# Mid IR Laser Sensor for Continuous $SO_3$ Monitoring to Improve Coal-Fired Power Plant Performance during Flexible Operations


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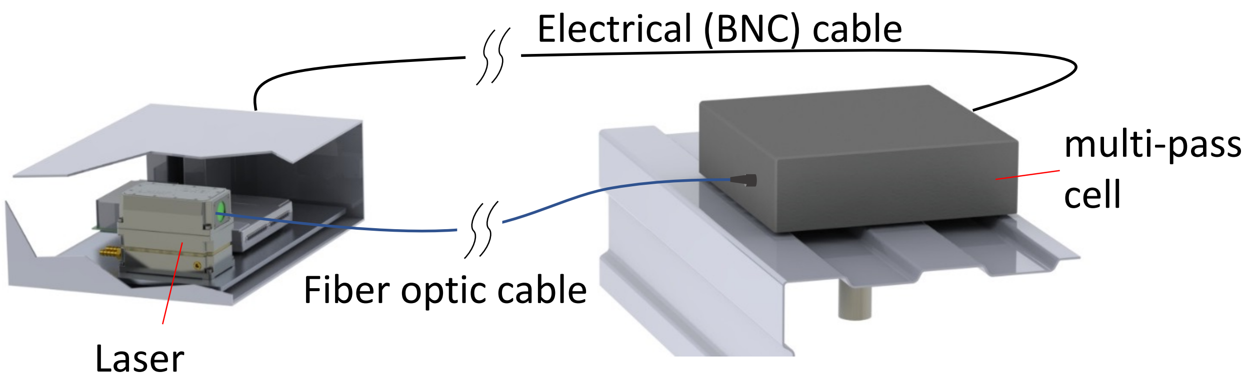
# Project Description and Objectives

**Purpose:**

- Produce and demonstrate a continuous $SO_3$ monitor for coal-fired power plants

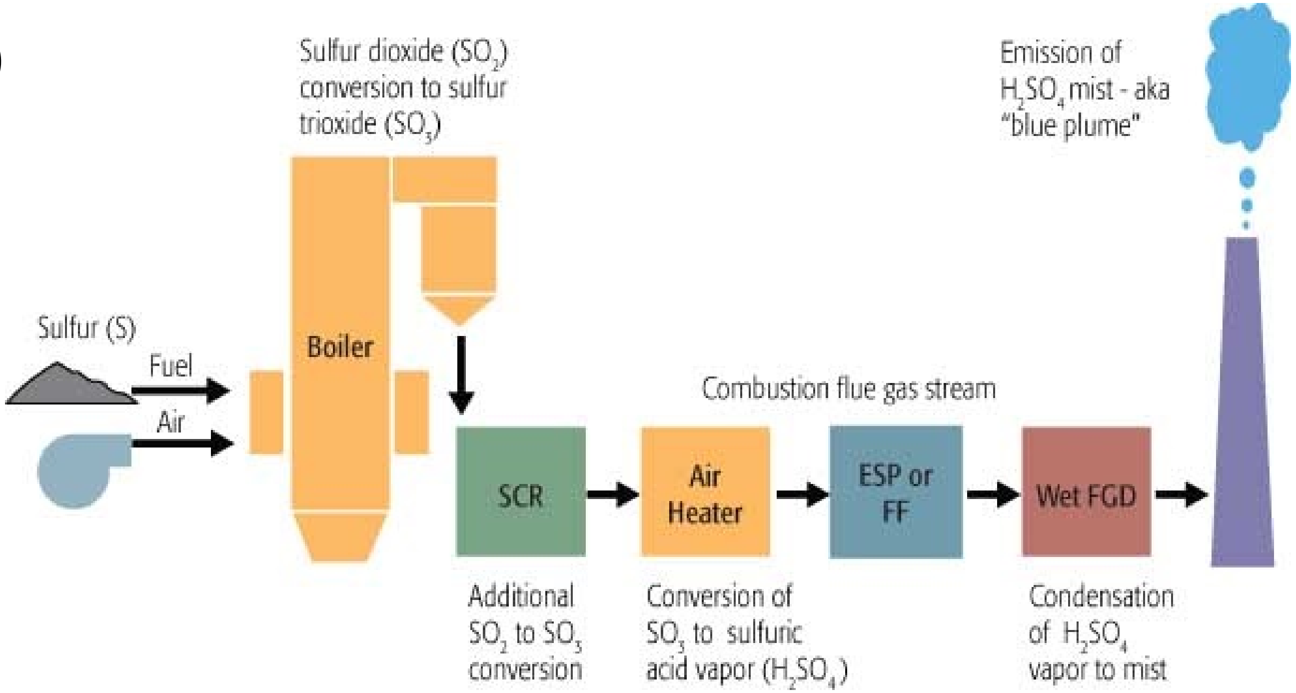



**Alignment to Fossil Energy objectives**

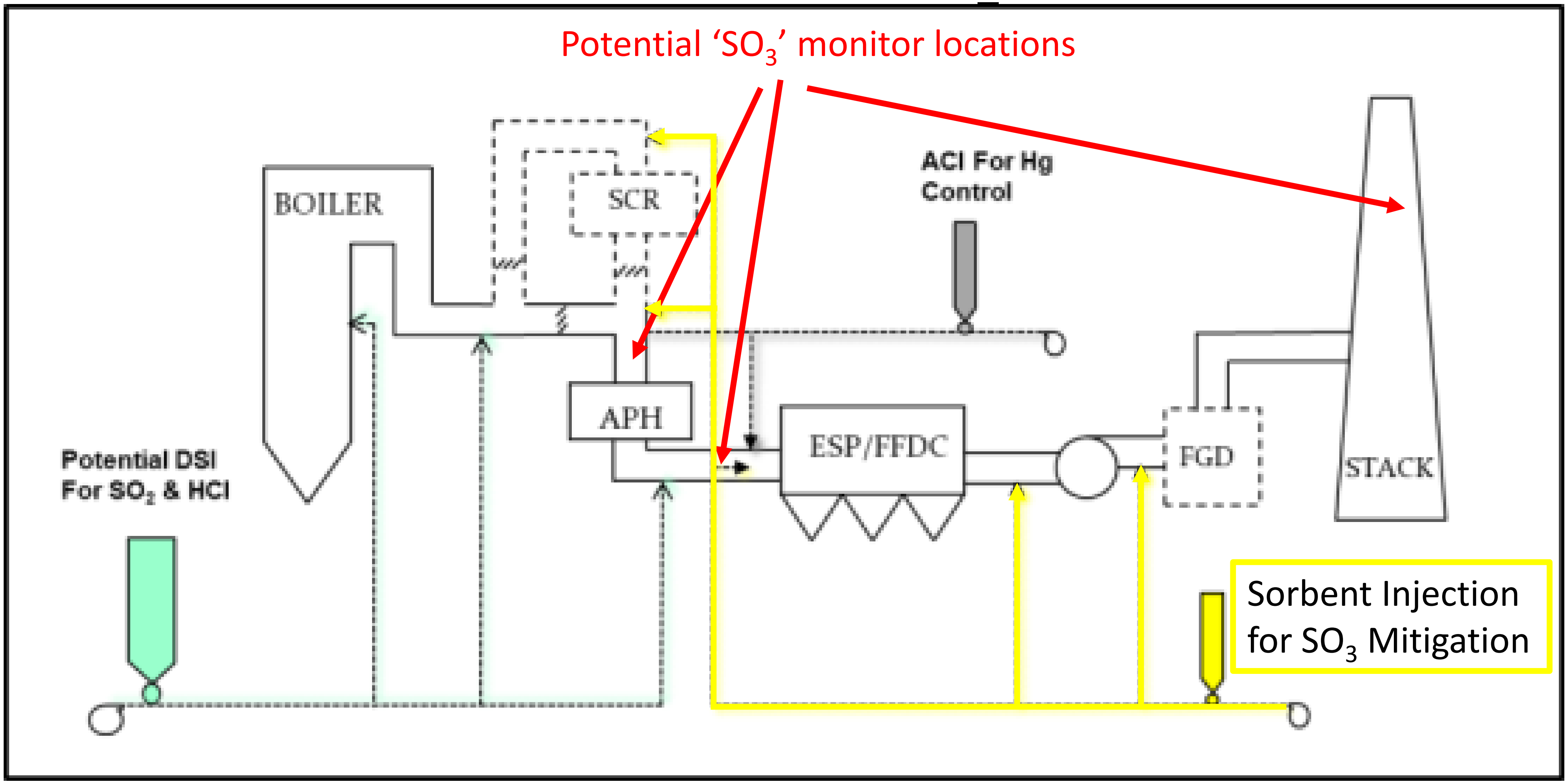
- Real-time information to optimized additive injection and minimize catalyst deactivation
- Without an $SO_3$ monitor, power plants over use sorbent => waste (typical sorbent costs $1M/yr)
- Sensor would enable cost savings ($100k/yr – $200k/yr) and improved flexible operations

**Driving questions**

- Can the sensor provide sufficient sensitivity in a challenging environment?
- Do measurements accurately reflect the composition of the flue gas?



# Sorbent Injection for $SO_3$ Mitigation

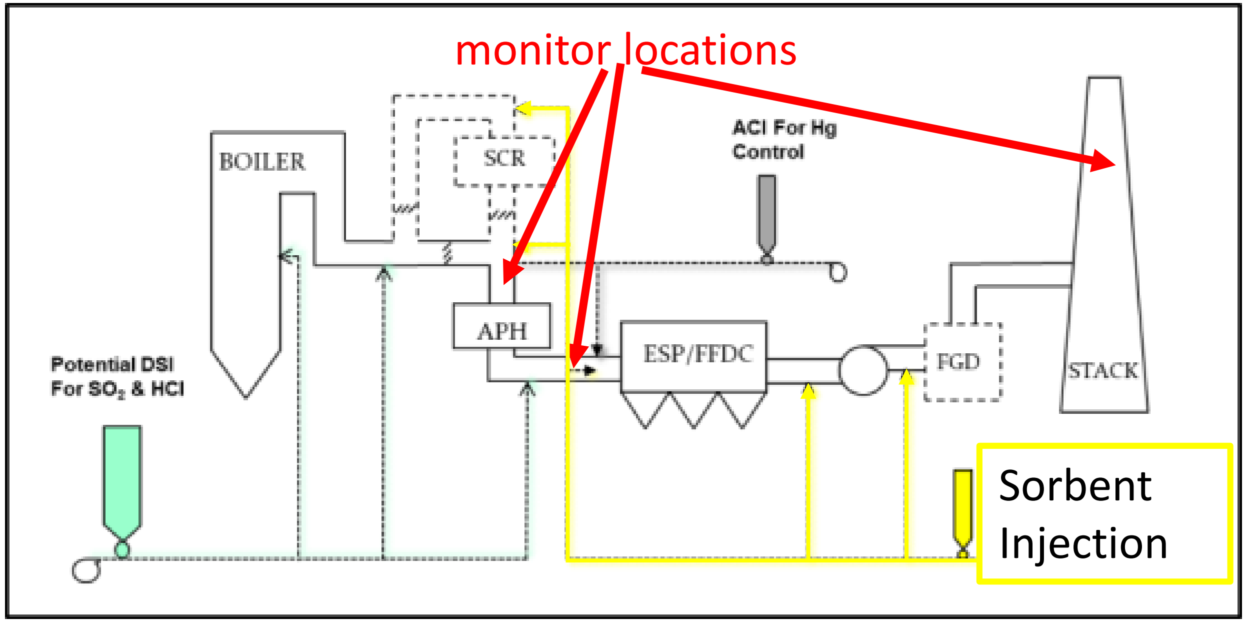



Lack of continuous $SO_3$ monitor limits ability to optimize sorbent injection rates

# Alkali Sorbent Injection

**Alkali sorbent injection uses include:**

- Mitigation of $H_2SO_4$ 'blue plume'
- Enhanced powdered activated carbon (PAC) efficiency in capturing mercury
- Mitigation of ammonium bisulfate (ABS) and $SO_3$ condensation impacts on air heater fouling
- Mitigation of duct corrosion due to $SO_3$ condensation

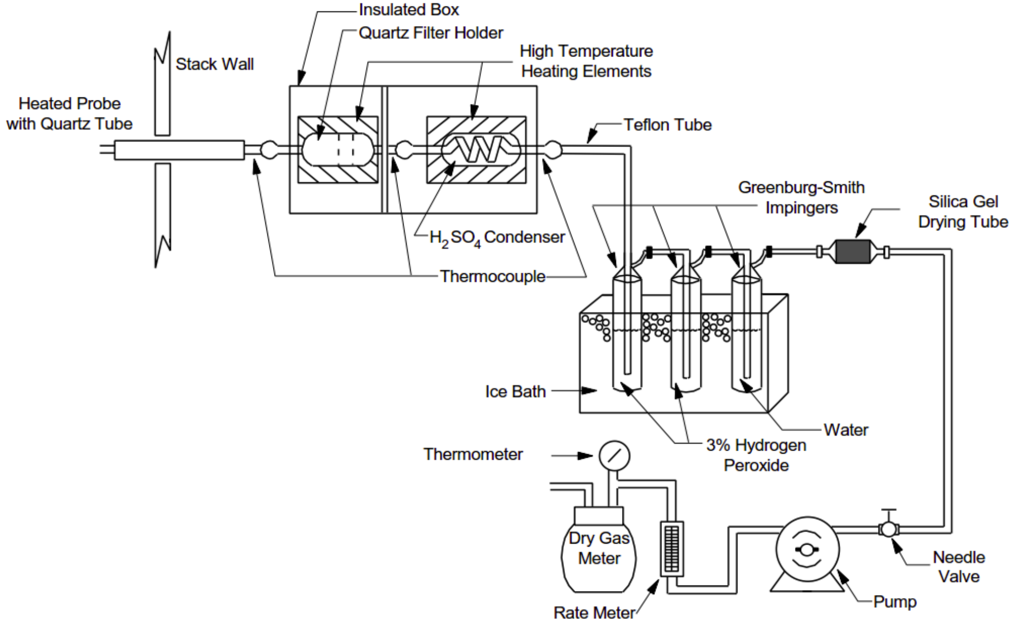



**Alkali sorbent injection locations moving upstream:**

- Originally downstream of air heater / upstream of particulate collection device
- Also between the Selective Catalytic Reduction (SCR) outlet and air heater
- Recently positioned upstream of the SCR

Lack of continuous $SO_3$ monitor limits ability to optimize sorbent injection rates

# Project Description and Objectives



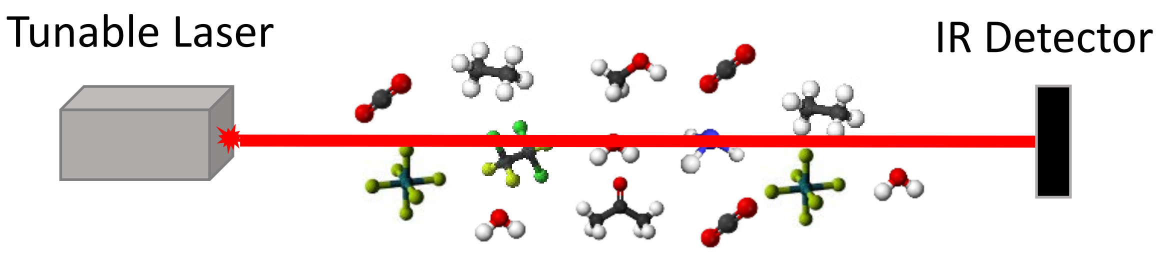

## Technology Benchmarking

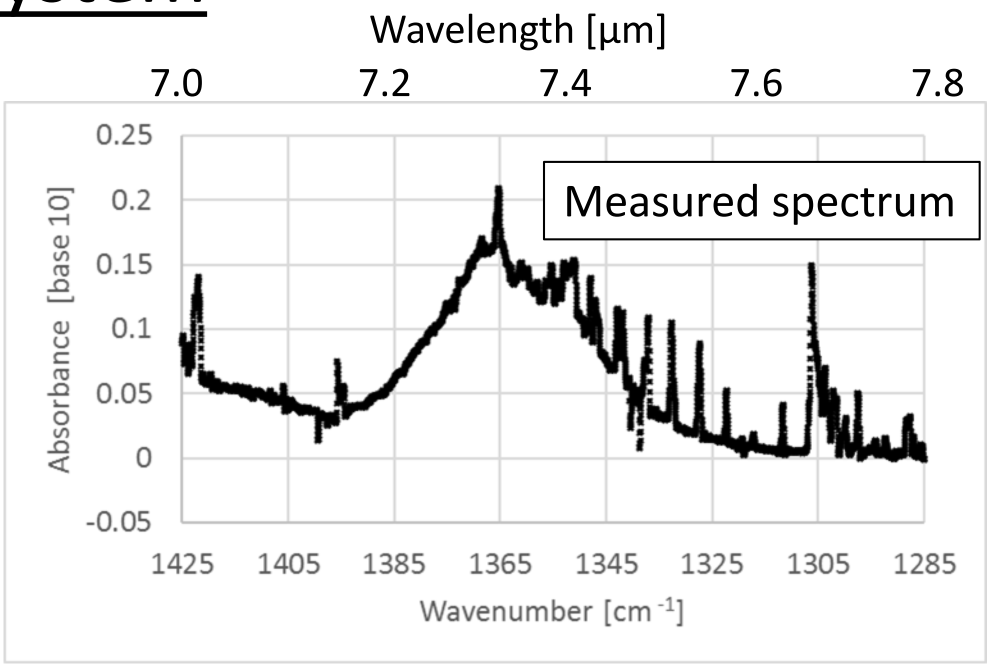
- Accepted standard is controlled condensation: wet chemistry, off-line process (EPA method 8A)
- Breen probe being used, but it is a non-specific condensation probe with limitations

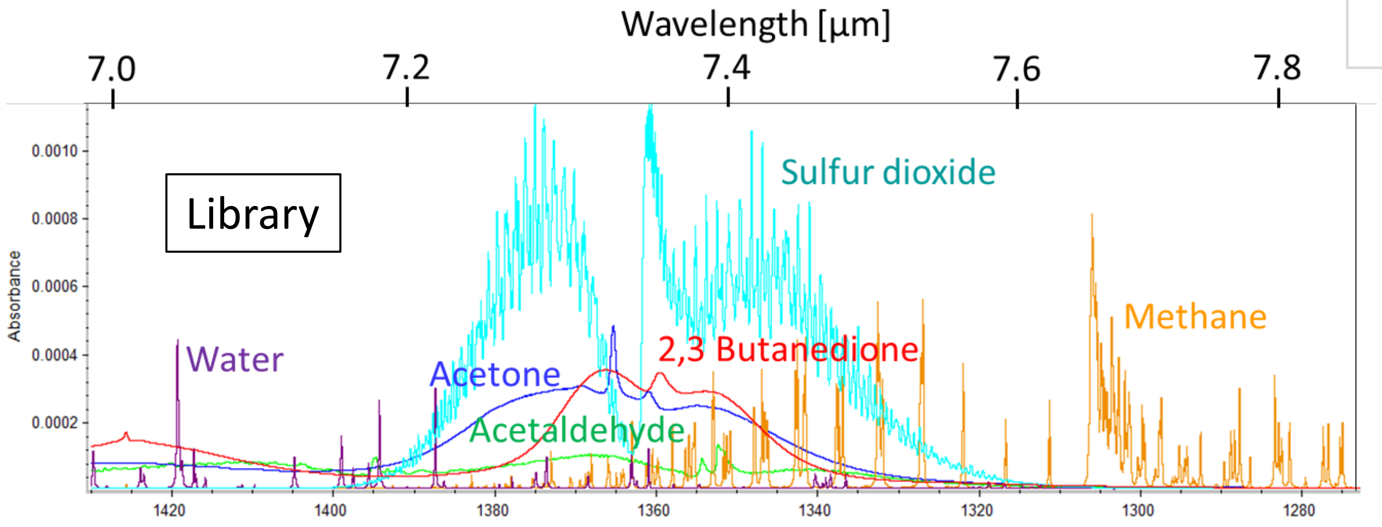
## Current Status of Project

- Protype laser absorption system tested/validated in laboratory tests of $SO_2$
- Working to generate $SO_3$ and $H_2SO_4$ for higher fidelity validation
- Industry feedback: "We need a solution now"

# Spectroscopy System



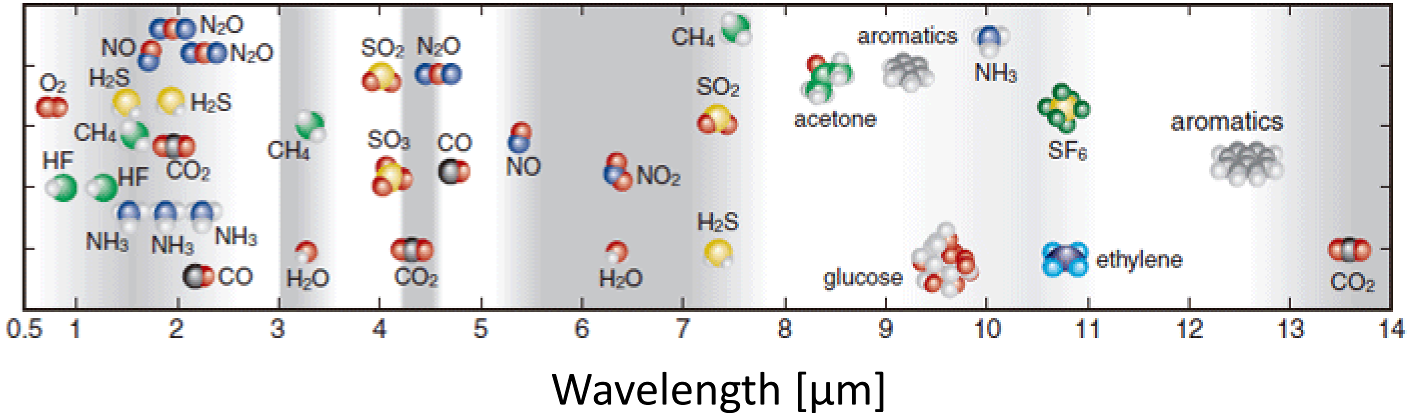



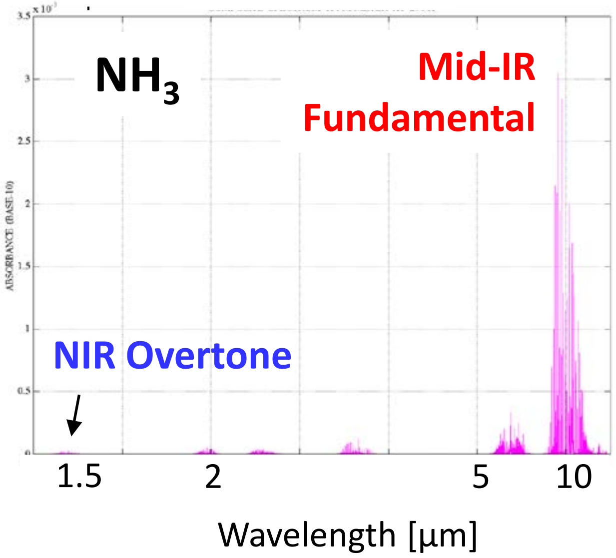



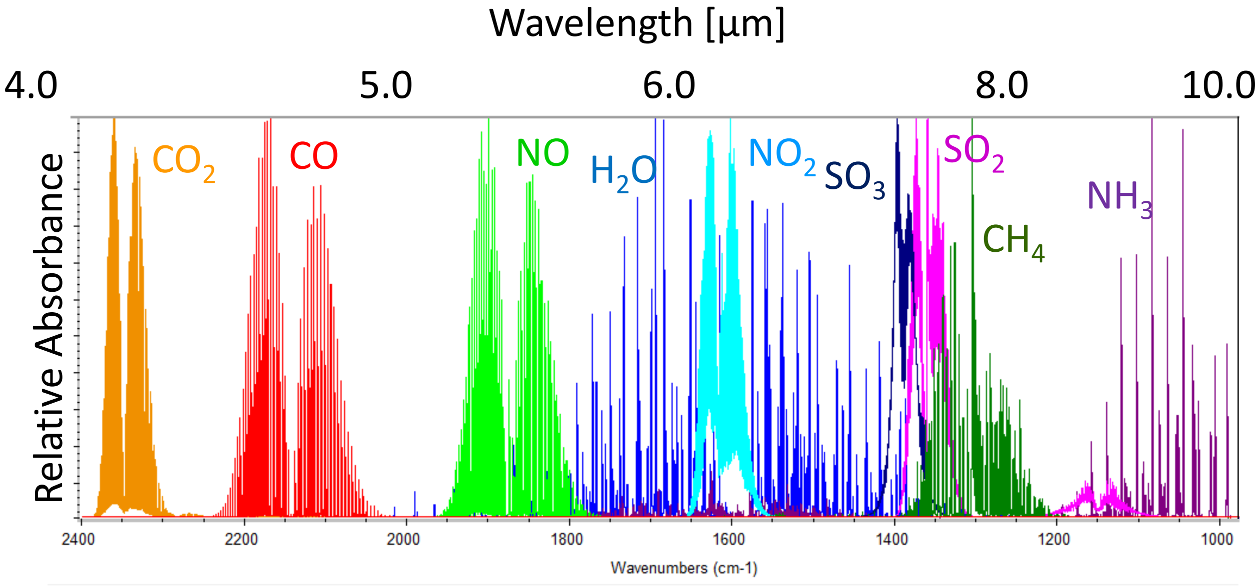

## Species Concentration

| | |
|---|---|
| 2,3 Butanedione: | 99.7 ppm |
| Acetaldehyde: | 230.2 ppm |
| Acetone: | 130.8 ppm |
| Methane: | 259.3 ppm |
| Water: | -38.8 ppm |
| Sulfur dioxide: | 2.5 ppm |

# Mid-Infrared Wavelength Range




## Mid-IR Spectroscopy

- Fundamental transitions in Mid-Infrared (λ: 2 -12 μm) stronger than overtones in NIR (λ: 1 -2 μm)
- Molecular species uniquely identified and precisely quantified
- But….. NIR benefits from developed components (telecom investments)

# Prior Related Work Using FTIR

**EPRI funded work[1]:**

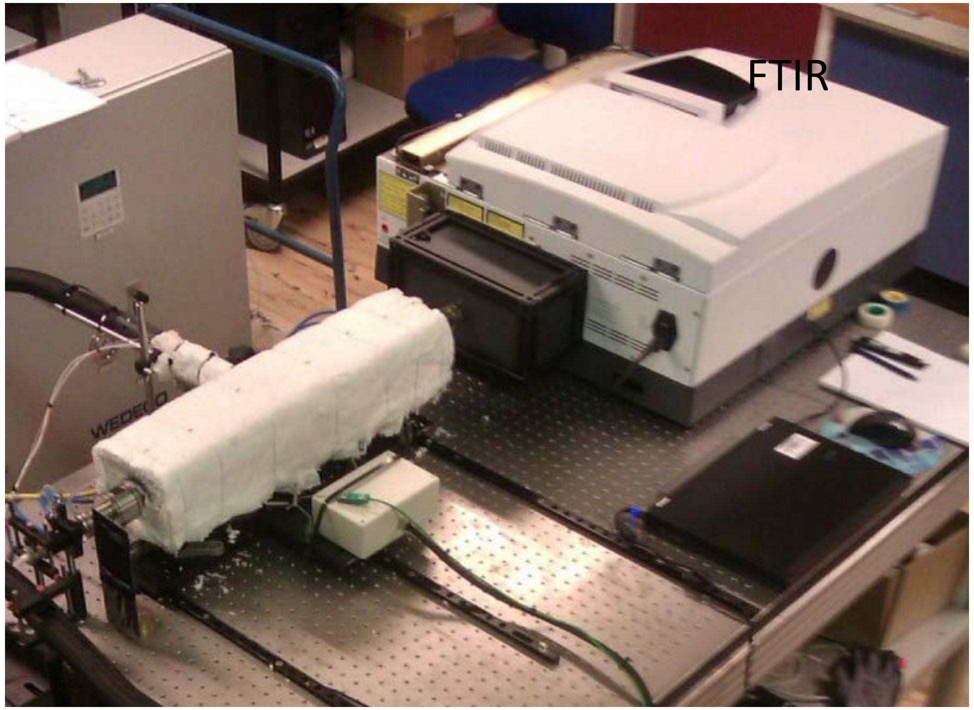
- Both $H_2SO_4$ and $SO_3$ can be detected and quantified
- Multi-port cross-duct measurements found minimal (10%) variation in $SO_3$ quantity across the duct

**Danish EPA funded work[2]:**

- Verified Mid-IR spectroscopy in heated lab cells
- Generated $SO_3$ with ozone method
- Could not measure $SO_3$ in field

**Comparison to Current Effort:**

- Lasers are more intense than FTIR source enabling faster and more sensitive measurements
- Current system for $SO_3$ generation uses catalyst

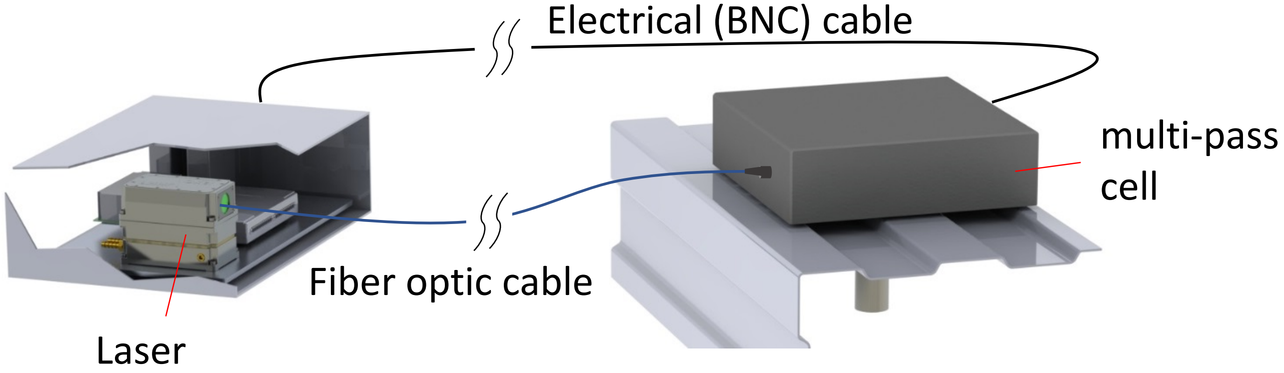


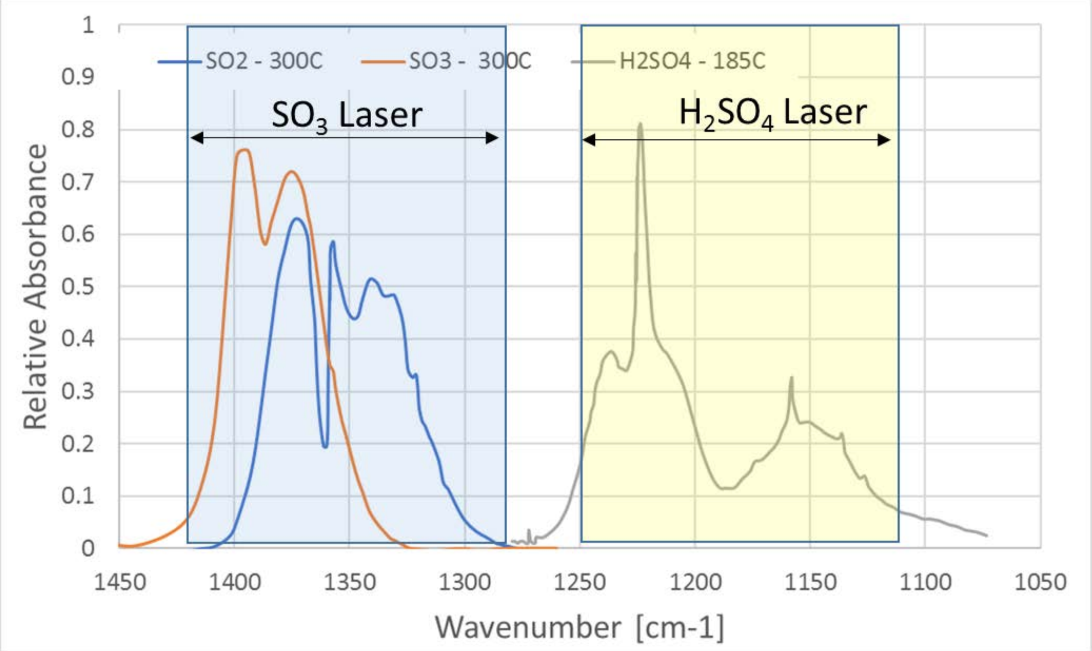
Fourier Transform Infrared (FTIR) Spectrometer

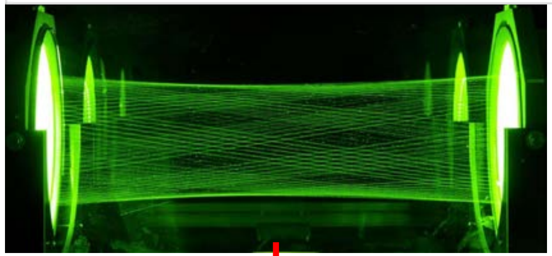
1. "Continuous Measurement Technologies for SO3 and H2SO4 in Coal-Fired Power Plants", EPRI Technical Report #1009812 (2006
2. "Sulfur trioxide measurement technique for SCR units", The Danish Environmental Protection Agency Project #1885 (2016).

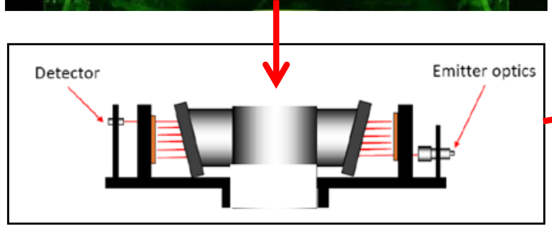
# Technology Development

- Dual laser approach for $SO_3$ and $H_2SO_4$
- Need "broad" wavelength tuning lasers
- Use close-coupled heated multi-pass cell
- Use inertial filter sampling
- Mid-IR Fiber Optics for remote laser delivery



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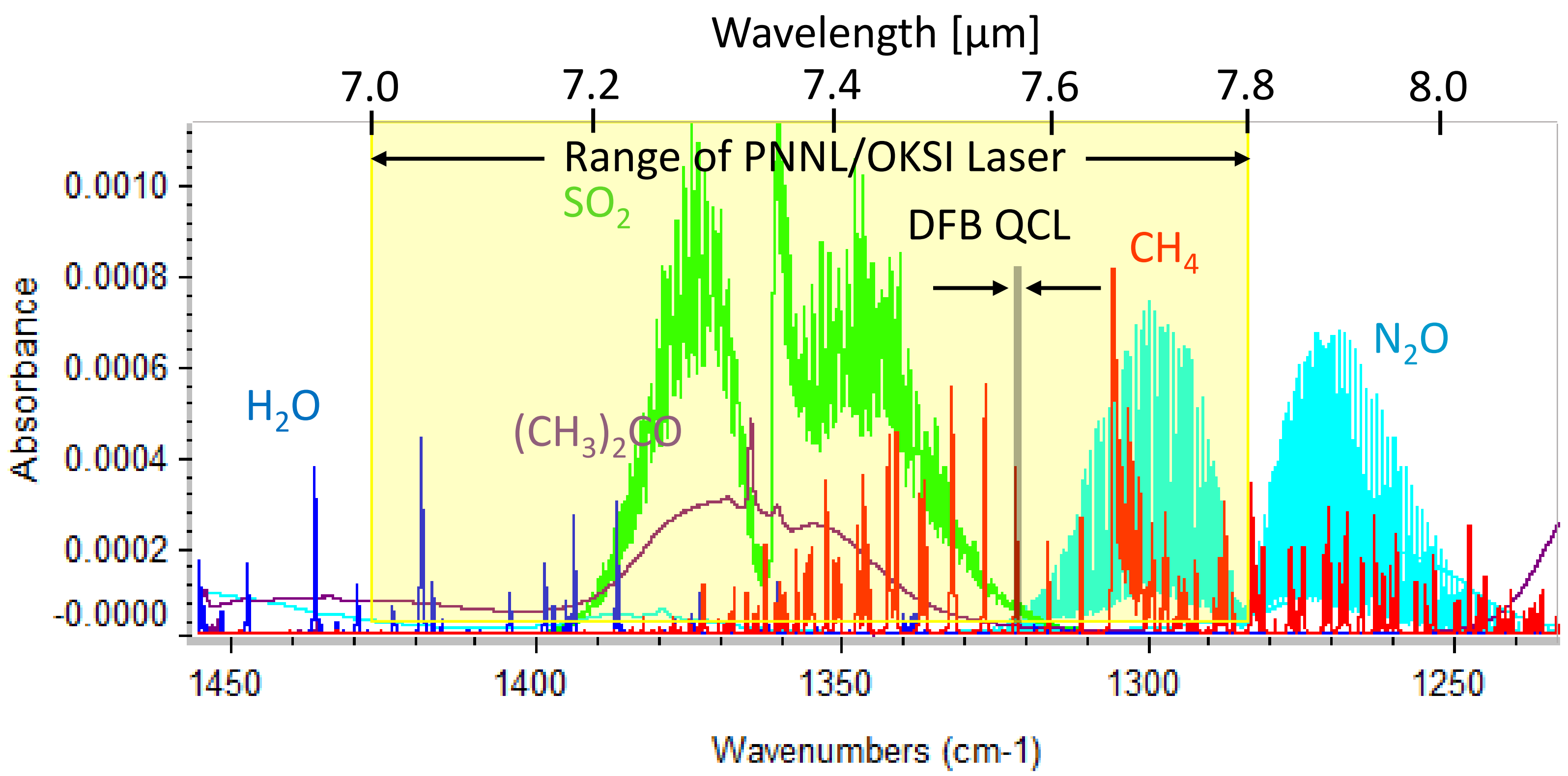
# Broad Tuning Laser




Pacific Northwest NATIONAL LABORATORY

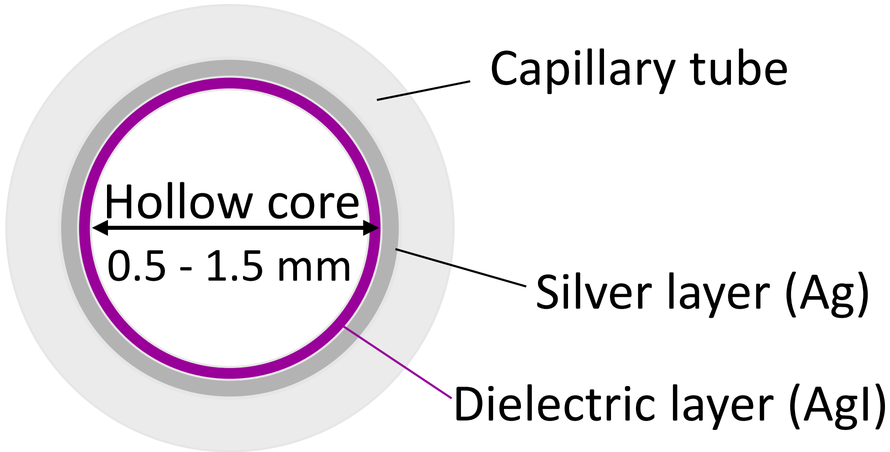
- External-cavity Quantum Cascade laser with broad-tuning capabilities
- Custom laser developed at Pacific Northwest National Laboratory (PNNL) transitioned to OptoKnowledge
- Sensitive to multiple gas species and able to measure “large” and “small” molecules
- Better solution than standard “narrow-tuning” Distributed Feedback (DFB) lasers

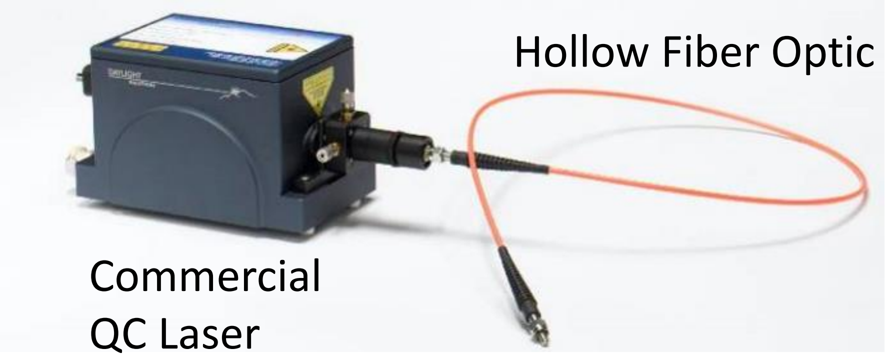
# Hollow Core Fiber Optics

## Hollow Fiber (Waveguide)

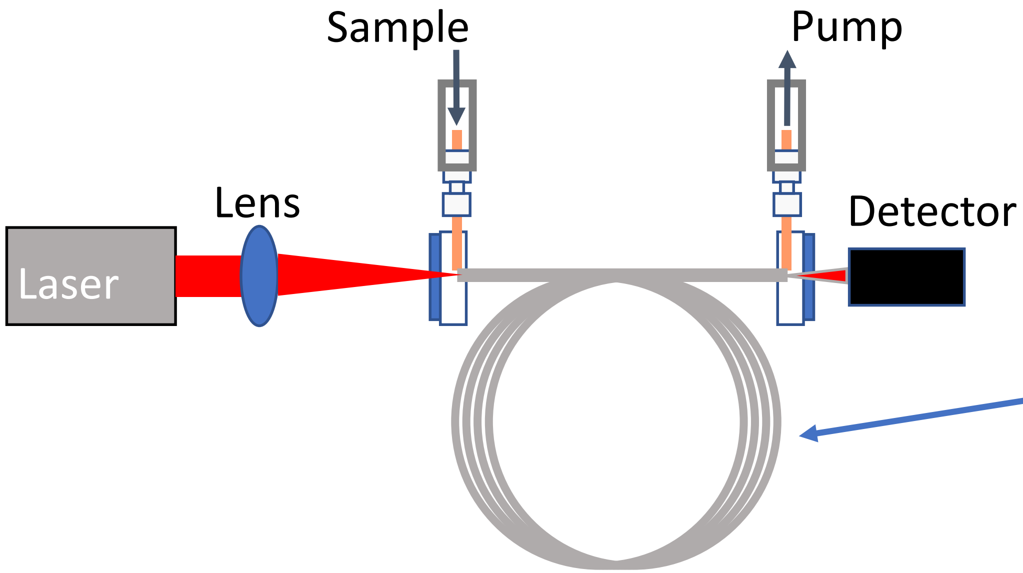
- Technique developed by Rutgers
- Transitioned to OptoKnowledge
- Manufactured and sold by OptoKnowledge
- Full-line of hollow fiber optics products
- Used as gas cell for other applications

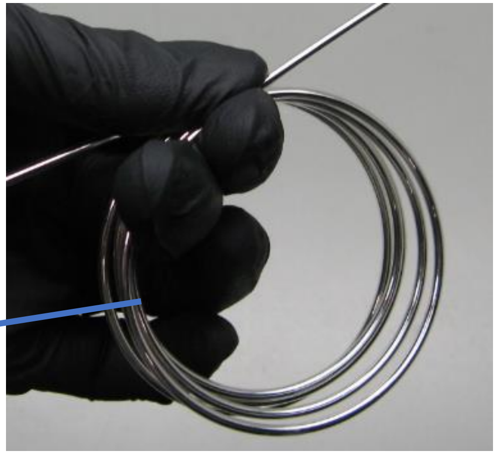
THE STATE UNIVERSITY OF NEW JERSEY RUTGERS




http://www.optoknowledge.com/fiberstore.html

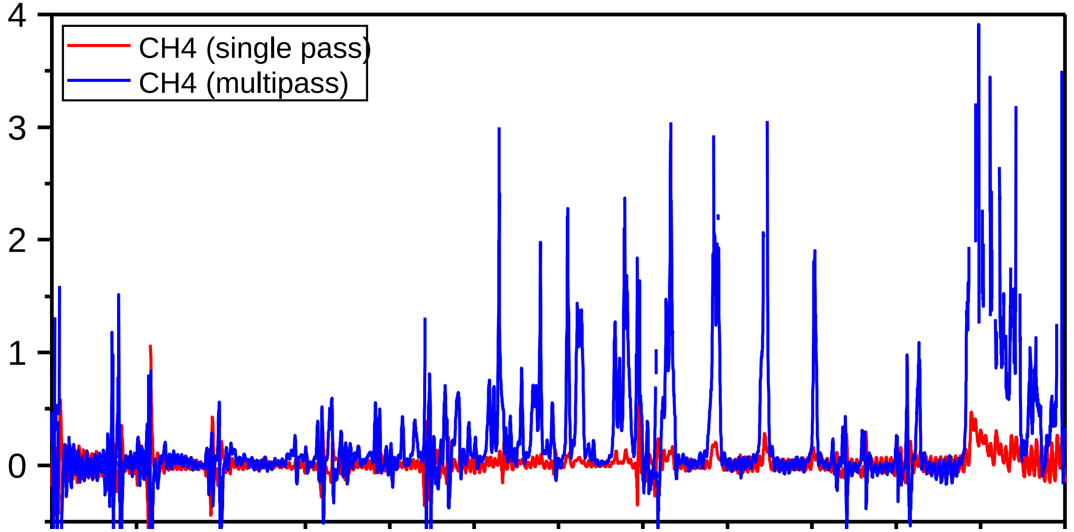


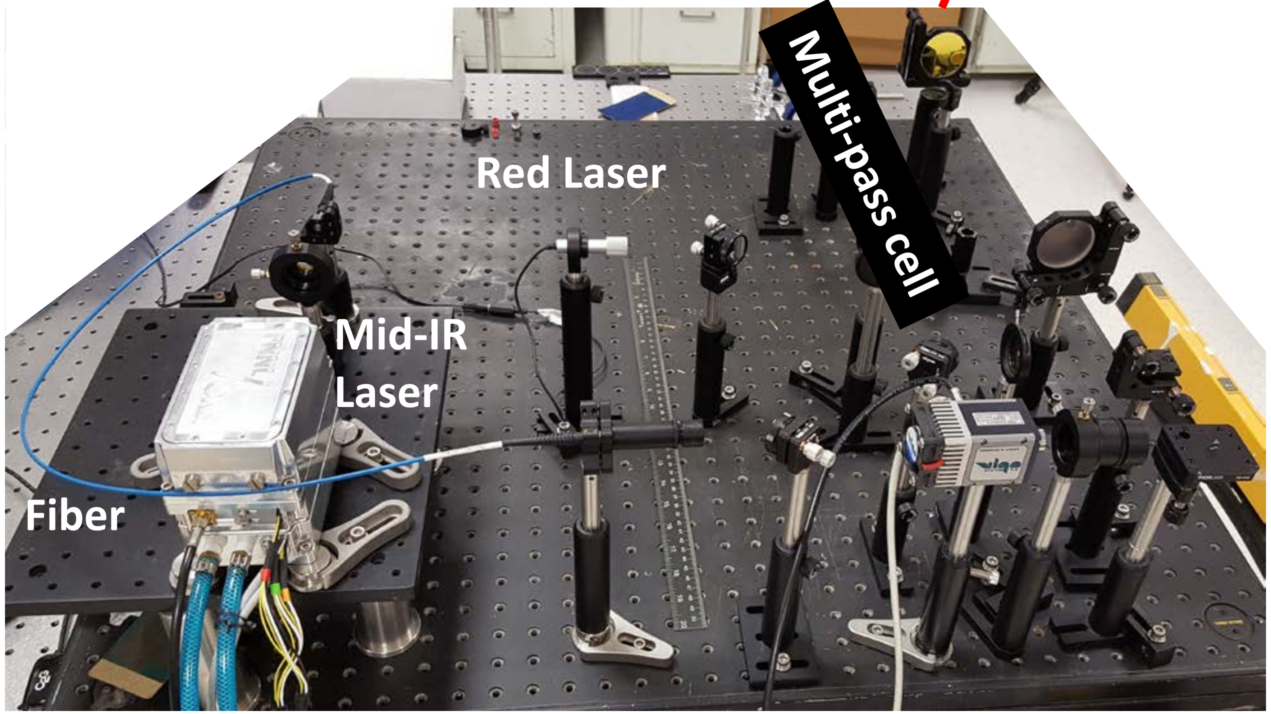
Coiled hollow fiber

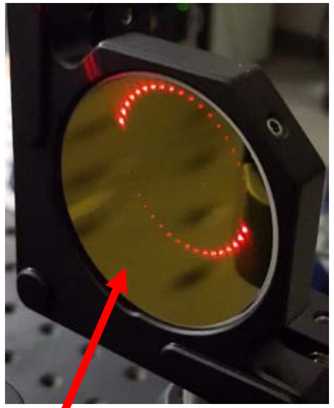
# Fiber Optic Delivery to Multi-pass Cell

- Investigate trade-off between transmission and beam quality
- Demonstrated remote delivery of laser with and L = 5 m fiber cable
- Sufficient transmission and beam quality for multi-pass measurements at 1 ppm level
- Also produced beam combiner for coupling two lasers into a single fiber




Measurement of Methane used to verify multi-path cell

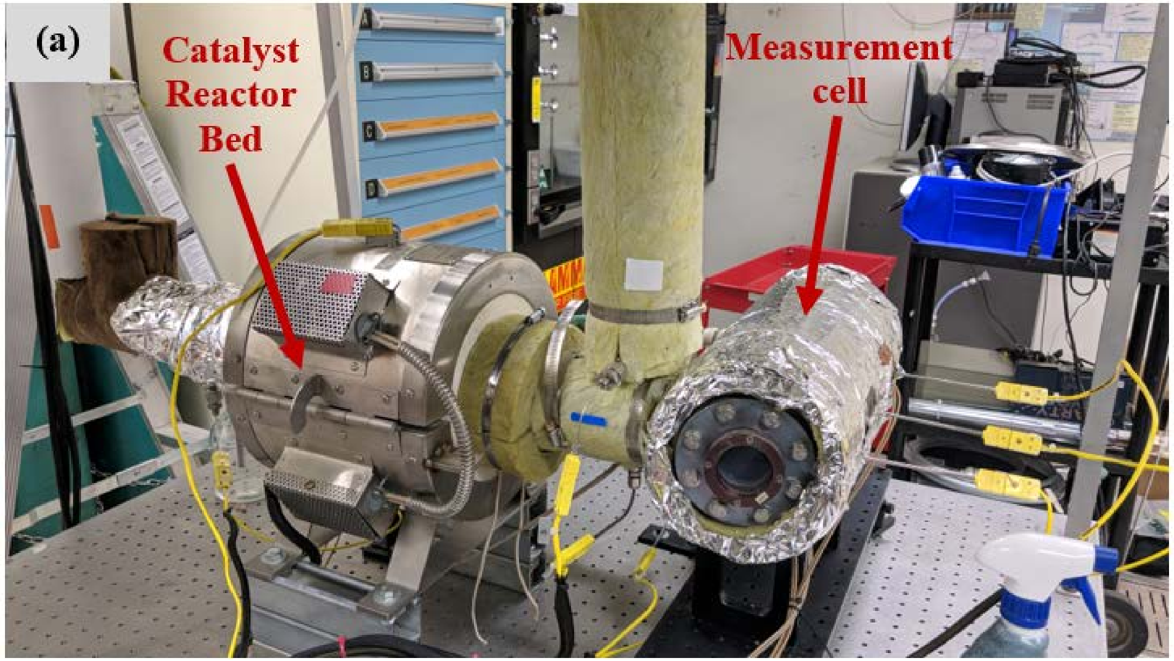


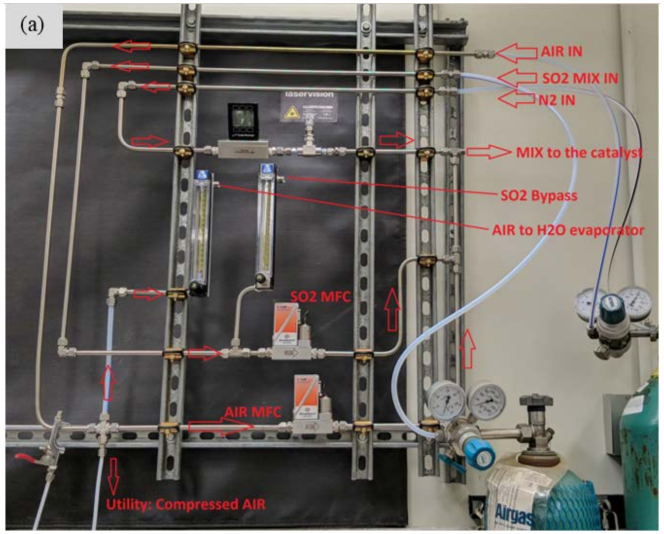



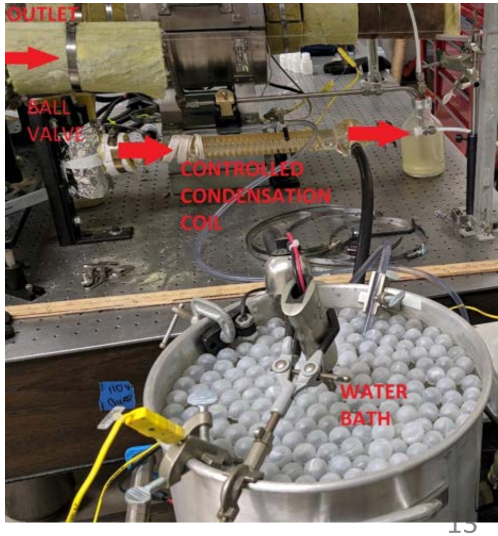
# Flue Gas Test Facility

UCI University of California, Irvine

- Heated vanadium catalyst bed reactor
- Heated optical cell with windows: T = 400°C (750°F)
- Controlled condensation setup for validation
- Still working on generating $SO_3$ and $H_2SO_4$ with known quantities

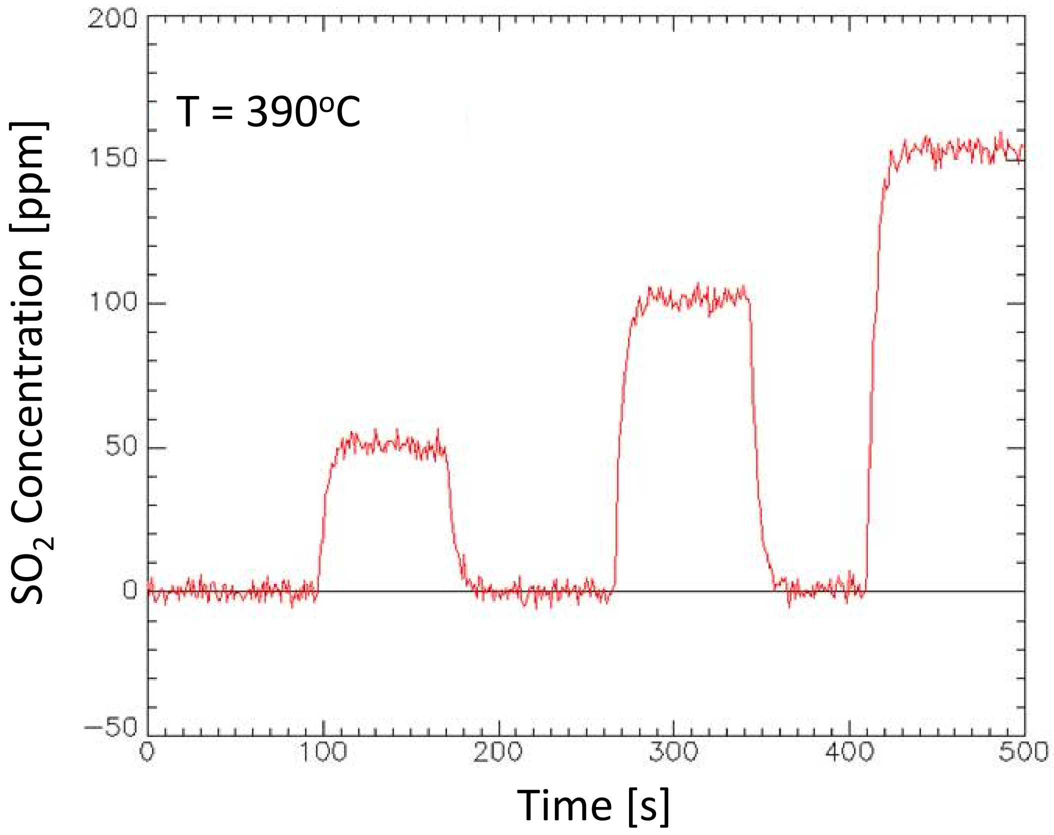


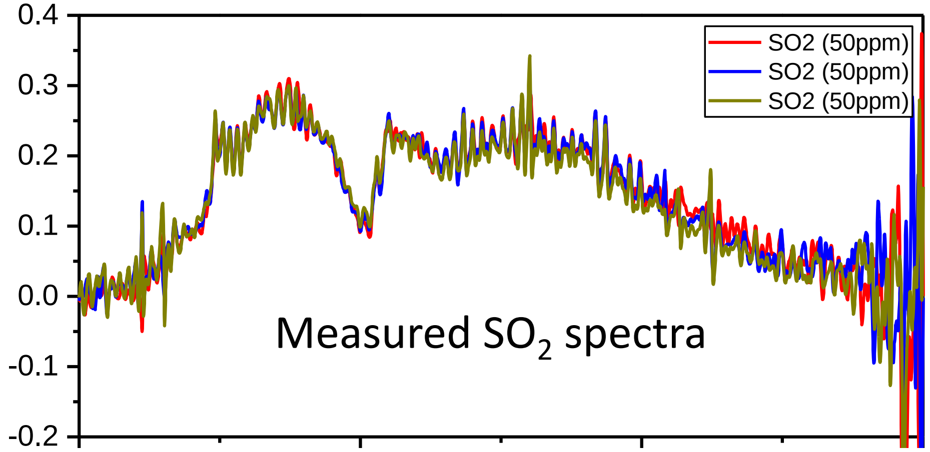



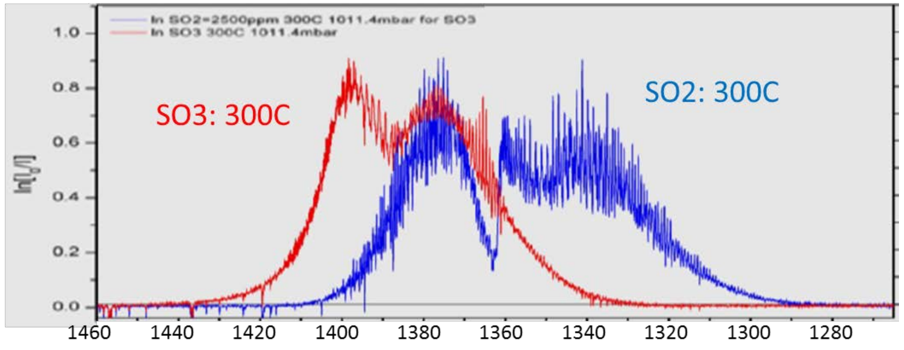



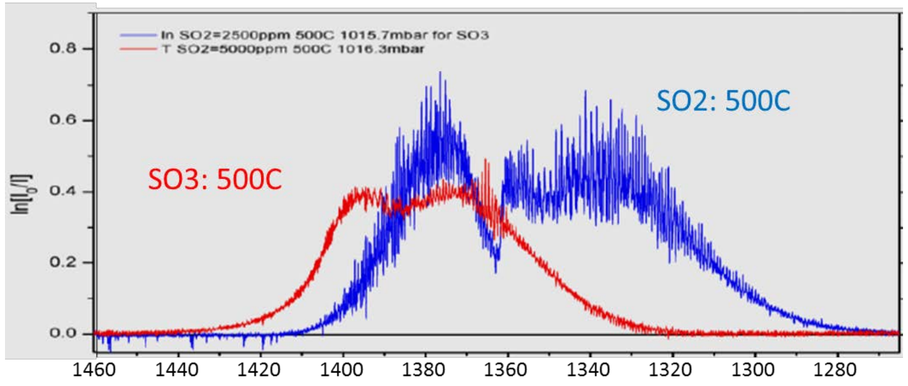
# Measurements

- Laser systems demonstrated with heated multi-pass test cell
- 1 ppm level sensitivity for $SO_2$ at elevated temperatures
- No evidence of $SO_3$ (problems with catalyst?)



# Power Plant Testing

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**FirstEnergy Harrison Station host site**

- 3 x 700 MW units equipped with:
  - SCR for NOx control
  - ESP for particulate control
  - FGD scrubbers for $SO_2$ control

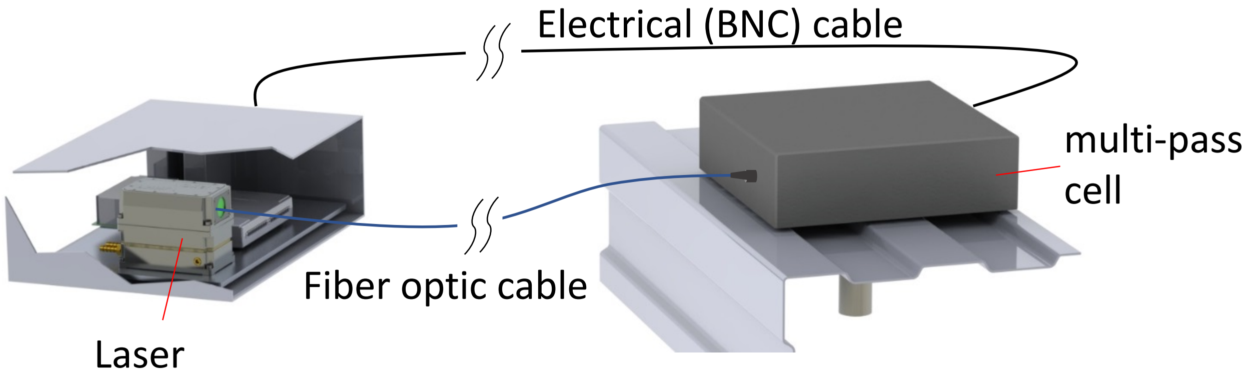
**Initial proof-of-concept testing scheduled in 2019**

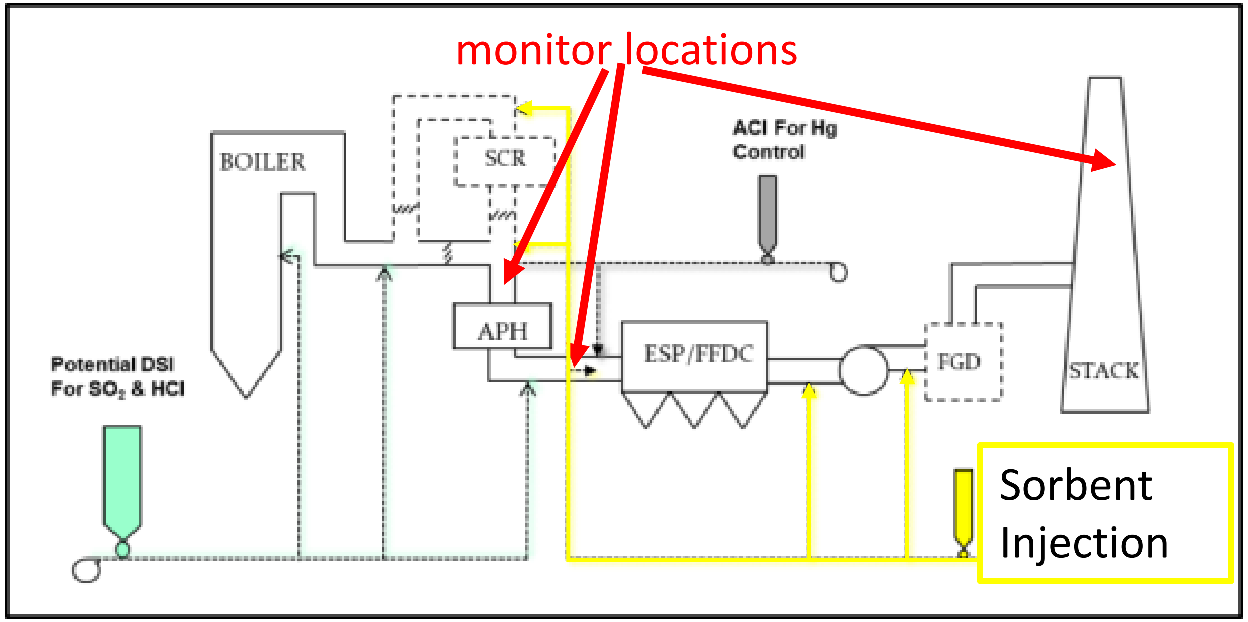
- First test conducted between economizer outlet and SCR ammonia-injection grid
- Second test conducted downstream of air heater focusing on $H_2SO_4$
- Controlled condensate wet chemical tests to be obtained in parallel ($SO_3$ + $H_2SO_4$)

FERCo FOSSIL ENERGY RESEARCH CORPORATION

# Summary

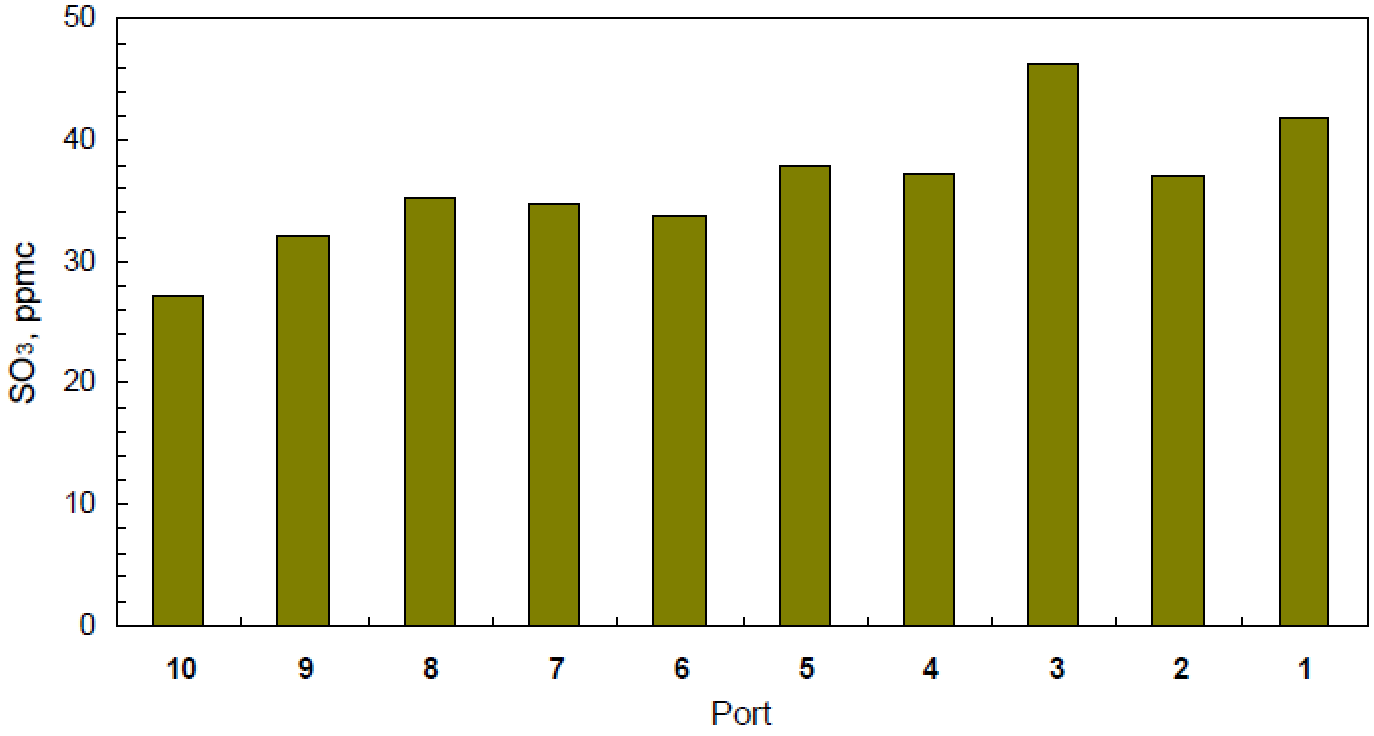
- A continuous $SO_3$ monitor is needed to optimize sorbent injection
- Mid-IR Laser spectroscopy solution
- Advancing the state of the art
  - Broad tuning Mid-IR lasers
  - Hollow core fiber optics
  - Close-coupled, heated multi-pass cell
- Technology proven with 1 ppm sensitivity of $SO_2$
- Working to generate $SO_3$ and $H_2SO_4$
  - UCI flue gas facility need to understand catalyst function
  - Will also conduct tests at alternative facility (FERCo)



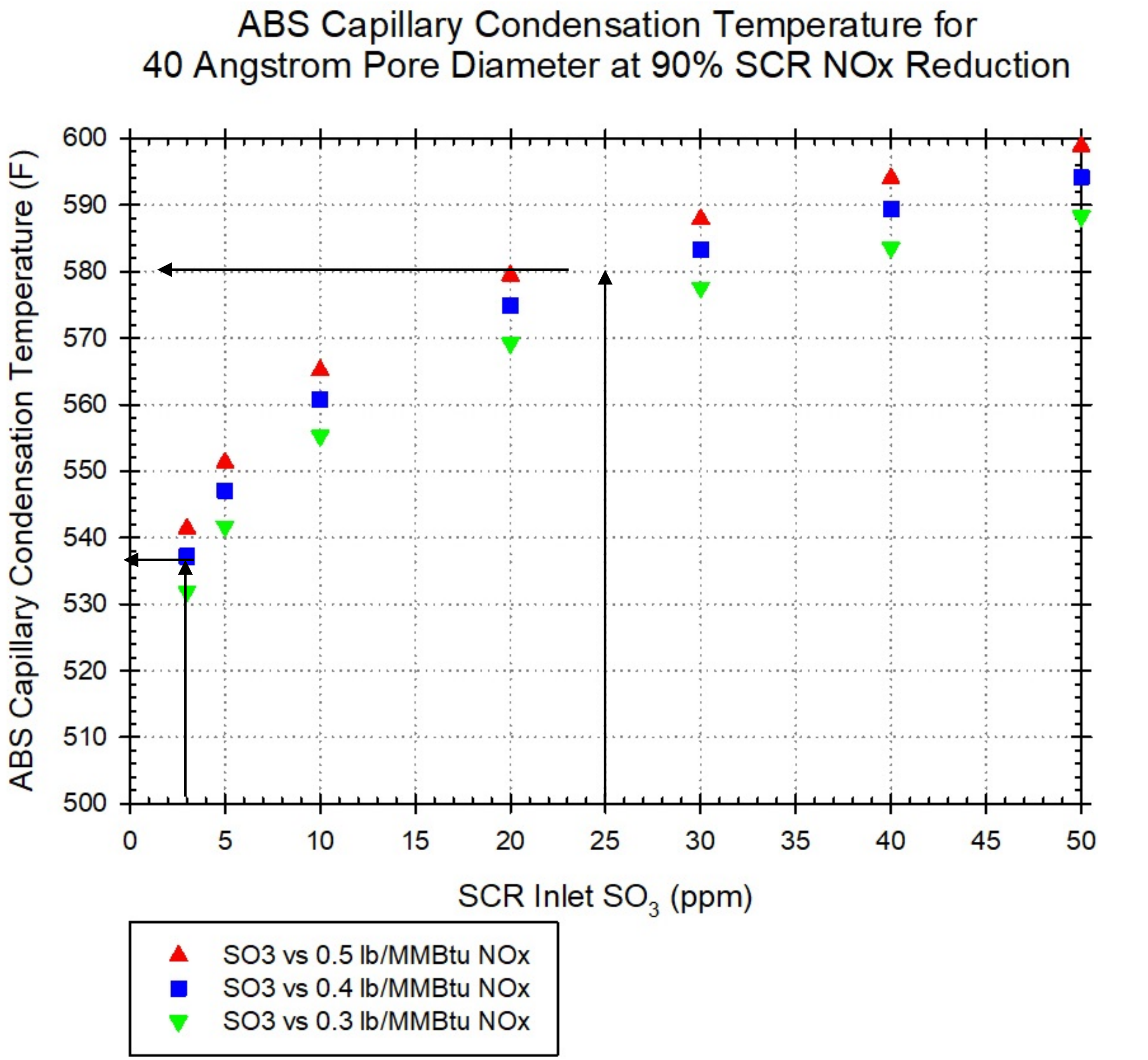
# Backup

# Cross Duct Measurements



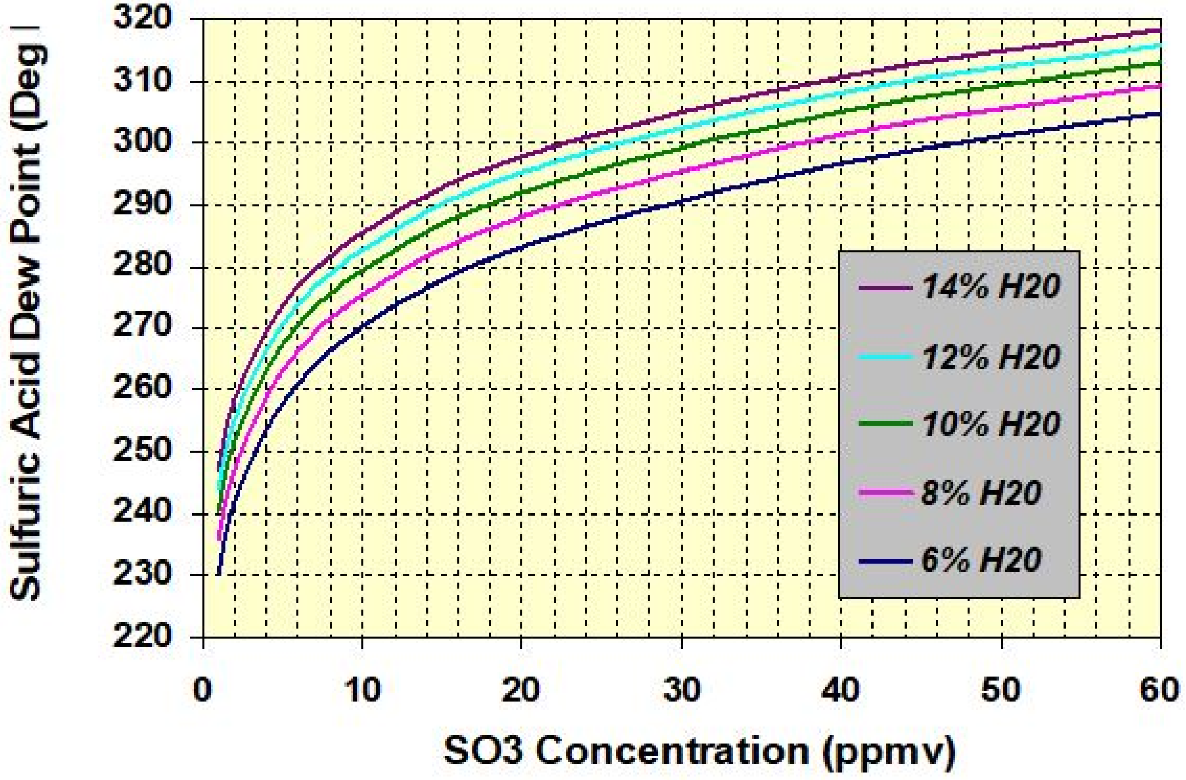
# Operational Benefits of Pre-SCR Dry Sorbent Injection

- Injection upstream of SCR reduces $SO_3$ and associated ABS formation potential
  - Control of $SO_3$ below 5 ppm reduces ABS capillary condensation temperature ~40°F
  - Reduced SCR minimum operating temperature enables deeper load cycling
    - Minimizes operating losses during uneconomic periods
    - Depending on load forecasts, can forestall taking unit off-line
- Lower $SO_3$ concentrations reduce rate of ABS formation
- Better mixing achieved with pre-SCR injection vs post-SCR injection due to increased residence time

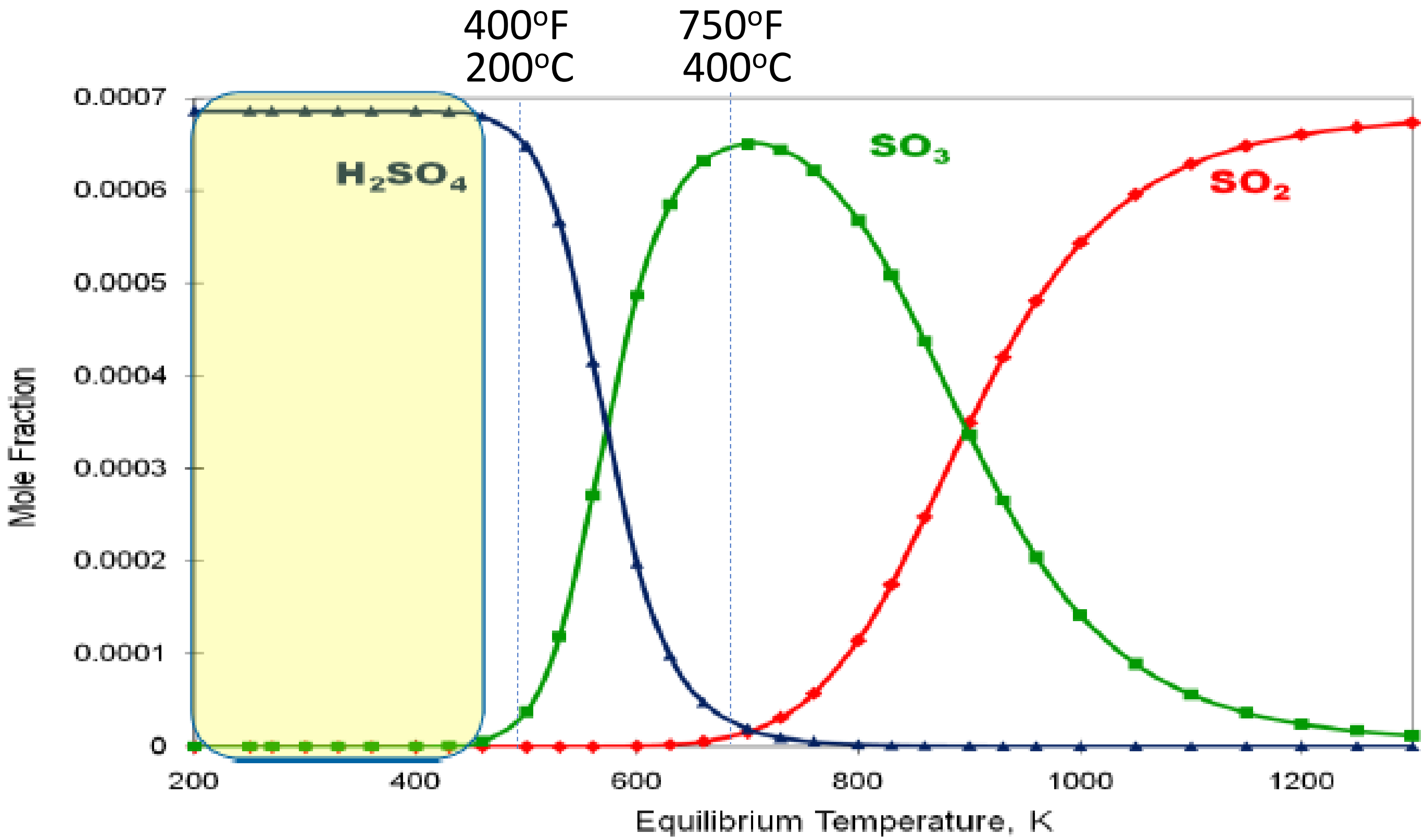


# Operational Benefits of Dry Sorbent Injection

- Mitigation of $SO_3$ and associated air heater fouling issues can also enable reduction in air heater gas outlet temperature
    - Potential for nominal 1% heat rate benefit
        - Proportional reduction in $CO_2$ emissions
- Reduced flue gas temperature from air heater can also:
    - Enhance Hg oxidation
    - Improve ESP performance
    - Reduce FGD scrubber liquor evaporation



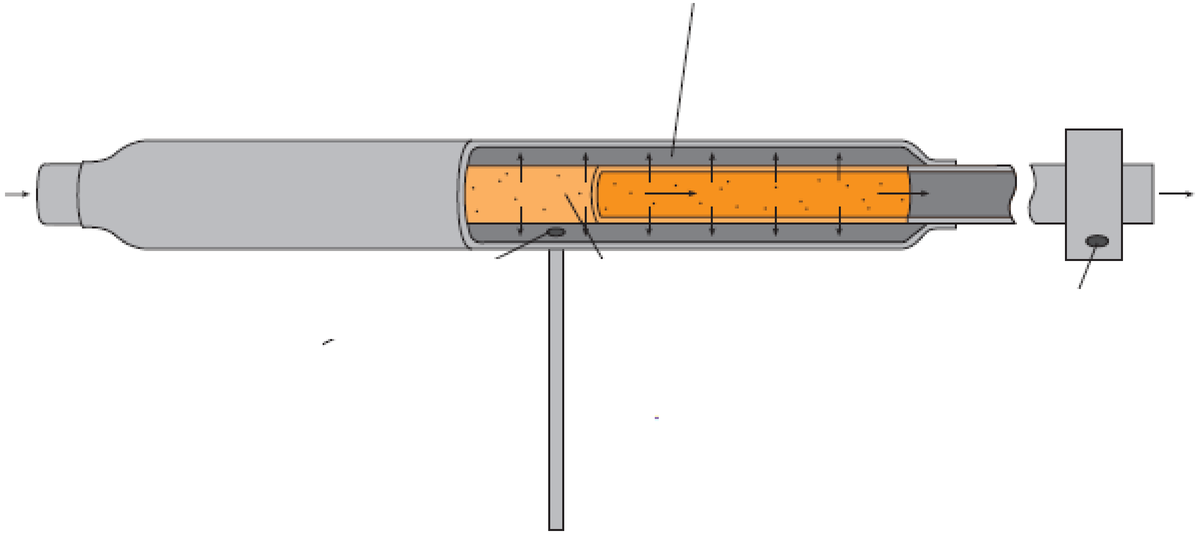
# Equilibrium Conditions vs Temperature



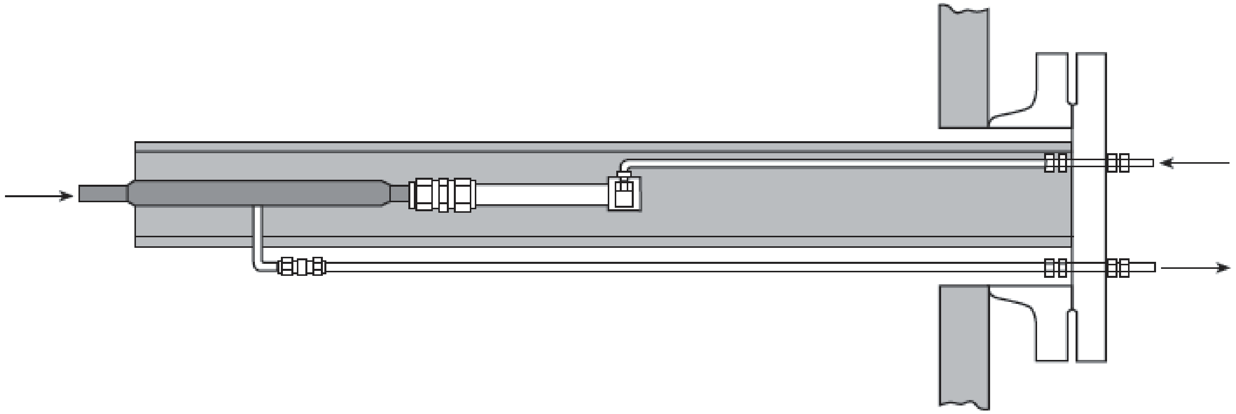
# Inertial Filter

Gas sampled through sintered metal tube at 0.05ft/sec, minimizing gas contacting at the surface of the sintered tube

Gas enters sintered metal tube at 70-100 ft/sec



Gas Sample to the analyzer



# Fiber Beam Combiner