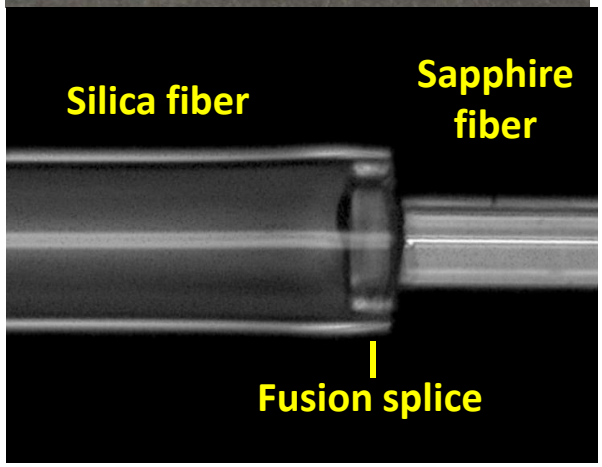
Fuel Quality	Coal – Heating Value (C,H, O), Minerals and ash
Fuel Quality	CH_4, other hydrocarbons, H_2 (~26%), CO (~37%), CO_2 & H_2S Conditions near 500 °C & up to 800 psi, Fast response
Exhaust Gas	NOx – 2-5,000 ppm, SOx 3-5,000 ppm, Hg(ppb), CO (ppm-%), CO_2 (%)
Temperature	1000-1600°C, highly erosive and corrosive
Pressure	Up to 1000 psi, errosive & corrosive Dynamic pressure for turbine applications
Materials Assessment	Refractory Life, Thermal Barrier Coating Life Piping and tubes for stress/strain, corrosion, cracking

Single Point Sapphire Temperature Sensor



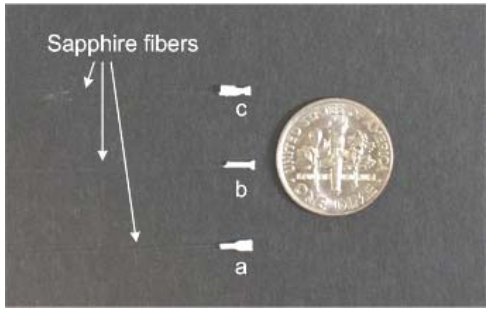
- **Fabry Perot Sensor**
- **Sapphire has desirable optical, high temperature and corrosion resistance properties**
- **Temperature measurement up to 1600°C with ~1°C resolution (0.1°C in lab)**
- **Methods, fabrication, designs, and packaging development since 1999**
- **Full scale testing – 7 months**
  - Additional testing planned
- **IP and licensing being evaluated**
- **Virginia Tech CPT**

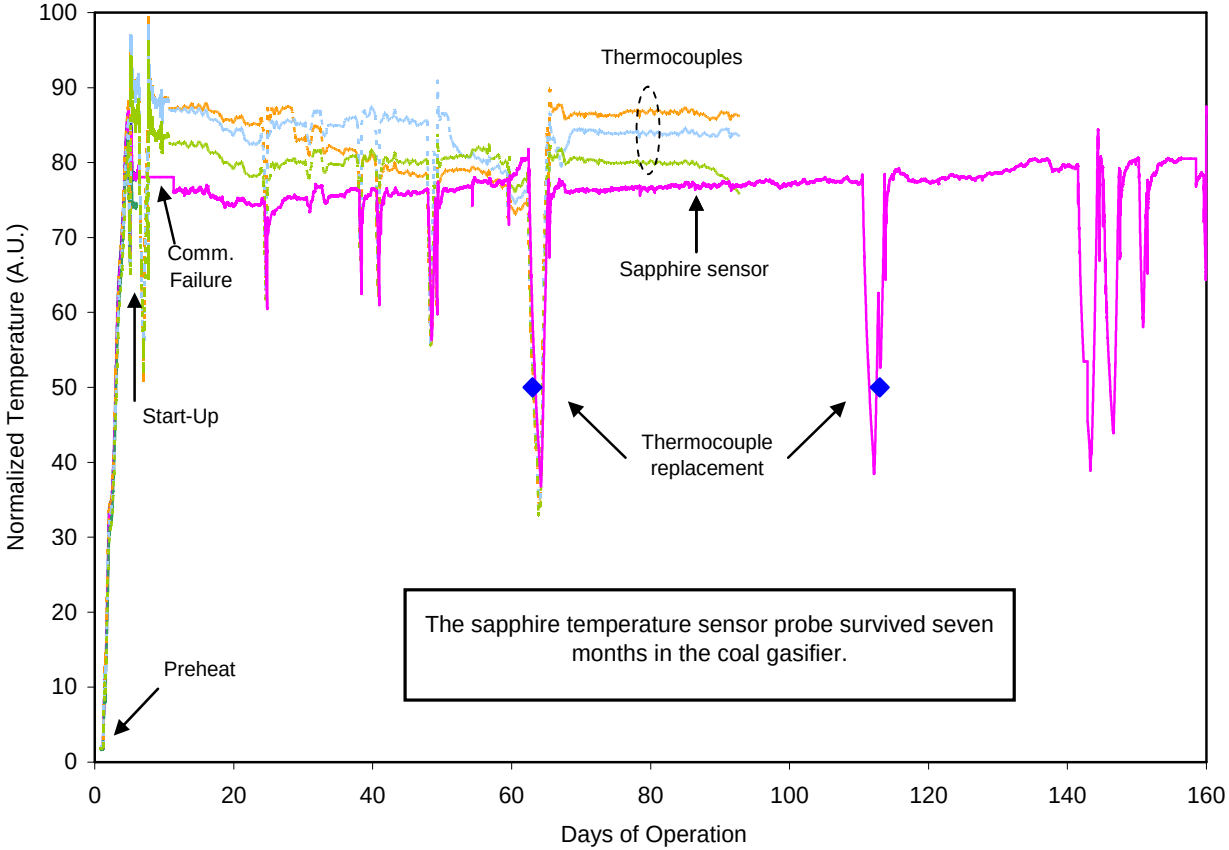




Sapphire Fiber Temperature Sensor

Full Scale Testing on a Coal Gasifier

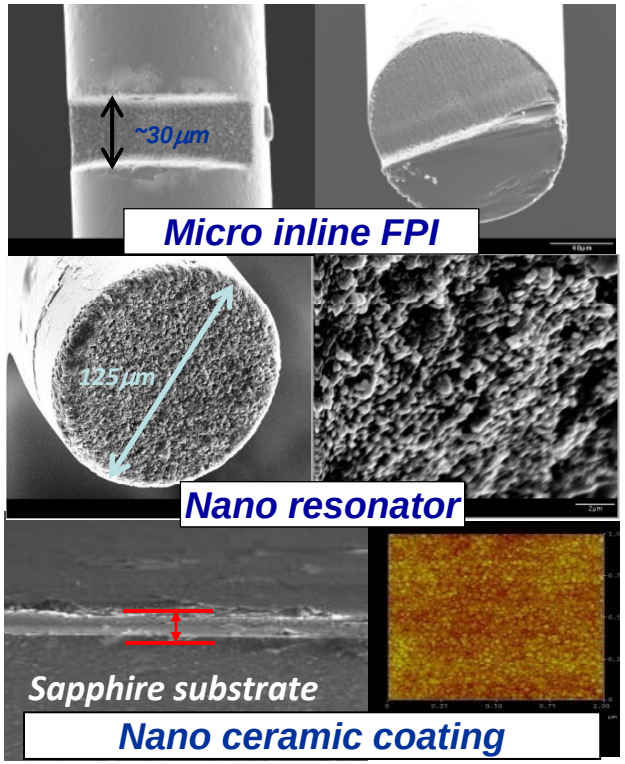


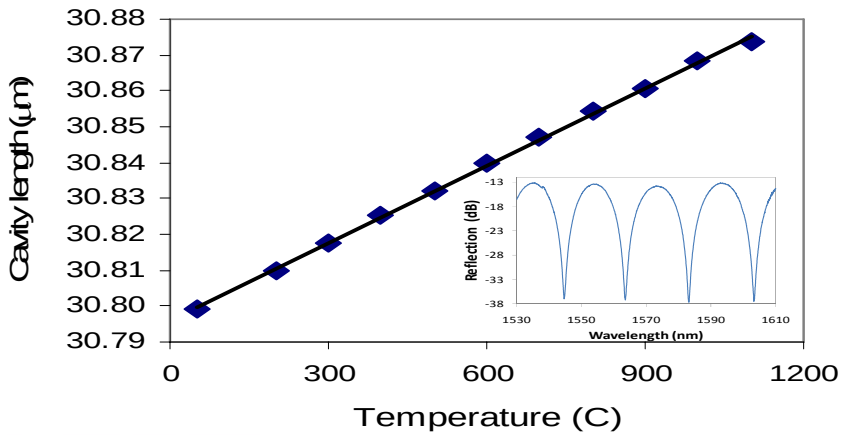


Micro-Structured Sapphire Fiber Sensors

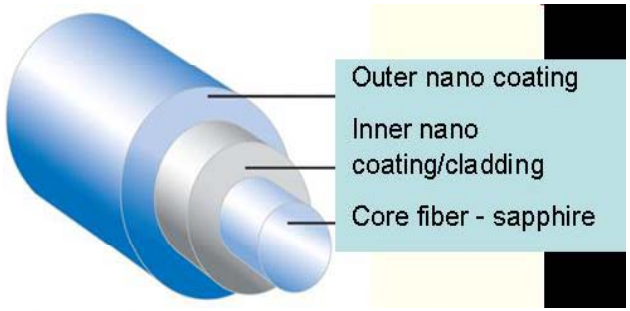
- Support new designs for high temperature fiber based sensing
- Target simultaneous measurements temperature (up to 1600°C) and pressure.
- Micro-machined sensor elements
- Cladding sapphire fiber with nano coatings
- Novel ceramic nano thin film coatings as double-layer cladding for protection in harsh environment.
- Preliminary work with silica fiber
- MST and UCinn – newly awarded

Fs laser micro/nano machining





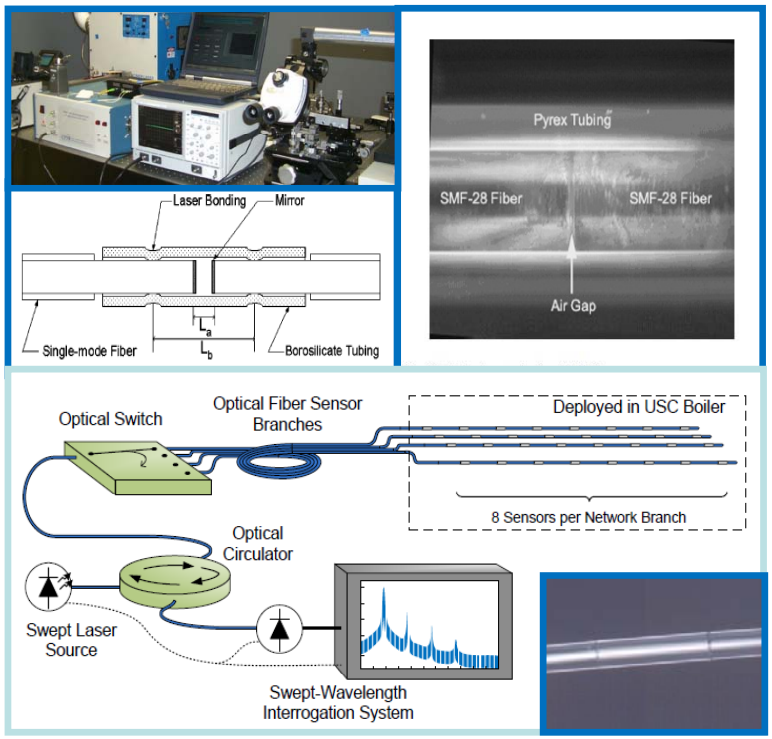
Temperature measurement up to 1100°C



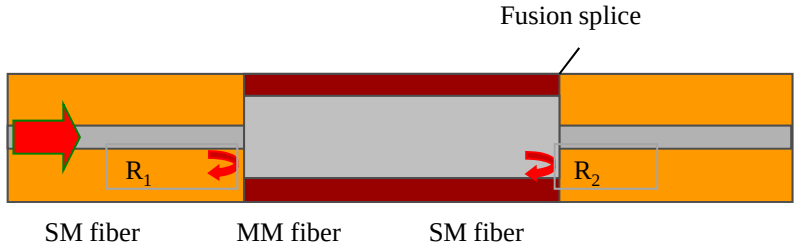
Multiplexed Sensing System

Temperature and Strain Measurement

- **Multiplexed sensors for massive distribution and data collection efforts**
- **Silica fibers using single mode / multimode interferometers for high temperature operation**
- **Targeting**
  - High temperature operation (up to 800 °C)
  - Up to 8 sensors per fiber
  - With high resolution (0.1 °C)
- **Numerous applications**
  - Initial application to advanced boiler systems and new boiler materials
- **Virginia Tech CPT**

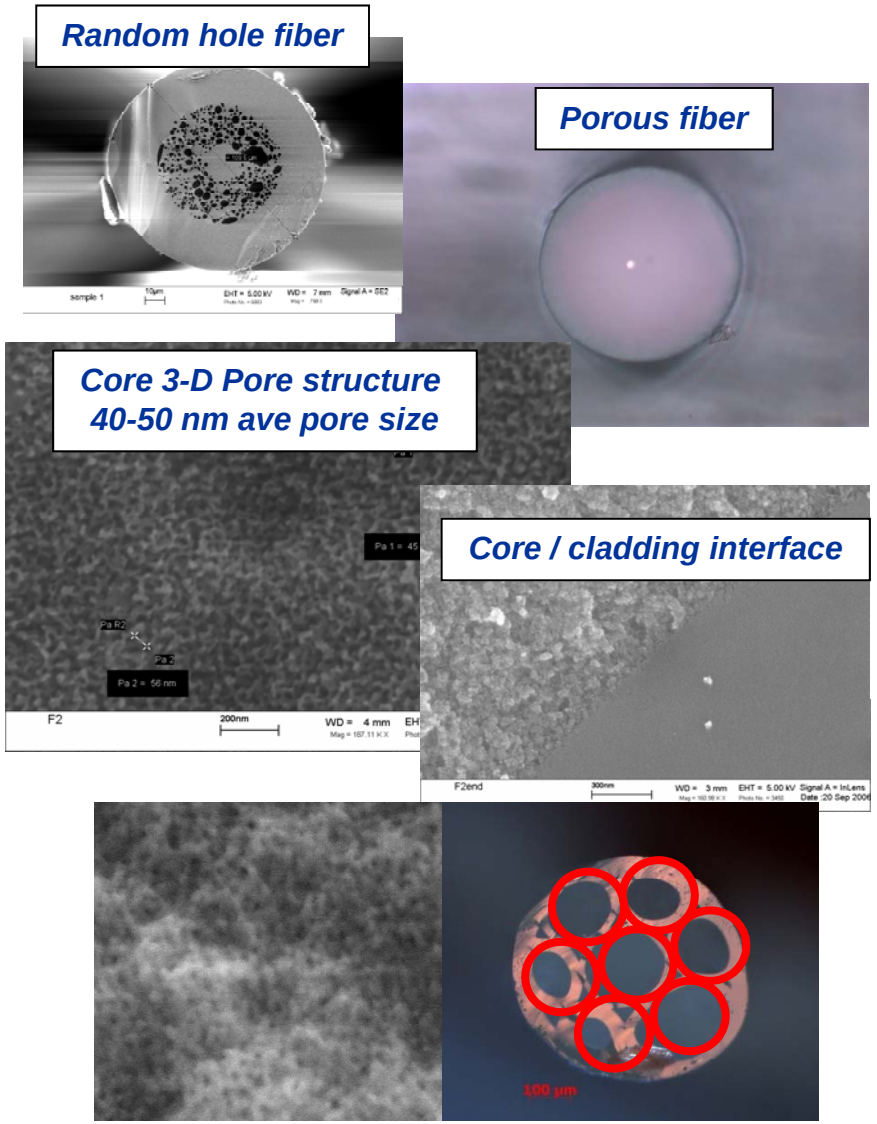


Interrogator with multiple fibers and multiple sensor elements



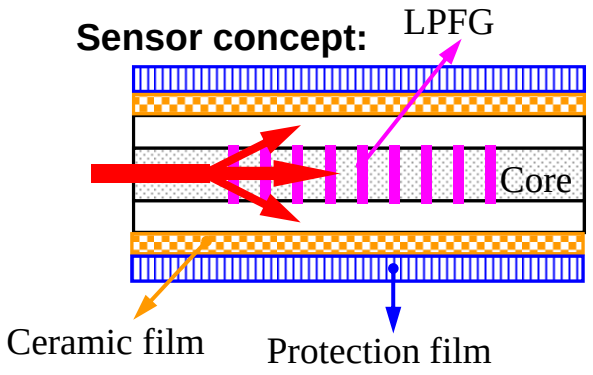
Nanostructured Porous Fiber Gas Sensors

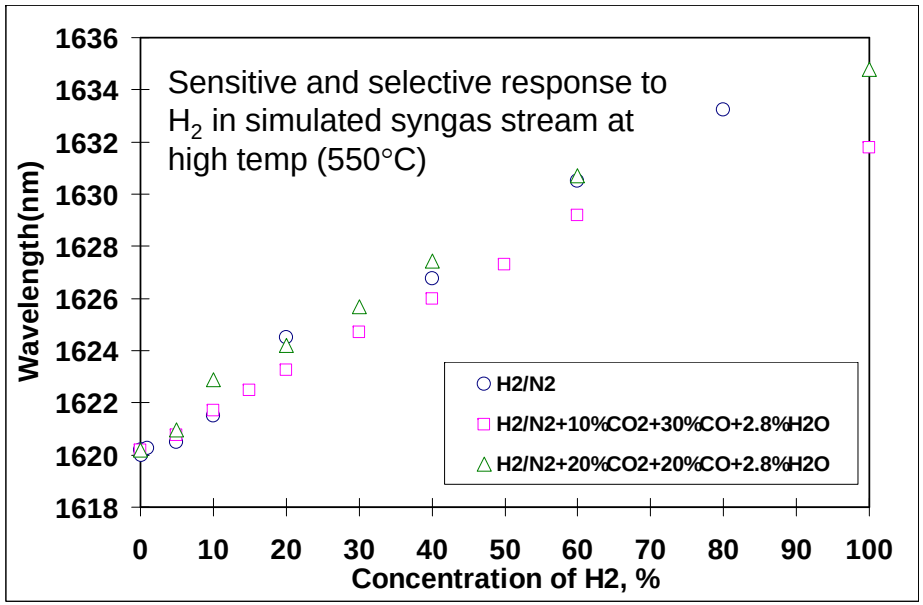
- **Enable gas sensing by manipulation of cladding around silica core**
- **Interaction of the evanescent wave with gas molecules results in a characteristic absorption spectra**
- **Traditional holey fibers have long response times (1 to 10 hours) due to the long diffusion path lengths**
- **Demonstrated the gas sensing capability of the fibers with significant improvement in sensor response time**
  - Over **1000 times** compared to published values for random hole optical fibers
- **Demonstrated 3-D porous photonic crystal fiber gas sensing capability**
- **Virginia Tech CPT**

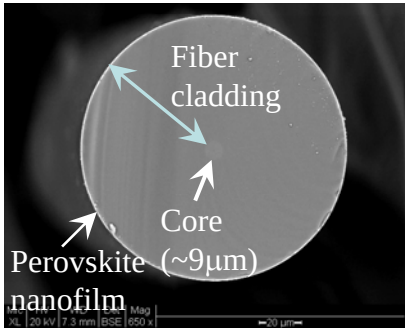


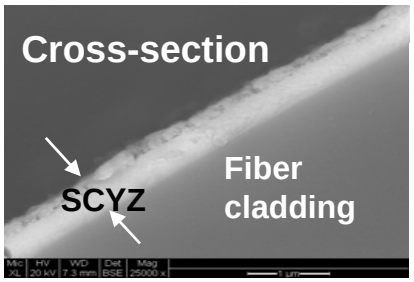
Coated Fiber for High Temperature Gas Sensing

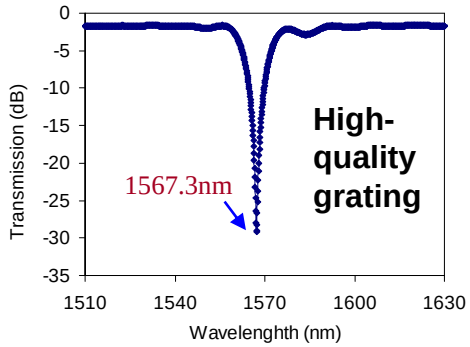
- **Feasibility to fabricate and sense at 500°C**
- **Silica fiber and nanocrystalline doped ceramics for detection of H_2, CO, CO_2, & H_2S**
- **Grating development, materials selection, & fabrication process**
- **Highly sensitive, large dynamic range**
- **NMT, UCinn, MST, ASU**

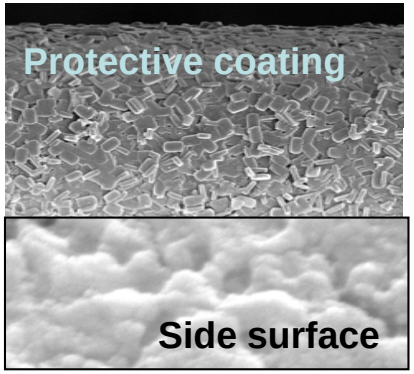












Collaboration Opportunities

- **Testing opportunities for sensors and/or optical interrogators – interrogator testing can include pressure sensor running instead of/in addition to temperature sensors.**

  Testing opportunities on a variety of engines and locations will be of significant value both for technology development and to ensure maximum progress towards commercialisation within the project timeframe.
- **Specification discussions – a broader specification investigation will help centre the project on the most promising applications as well as understanding the feasibility of tackling further uses (including outlier points)**
- **Potential for technology collaboration in specific areas, most likely to be additional elements arising from the broader specification discussion.**
- **These are the readily identifiable collaboration opportunities in the *short term*. There may well be others identified by discussion for both short term (between existing projects) and longer term (new collaborations).**

NATIONAL ENERGY TECHNOLOGY LABORATORY

UK Presentation

Fast REsponse Temperature Sensor for GAs Turbine Efficiency (FRETSGATE)

Lead Partner – Oxsensis

Collaborators – Rolls-Royce and Siemens Industrial Turbines (UK)

Project Outline

Overall Aim:

Development of an optical temperature sensor system capable of measuring gas path temperature to at least 1200°C (stretch target 1700°C) in Gas Turbines.

Purpose:

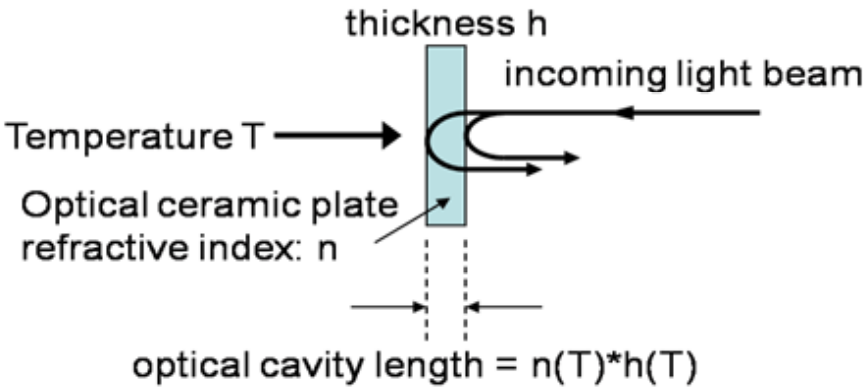
For use in combustion monitoring and control initially for engine development with the aim of moving into operational control systems. Targeted improvements include improved overall efficiency (specific fuel consumption), prevention of damaging events (e.g. flashback) and as part of a condition based monitoring scheme for operational turbines.

Key Technology Targets:

Attribute	FRETSGATE TARGET
Response Time	≤0.1s (stretch target ≤0.05s)
Sensor Lifetime	150 hrs (development sensor) 25,000 hrs (production sensor)
Max Continuous Temperature	1200°C (stretch target 1700°C)
Max Short Term Temperature	1400°C (stretch target 1700°C)
Accuracy	<1% of measurement

Technology Starting Point

Fabry-Pérot Interferometer Sensor

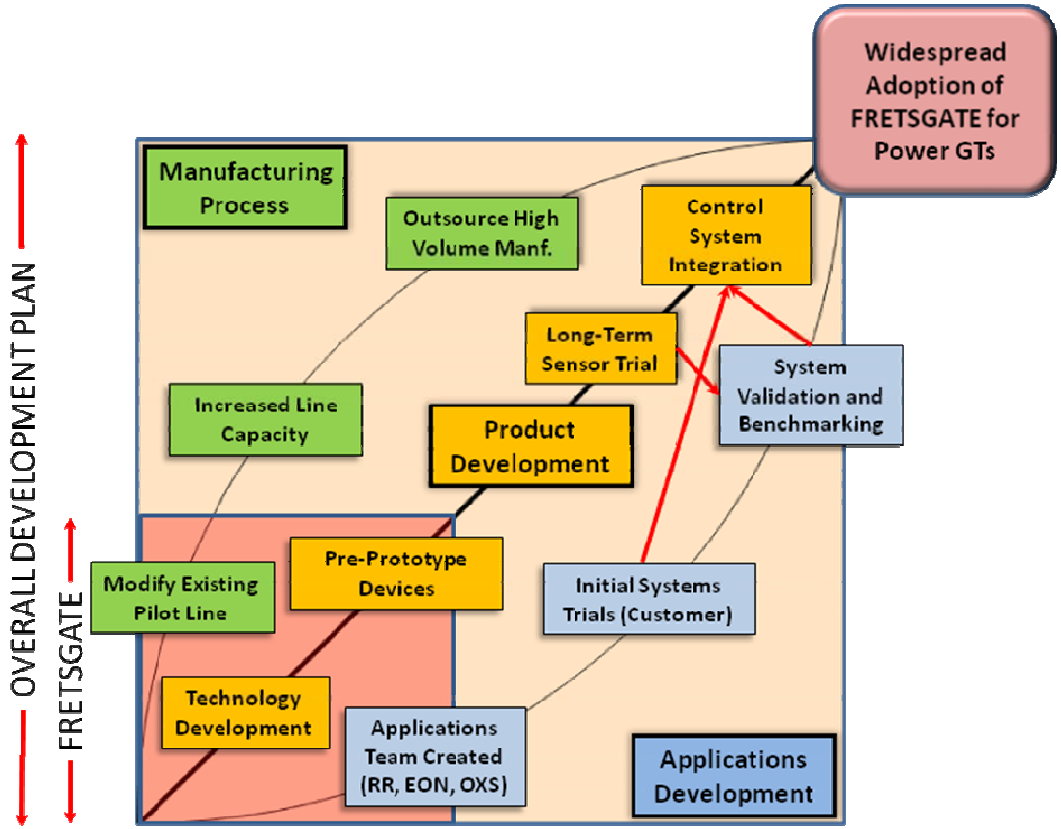


- Optical cavity length changes in response to temperature by:
  - Expansion ($\Delta h \propto \Delta T$)
  - Refractive Index change ($\Delta n \propto \Delta T$)
- For fast response:
  - Thermal mass is small
  - Sensor element geometry is critical

Technology transfer from Oxsensis existing dynamic pressure sensor system

New interrogator under development for T sensors which may (with adaption) have application for multiple parameter measurements (e.g. Pressure and Temperature).

Where Does the FRETSGATE Project Fit?



Additional Benefits From FRETSGATE

- **Fast response offers potential benefits in flexible fuelling conditions, particularly with H_2 rich fuels**
- **When coupled with dynamic and static pressure sensors FRETSGATE can form part of a more complete 'portfolio' of optical sensors for Gas Turbines**

Collaboration Opportunities

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Oxsensis' key message to external audience on FRETSGATE and work generally on carbon abatement

• GT based generation is a key part of the energy mix
• For base load particularly ahead of a new wave of nuclear generation
• To enable grid balancing in a more uncertain renewable world
• Improving efficiency of GTs has a key role in optimising our fossil fuel resources.
• Advanced instrumentation (as being developed in FRETSGATE) is an enabling technology for improved GT efficiency particularly in variable load conditions
• Flexible fuelling of GTs with mixed quality natural gas and hydrogen rich fuels is of increasing importance in energy generation and FRETSGATE sensors are particularly relevant to engine management in a mixed fuels environment.

Oxsensis views on possibilities for external organisations to be involved in developing technology parallel to the project

• Oxsensis is engaged with US and other international organisations on evaluating its existing products. Oxsensis dynamic pressure sensors for extreme environments have been trialled in civil and military programmes.
• To maximise the benefit of the technology development in FRETSGATE it would be helpful to identify opportunities for testing across a wide range of engine types. This would reduce the time for product development to service the market on completion of the current applied research project.
• Similarly input on specification would be welcome. The proviso on involving external partners is that the focus on technology development must be maintained avoiding the danger of turning FRETSGATE into an applications engineering project. A critical requirement from external partners would be the provision of resource to address sensor installation requirements and data analysis.

Oxsensis thoughts for future possibilities for collaborative projects e.g. with US

• Oxsensis is actively seeking collaborative projects with the US and is involved in discussions with both defence and civil partners
• Oxsensis has incorporated in the US to ease some of the logistical difficulties of managing international collaborations with US companies and non-profit organisations. Increased US collaboration would enable Oxsensis to justify increasing its US presence.
• There is a key requirement for programmes to cover the gap between technology development and product deployment. This area covers the need for long term testing and validation of new technologies.
• A further area for international (transatlantic) collaboration is in establishing clear and accepted routes through the regulatory system to enable uptake of new technology. This is of particular importance in safety critical applications where there can be significant regulatory hurdles slowing technology progress.