Flue Gas Aerosol Pretreatment Technologies to Minimize Post-Combustion CO_2 Capture (PCC) Solvent Losses

DOE funding award DE-FE0031592

Devin Bostick

2019 NETL CO_2 Capture Technology Meeting
August 26, 2019
Pittsburgh, PA

Making our world more productive

Acknowledgement and Disclaimer

Acknowledgement: This presentation is based on work supported by the Department of Energy under Award Number DE-FE0031592. We want to thank DOE-NETL for their sponsorship.

Disclaimer: “This presentation was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.”

Project Overview

Objectives, Participants, Timeline & Funding

Making our world more productive

Project Objectives

Overall Objective

Demonstrate and evaluate two innovative flue gas aerosol pretreatment technologies identified to significantly reduce high aerosol particle concentrations (>10^7 particles/cm^3) in the 70-200 nm particle size range:

1) A high velocity water spray-based system with unique design features
2) A novel electrostatic precipitator (ESP) device with optimized design and operating conditions.

In addition, a non-regenerative sorbent technology for SO_x and NO_x removal developed by InnoSepra will be evaluated for its aerosol removal potential.

Specific Objectives

— Complete an aerosol mechanism literature review and develop a mechanistic model characterizing aerosol formation and interaction with amine solvent in the absorber of a PCC plant

— Design, build, install, commission, and operate the three technologies for flue gas aerosol pretreatment at a coal-fired power plant host site providing the flue gas as a slipstream at a flow rate of 500-1000 scfm

— Complete parametric testing and analysis of each technology to demonstrate achievement of target performance

— Complete a benchmarking study to identify the optimal aerosol pretreatment system for commercial deployment and integration with solvent-based PCC technology

Project Team

Abbott Power Plant Host Site
- 2 operating coal-fired boilers
- 15 MWe output

PRIME CONTRACTOR
Linde Gas North America LLC
PI: Devin Bostick
- Prime contract
- Overall program management
- High velocity water spray-based aerosol pretreatment technology owner

U.S. Department of Energy Sponsorship
Project Manager: Andy Aurelio

SUBAWARDEE
University of Illinois (UIUC)
Dr. Kevin O'Brien
- Aerosol mechanisms review
- Host site liaison
- Flue gas & liquid effluent analysis

SUBAWARDEE
InnoSepra
Dr. Ravi Jain
- Sorbent material validation tests
- Sorbent material procurement for pilot tests & test result analysis

SUBAWARDEE
Affiliated Construction Services (ACS)
Greg Larson
- Detailed engineering and procurement management for high-velocity water spray-based system and sorbent filter vessel
- Construction management for site modifications & module installation

SUBAWARDEE
Washington University in St. Louis (WUSTL)
Dr. Pratim Biswas
- Aerosol mechanisms modeling lead
- ESP pretreatment technology owner
- Aerosol particle characterization

Project Timeline & Milestones

BP1: Design & Engineering
6/1/2018 - 2/28/2019

BP2: Procurement, Fabrication & Installation
3/1/2019 - 11/29/2019

BP3: Testing & Analysis
12/2/2019 - 11/30/2020

Task	ID	Milestone	Completion Date
1	A	Updated PMP	06/29/18
1	B	Kick-Off Meeting	07/27/18
2	C	Mechanisms review & modeling complete	10/31/18
3	D	Design & engineering complete	01/31/19
3	E	Test plan complete	01/31/19
4	F	Fabrication & procurement complete	08/26/19
5	G	Installation & commissioning complete	11/29/19*
6	H	Parametric testing complete	5/1/20*
7	I	Benchmarking analysis complete	11/30/20*
8	J	Removal of equipment complete	11/30/20*

*expected completion date

Project Budget: DOE Funding and Cost Share

Source	Budget Period 1 Jun 2018 – Feb 2019	Budget Period 2 Mar 2019 – Nov 2019	Budget Period 3 Dec 2019 – Nov 2020	Total
DOE Funding	$457,822	$1,290,725	$1,078,826	$2,827,374
Cost Share	$176,612	$260,949	$269,860	$707,421
Total Project	$634,435	$1,551,674	$1,348,686	$3,534,795

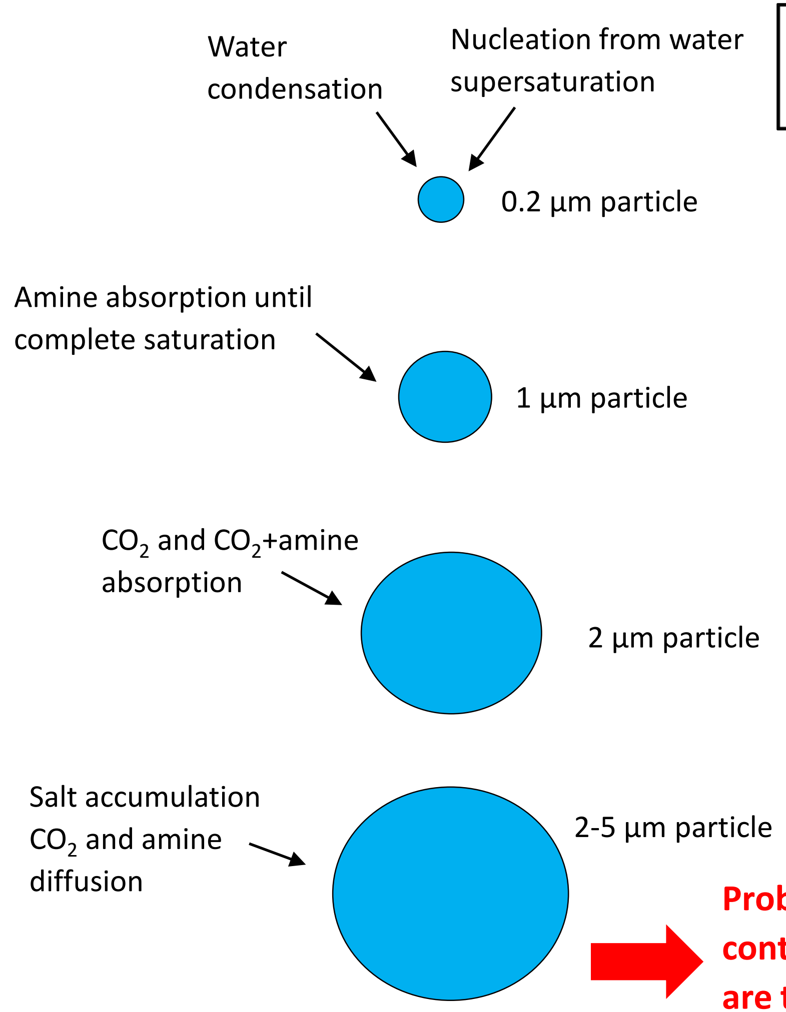
Technology Development

Rationale, Background & Previous Research

Making our world more productive

Aerosol particle interaction with amine solvent inside PCC absorbers → leads to solvent losses in treated gas

Phase I Aerosol growth and nucleation from water in absorber	
Phase II Aerosol growth from amine in absorber	
Phase III Buildup of captured CO_2 and amine bound to CO_2 in aerosols	
Phase IV Salt accumulation inside particles causing further amine and CO_2 diffusion into aerosols	



$$d^* = \frac{4\sigma M}{\rho RT \ln(p/p_0)}$$

The Kelvin equation gives the minimum particle diameter, d*, of a liquid → supersaturation leads to nucleation of smaller particles

Problem: Amine compounds contained in aerosol particles are then emitted from PCC absorber in treated gas stream

Benefits of aerosol particle reduction upstream of PCC plant (pretreatment)

Benefits

- Manageable solvent supply and transport logistics

- Optimum power plant efficiency when integrated with PCC

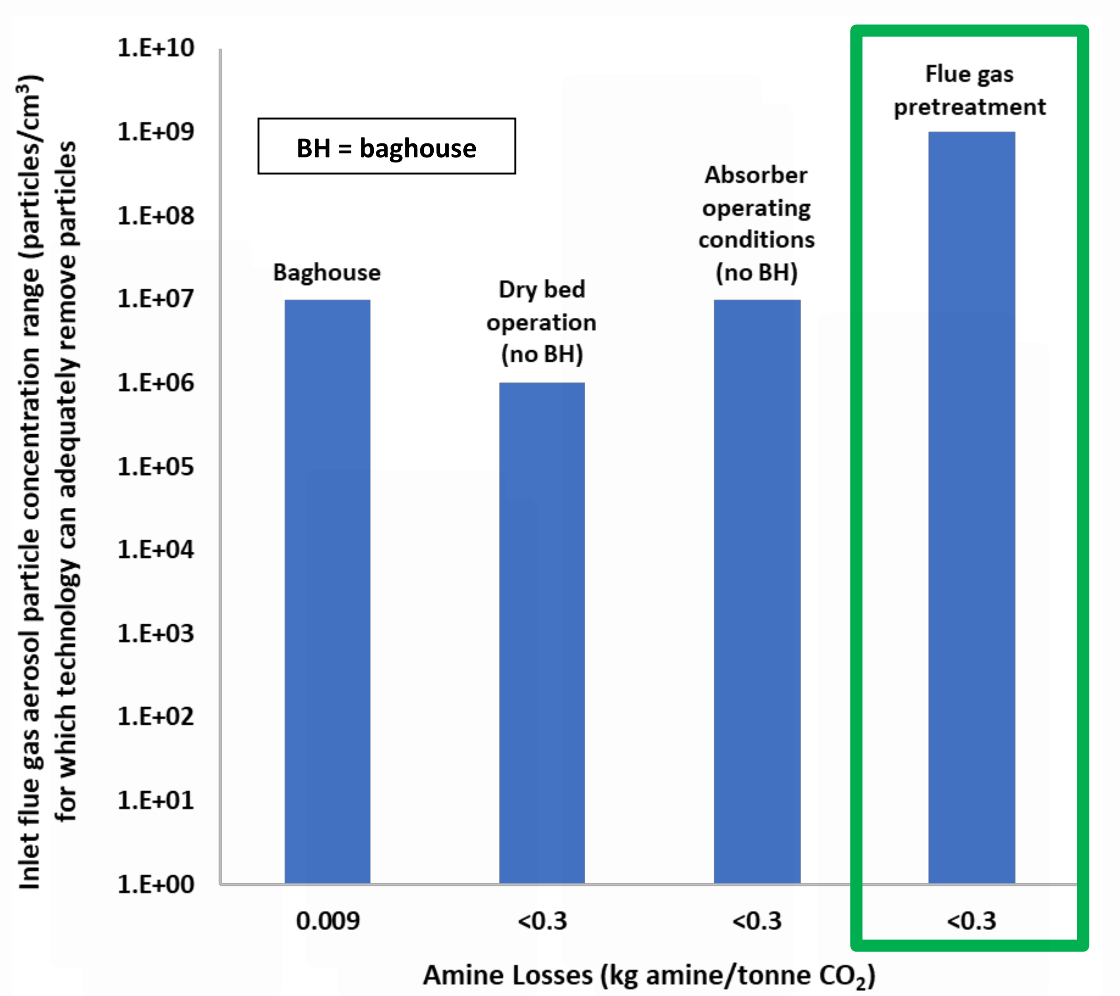
- Reduction of particulate that can unfavorably react with amine solvent

- Improved PCC plant specific energy performance

- Environmental sustainability and performance

- Improved PCC plant business case/lower cost

Methods to reduce aerosol-driven solvent losses:
Flue gas aerosol pretreatment provides optimum solution[1]



1. Based on single point experience, some options e.g. dry bed conf. may handle higher particle concentrations than others

- For power plants integrated with solvent-based PCC **without an existing baghouse**, optimized flue gas aerosol pretreatment is the only viable option to reduce aerosol concentrations from $>10^9$ particles/cm^3 to manageable levels near 10^4-10^6 particles/cm^3 for particles with diameters in the range of 70-200 nm.
- Pretreatment has traditionally been performed using simple ESPs and Brownian filters.
- Few systematic studies have been conducted to evaluate performance of different technologies over a full range of conditions.

High velocity water spray-based aerosol pretreatment technology

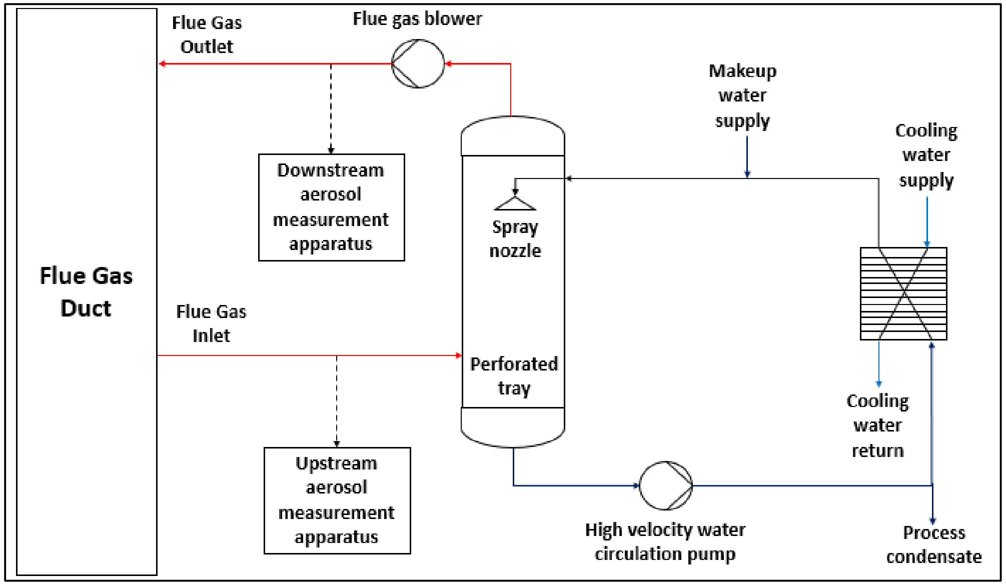
Developed by RWE & tested in Niederaussem, Germany at lignite-fired coal power plant

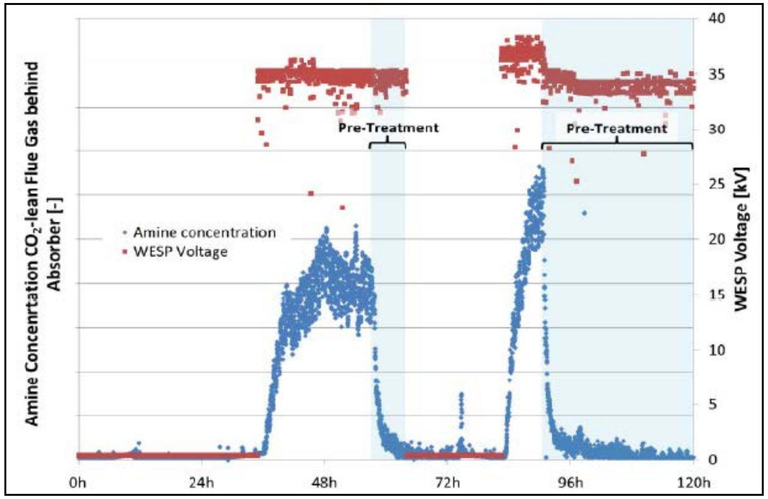
Mechanism of action

Water circulates in loop at high velocity and contacts aerosol particles using a spray nozzle comprised of very small holes. Contacting spray causes condensation and growth of particles that are then captured in loop and removed from vapor phase.

Performance

High velocity spray-based pretreatment reduced amine losses ~15-18 times during testing at 0.45 MW_e PCC pilot in Niederaussum that began in 2009.





Typical inlet flue gas conditions at Abbott Power Plant:
~190 °F
~1 bar
~9.2 mol% CO_2 (dry), ~100-200 ppmv SO_2

Tests

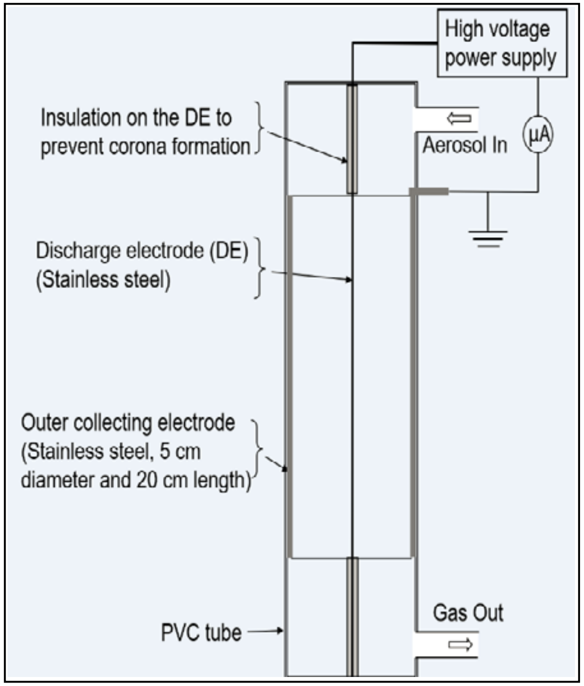
Planned tests will evaluate new nozzle & perforated tray designs and the impact of several operating conditions (flows, temperatures, etc.) on performance.

Advanced ESP-based aerosol pretreatment technology

Developed by Washington University in St. Louis (WUSTL) and tested at NCCC in Wilsonville, AL on 6.5 slpm flue gas sample

Mechanism of action

ESP applies high voltage between plate and wire that ionizes flue gas aerosols. Ionized particles are diverted towards collecting plates for removal. WUSTL's system will incorporate a patented photo-ionizer technology that enhances particle capture efficiency.

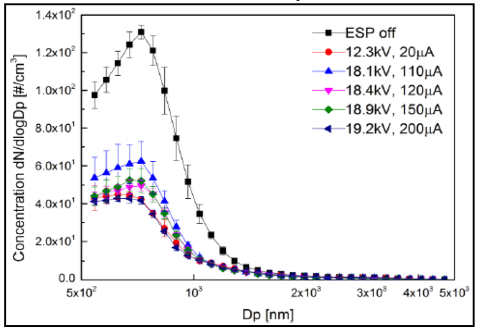


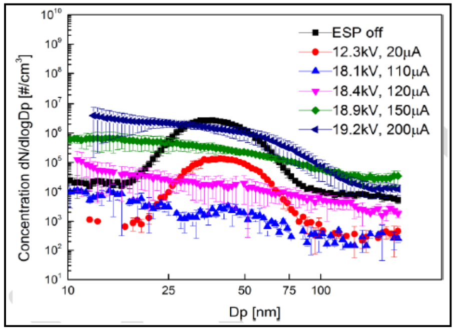
Performance

Based on flue gas testing at the Linde-BASF 1.5 MW_e pilot at NCCC in 2016, WUSTL's ESP is expected to provide 98-99% removal efficiency for 1000 scfm gas flow and a specific collection area (SCA) of 95 $m^2/(m^3/s)$, which can be increased to remove more particles in the size range of 10-500 nm.

Tests

Planned tests will evaluate voltage & current effects and the impact of the photo-ionizer on ESP performance. The effect of reduced SO_x from the InnoSepra sorbent filter and the filter's own aerosol removal performance will also be evaluated.



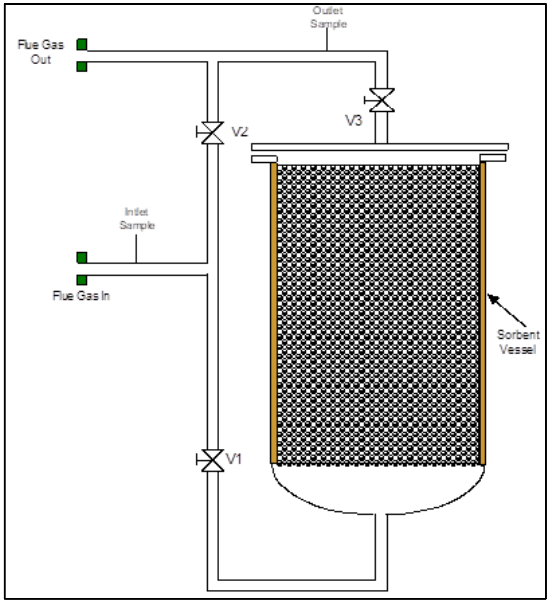


InnoSepra sorbent filter technology for NO_x and SO_x removal

Developed by InnoSepra LLC and tested in Middlesex, NJ lab and at NCCC

Mechanism of action

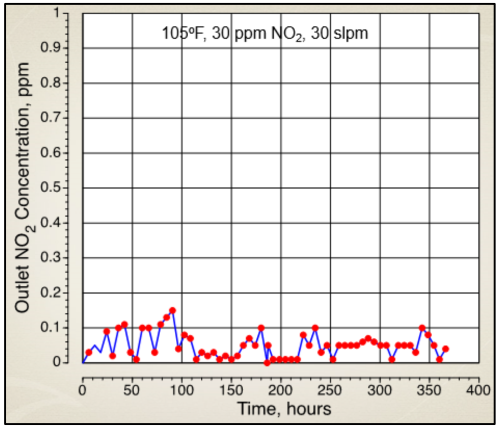
Cost-effective, sorbent-filter based removal of residual SO_3, SO_2, NO_2, HCl, and HF from PCC flue gas after the FGD and potential for aerosol particle reduction

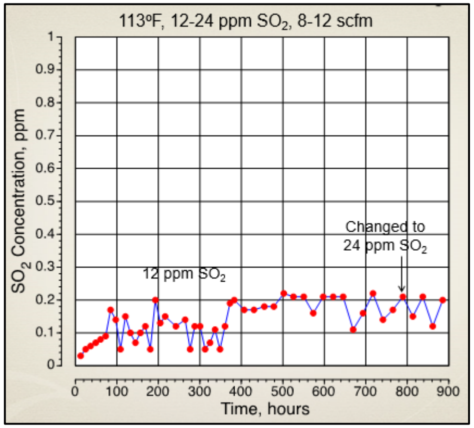


Performance

Sorbent material validation tests show:

- >99% SO_2 and SO_3 removal for both impregnated and non-impregnated sorbents
- Very high capacities (20-30 wt%) for feed SO_2 & SO_3 concentrations of 5-15 ppmv
- Low material production costs (<$0.20-0.75/lb)
- Best results achieved with impregnated materials → 30 wt% SO_2 capacity for feeds containing 12-30 ppmv SO_2





Tests

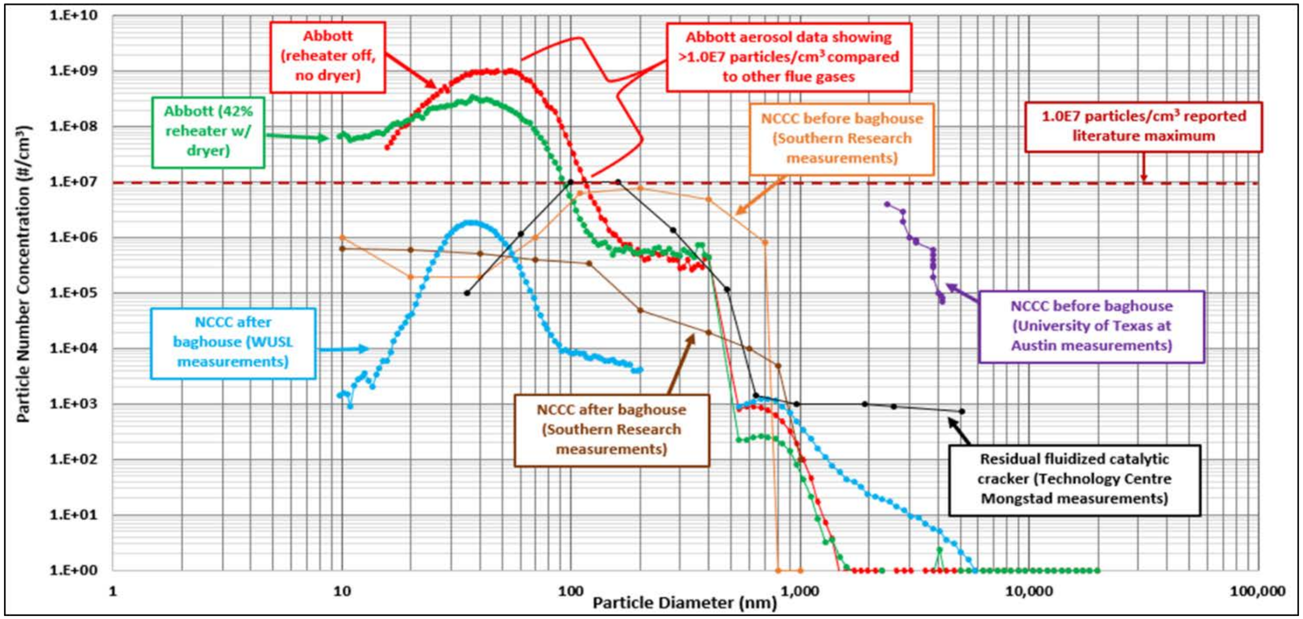
Planned tests will further evaluate the SO_x and NO_x reduction & aerosol particle removal capabilities of the InnoSepra sorbent material

Technical Approach

Host Site Setup, Innovation Targets & Success Criteria

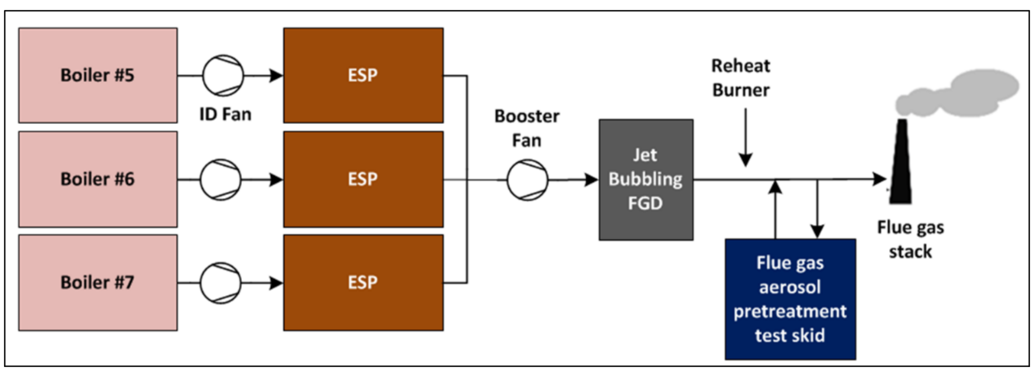
Making our world more productive

Pilot host site: Abbott Power Plant at UIUC in Champaign, IL



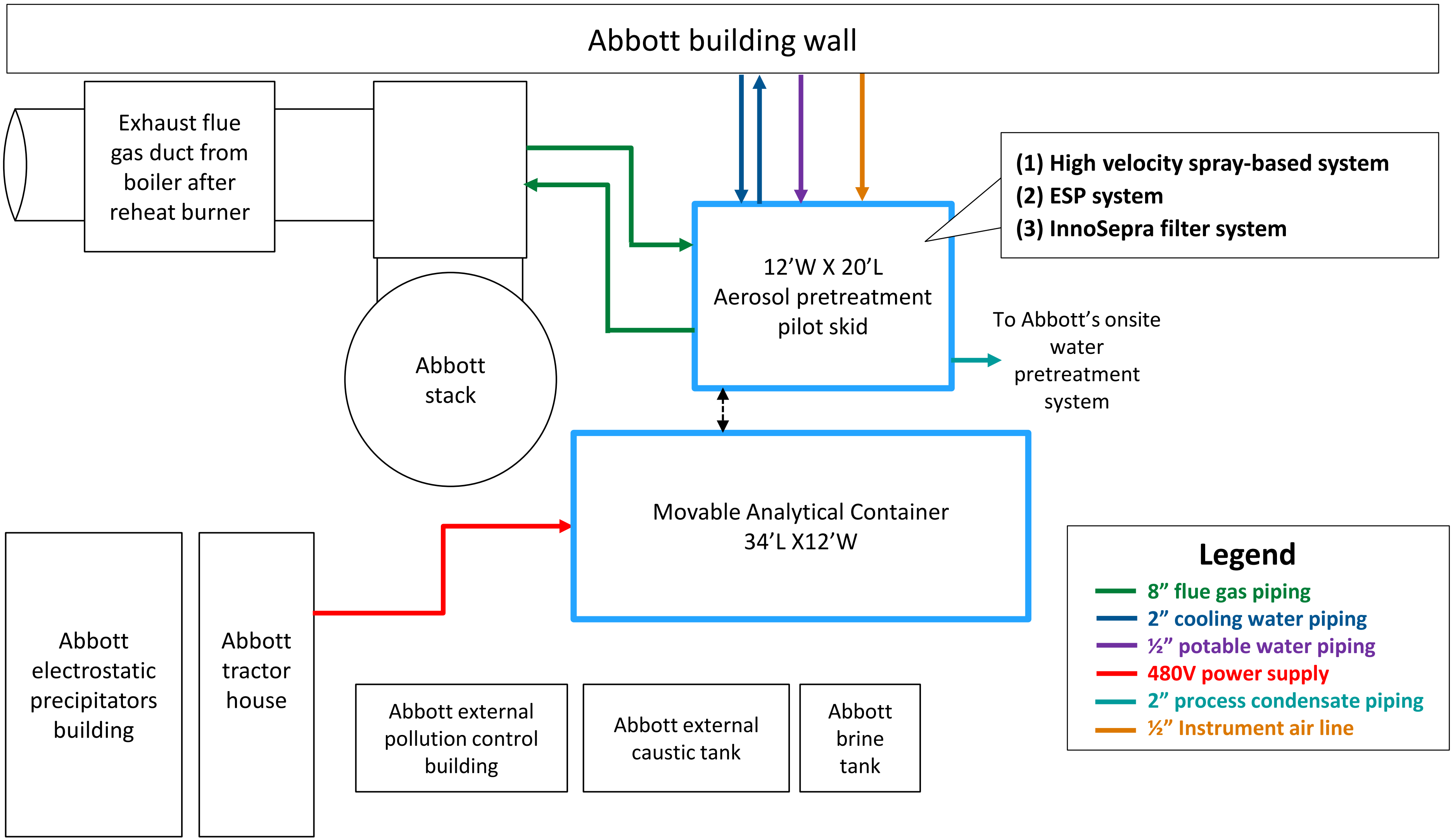
Abbott chosen as optimal host site for testing since aerosol concentrations were measured to be among the highest found in scientific literature

Abbott plant schematic and tie-in points to pilot skid



Abbott plant aerial view

Pilot skid layout at Abbott Host Site



Pilot test innovation targets

Parameter	Rationale	Expected target
Particle removal efficiency* for 500-1000 scfm flue gas slipstream (%)	Flue gas aerosol particles in size range 70-200 nm lead to amine losses in the treated gas of amine-based PCC plants	>98%
Cost competitiveness** (COE = cost of electricity)	Reduced capital and operating costs are required for commercial application of enabling technologies for PCC	COE < $133.20/MWh and cost of CO_2 captured < $58/tonne when compared to DOE-NETL reference case B12B
Energy efficiency**	Low electricity consumption reduces parasitic load for enabling technologies	Energy consumption < 14 MWe (threshold above which energy consumption greatly impacts COE and cost of CO_2 captured)
Environmental sustainability when integrated with PCC technology for supercritical coal-fired power plants without a baghouse	Minimal environmental impact is required to meet process safety & regulatory requirements for customers	Process condensate adequately removed & treated as needed; ESP solids removed and treated as needed.

**Particle removal efficiency = (Particle concentration before aerosol pretreatment (#/cm^3) - Particle concentration after aerosol pretreatment (#/cm^3))/(Particle concentration before aerosol pretreatment (#/cm^3)) * 100*

*** when integrated with PCC technology for a 550 MWe supercritical coal-fired power plant without a baghouse*

Decision points and success criteria

Decision Point	Date	Success Criteria
Equipment procurement and fabrication of both aerosol pretreatment systems and components for installation	2/28/2019	• Successful completion of designs, HAZOP/safety reviews and engineering documents that have been accepted by host site and reviewed by NETL • Update of costs based on vendor quotes and cost proposal within budget • Preliminary parametric test matrix in accordance with FOA guidelines and agreement with NETL
Installation of aerosol pretreatment systems on site	08/30/2019	• Host site is prepared and ready to receive aerosol pretreatment systems for installation
Handover to testing team	11/29/2019	• Successful completion of commissioning activities • Close-out of action items related to construction and installation from HAZOPS and safety reviews.
Start of testing phase	12/02/2019	• Finalization of a test matrix for the parametric testing campaign with minimal changes from preliminary test plan and agreement with NETL • Coal flue gas availability from host site
Project closeout	11/30/2020	• Successful demonstration of test objectives

Technical risks and mitigation strategies

Description of Risk	Probability	Impact	Risk Management Mitigation and Response Strategies
Technical Risks:			
Material Compatibility	Low	Medium	• Flue gas composition and analysis will be used as part of the design basis. Material compatibility with corrosive contaminants in the flue gas can be addressed by host site and Linde Engineering experience with flue gas handling.
Waste Handling	Low	Medium	• Batch analysis of flue gas condensate and other liquid waste streams for regulatory compliance before disposal. • Treated flue gas will be sent back to the Abbott power plant stack for monitoring before exhaust. • Solid waste (flue gas particles) is expected to be low.
Flue gas aerosol variability	Medium	Medium	• The aerosol control methods being tested are expected to work over wide ranges of aerosol particle concentrations and size distributions.
Plugging process equipment	Low	Medium	• The aerosol particle concentration in the Abbott flue gas has been measured. The design and operation of all equipment components for each aerosol control module will be sufficient to prevent plugging based on these measurements and Linde Engineering experience with similar systems.
Flue gas condition variability affecting aerosol measurements	Low	Medium	• Online flue gas analysis (temperature, composition, pressure, humidity, etc.) during testing; team experience handling various flue gas qualities.

Progress and Current Project Status

Budget Period 1 & Budget Period 2

Making our world more productive

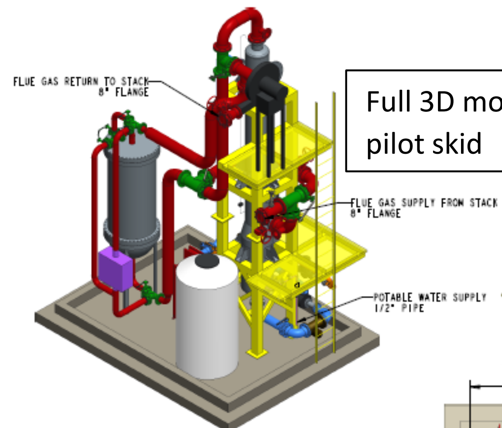
Milestone status through August 26th, 2019

ID	Task Number	Description	Planned Completion Date	Actual Completion Date	Verification Method
a	1	Updated Project Management Plan	06/29/2018	**06/29/2018**	Project Management Plan file
b	1	Kickoff Meeting	07/31/2018	**07/27/2018**	Presentation file
c	2	Review and modeling effort of aerosol-driven amine loss mechanisms complete	11/30/2018	**10/31/2018**	Report to DOE
d	3	Design, Engineering and Cost Analysis Complete	11/30/2018	**01/31/2019**	Report to DOE (Review Meeting)
e	3	Complete preliminary test plan	11/30/2018	**01/31/2019**	Test Plan Document
f	1	Completion of statement of host site acceptance of HAZOP and safety reviews	10/31/2018	**12/20/2018**	Host Site Statement Document
g	1	Submission of an Executed Host Site Agreement	11/30/2018	**01/16/2019**	Host Site Agreement Document
h	4	Fabrication and procurement complete	08/30/2019	**08/26/2019**	Report to DOE
i	5	Site Installation and Commissioning complete/Both ACMs ready for testing	11/29/2019	**On Track**	Presentation file

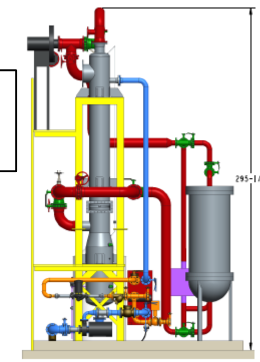
Successful completion of design, engineering and cost estimate in Budget Period 1 (Jun 2018 – Feb 2019)

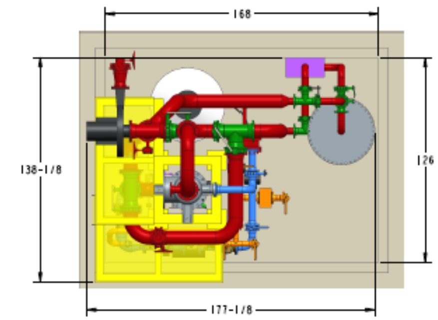
- Task 2: Review of aerosol-driven amine loss mechanisms for PCC plants
  - Review and modeling work completed, report submitted & presentation made to DOE-NETL
  - Pilot plant operating conditions informed from modeling study

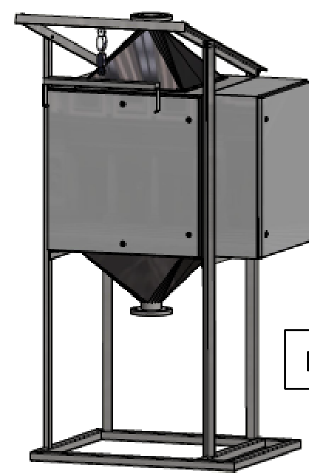
- Task 3: Pilot plant design and engineering
  - Design basis completed with Abbott Power Plant (UIUC)
  - Basic design & engineering for spray-based system completed by Linde
  - Basic design & engineering for ESP system completed by WUSTL. Sorbent filter system designed by InnoSepra.
  - Detailed engineering completed:
    1) ACS: spray-based system & sorbent filter vessel
    2) WUSTL: ESP system
  - Hazard and operability study (HAZOP) completed with project team in Oct 2018 and host site in Dec 2018
  - Host site agreement executed in Jan 2019
  - Pilot plant cost estimation completed and budget updated



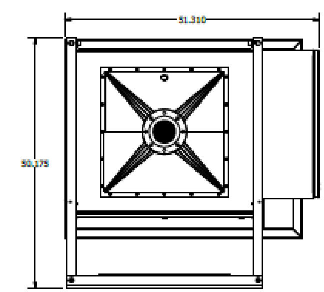
Full 3D model pilot skid







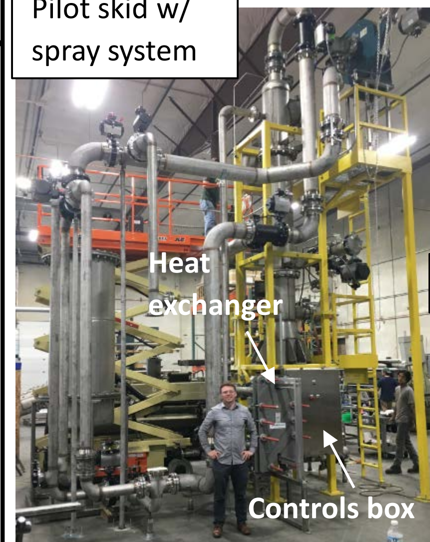
ESP system



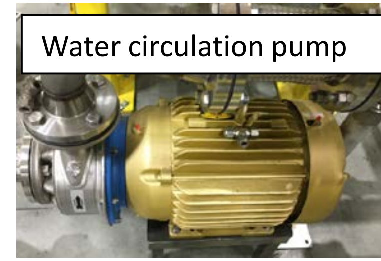
Successful completion of procurement & fabrication in Budget Period 2 (Mar 2019 – Nov 2019)

- Task 4: Pilot equipment procurement and fabrication
  - All inside battery limit (ISBL) pilot equipment & raw materials procured
  - Spray system, ESP system, and sorbent filter vessel fabrication complete. Spray tower system factory acceptance test will be completed by 8/30/19.
  - Local contractors selected for outside battery limit (OSBL) piping fabrication. OSBL piping installation to begin after module installation in September 2019.
  - Contract executed with local construction firm to install flue gas supply & return ports in Abbott plant duct; port fabrication work in progress
  - Aerosol measurement equipment and gas composition analysis system procured
  - Vendor packages prepared for shipment & installation at Abbott host site
  - Control logic and safety matrix developed based on HAZOP review and action items
  - Control system signals from ESP, InnoSepra filter, and gas analyzer rack incorporated into final design
- Task 5: Pilot plant installation planned to begin on 9/3/2019

Pilot skid w/ spray system



Water circulation pump

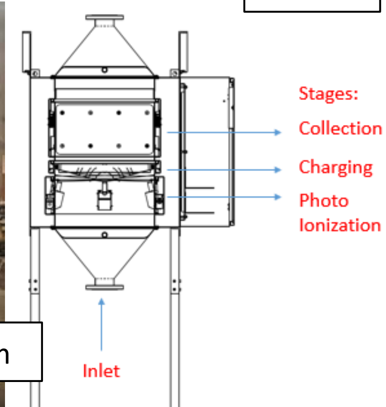


Water loop piping

Blower

Sorbent filter

ESP system



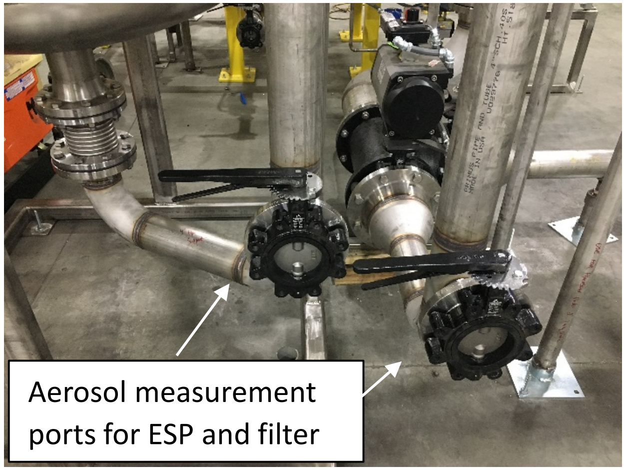
Fabricated aerosol pretreatment skid – High velocity spray system

Perforated plate change-out flange

Perforated plate

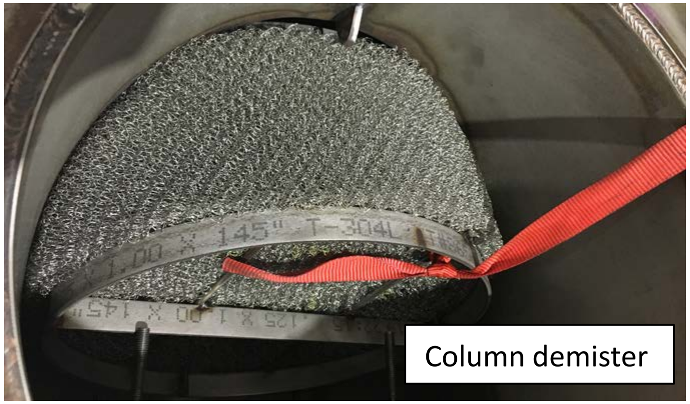
Aerosol measurement port for spray tower

Spray nozzle insert

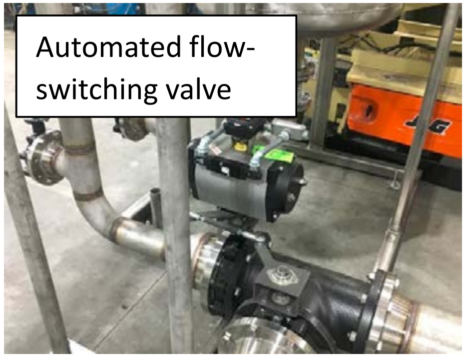


Aerosol measurement ports for ESP and filter

Controls box



Column demister

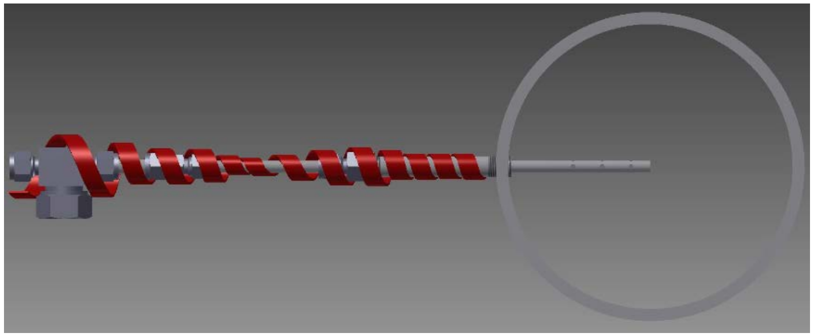


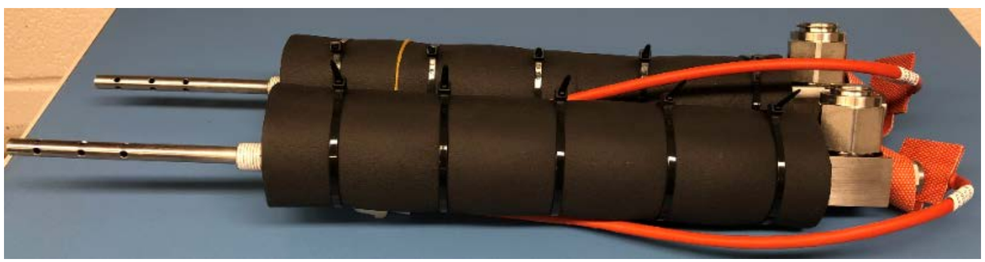
Automated flow-switching valve

Process water heat exchanger

Flue gas composition analysis system - UIUC

Gas sample probes designed and fabricated by UIUC





SO_2 dilution system procured and calibrated by UIUC based on host site conditions

Other completed items:

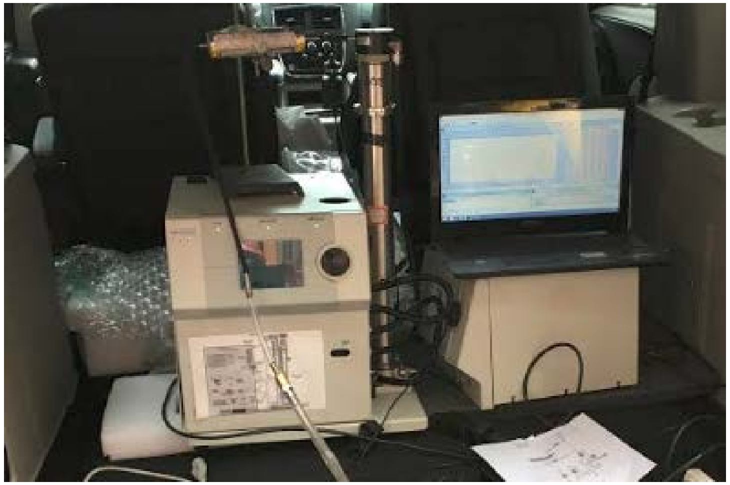
- Unneeded equipment removed from analytical trailer
- SO_2 analyzer calibrated and ready for testing
- Calibration gas cylinders and related equipment delivered to host site
- Analytical trailer transport plan coordinated with shipping vendors

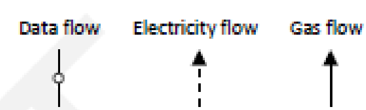
Aerosol measurement equipment - WUSTL

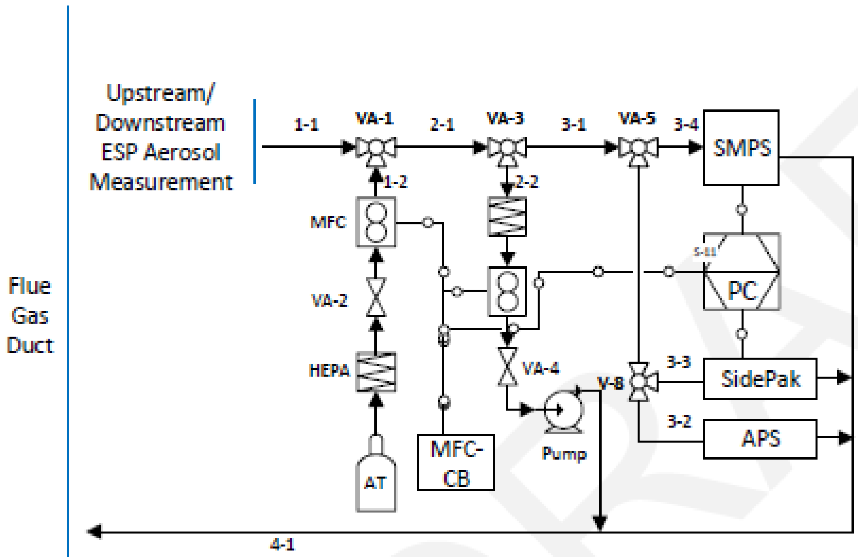
Aerosol particle profile for inlet and outlet of each process component will be measured.

Scanning mobility particle sizer (SMPS) characterizes particles in the 1-450 nm size range

Aerodynamic particle sizer (APS)-characterizes particles in the 0.5-20 µm size range







Instrument List	
PFD ID	*Equipment Component*
SMPS	Scanning Mobility Particle Sizer
APS	Aerodynamic Particle Sizer
SidePak	SidePak Personal Aerosol Monitor
PC	Personal Computer
AT	Air Tank
HEPA	HEPA Filter
MFC	Mass Flow Controller
MFC-CB	Mass Flow Controller Control Box
	Upstream/Downstream Aerosol Measurement
	Flue Gas Duct

Detailed installation and commissioning plan developed

	Start	Finish
Installation phase	**9/3/19**	**11/29/19**
Pour equipment pad, pad curing, set analytical trailer	9/3/19	9/11/19
OSBL electrical work (run 200 A feeder from tractor house, run power to trailer & skid)	9/3/19	9/23/19
OSBL mechanical piping (install process water, potable water, flue gas piping)	9/3/19	9/30/19
ISBL installation (set fabricated equipment, install interconnecting piping, leak check piping, install instrumentation, heat tracing, and insulation)	9/11/19	11/11/19
Commissioning phase	**10/17/19**	**11/29/19**
Spray tower, sorbent filter, and ESP I/O checkout	10/17/19	11/29/19
Operations & safety training	11/25/19	11/29/19

On track to complete BP2 on schedule (11/29/19)

Plans for future development

Project team plans to use constructed aerosol pretreatment equipment in future government-funded CO_2 capture demonstration projects

Processes can easily be scaled up 10-100 times for demonstration and/or commercial application based on existing designs

Team will continue to identify technology component improvements (e.g. better performing spray nozzle designs & optimized operating conditions, ESP photo-ionizer design optimization, etc.)

Thank you for your attention

Making our world more productive