# Toward A Technology to Mitigate Syngas Cooler Plugging and Fouling

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*Prepared for The Mcilvaine Company Hot Topic Hour*

*Coal Gasification Air Pollution Control*

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REACTION
ENGINEERING
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# Motivation

- US Dept. of Energy (DOE) funded study to investigate methods to mitigate fouling of the Convective Syngas Cooler (firetube heat exchanger) located between gasifier and combustion turbine in IGCC plants
  - » In US – petcoke fired
  - » Outside US – petcoke, coal, opportunity fuels but similar issues
- Focus – improve SC availability

  IGCC ➔ reduce Cost of Electricity (COE)
  Other ~ target 8,000 hrs/yr
- How ?
  - » Understand deposit formation
  - » Laboratory analysis of SC deposits
  - » Laboratory scale experiments
  - » Modeling
    - – Techno-Economic Analysis (TEA)
    - – Thermodynamic Equilibrium, Process, CFD

**Tube Sheet Fouling**

Source – Global Energy, Inc

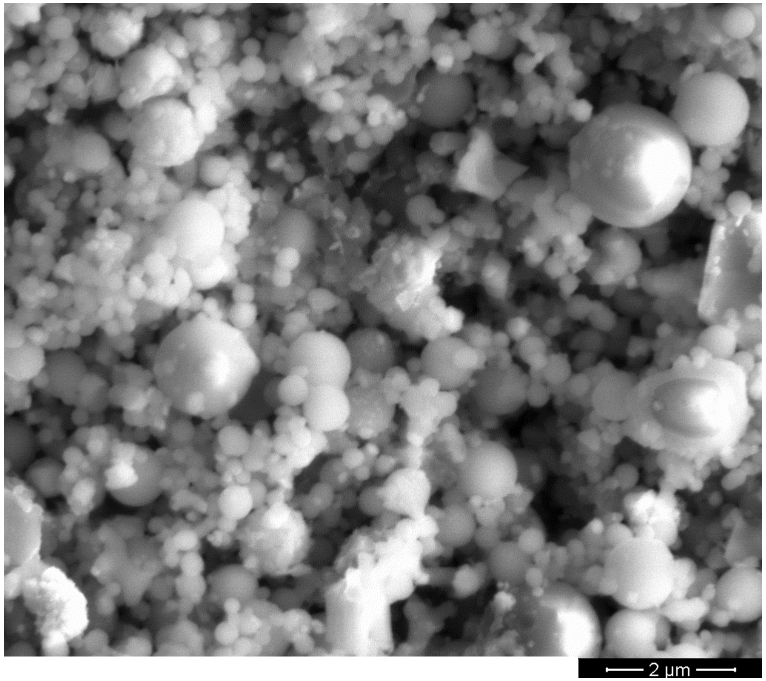
[Guenther, GTC 2011]

[McDaniel & Hornick, 2002]

- Current cleaning strategy ➔ plant shutdown and clean tubes
  - » Blowout deposits and/or chemical cleanout
  - » Schedule tube cleaning w/ other system maintenance
- Benefits:
  - » Improved plant economics (increased availability)
  - » Reduced maintenance (clean/repair)

# SC Deposit Analysis - Findings

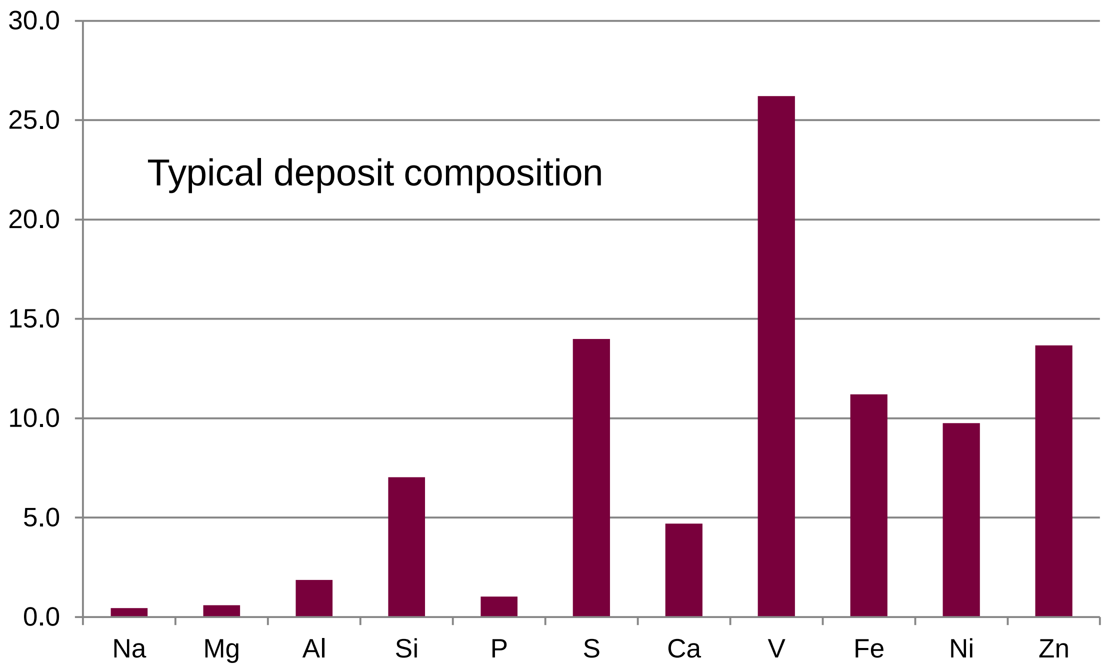
- Deposits have fairly uniform composition along flow path
- No initiation layer typical of deposits in coal fired boilers
- Three main phases observed
  - » Calcium alumino silicates
  - » Sulfide rich
  - » Vanadium rich




- Deposits consist mainly of fine (<1 μm) to small (<5 μm) spherical particles that appear to sinter and diffuse over time to create strong, tenacious deposits
- Char particles (10-20 μm) observed occasionally on surface of gas side of deposit.

# SC Deposit Analysis – Composition

- Deposits are similar in composition with some variation by hot path location
- Representative deposit elemental composition
  - » Very enriched levels of vanadium (V), iron (Fe), sulfur (S)
  - » Moderate levels of nickel (Ni) and zinc (Zn)

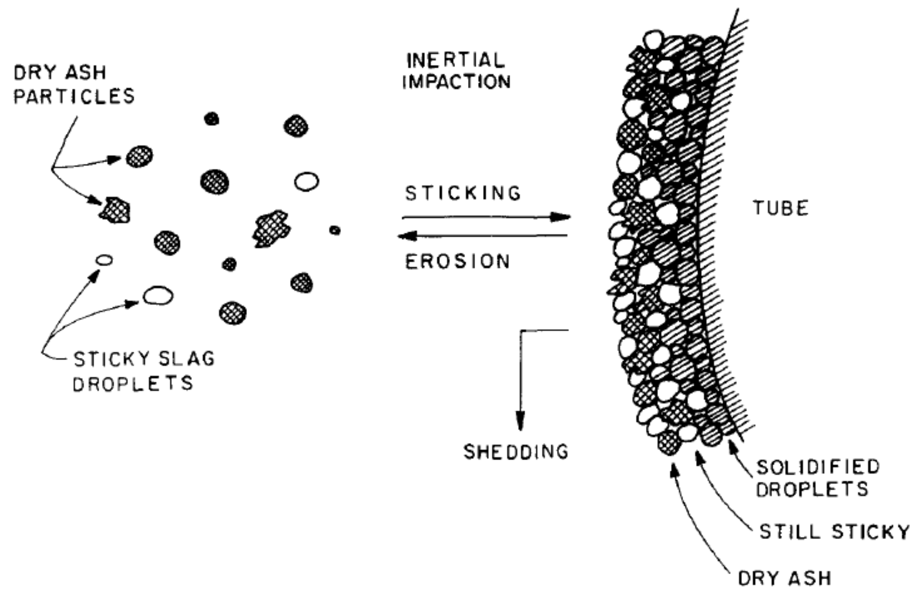


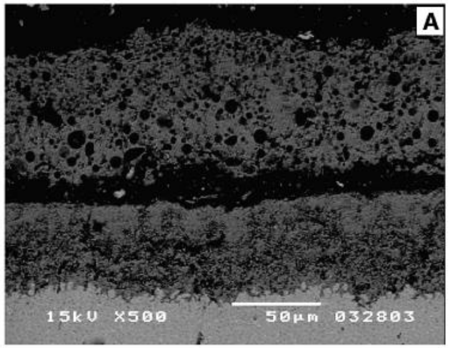
# SC Deposits - No Layering

For coal fired boilers , deposits build up in layers

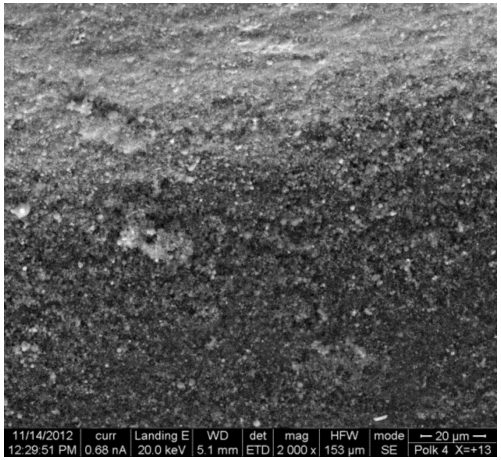
- Initial layer due to “sticky” particles that deposit on surfaces
- Larger particles deposit and stick to surface
- Repeat process

[Walsh et al., 1990]



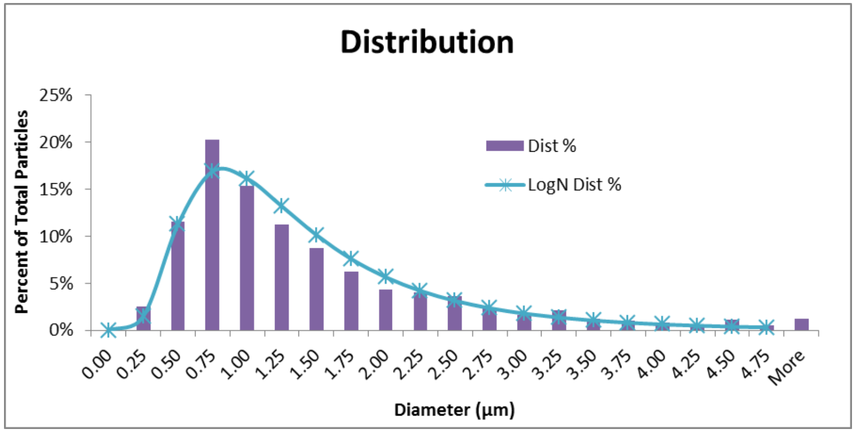

PC Boiler [Li et al., 2007]

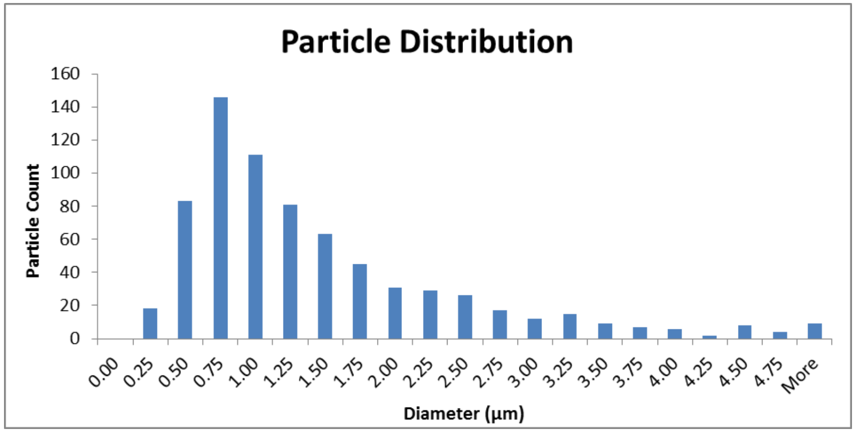



IGCC Plant Sample

# SC Deposits - SEM Particle Size Analysis

- Image analysis software (ImageJ) used to analyze the SEM images
  - » estimate particle counts and particle size distributions (PSD)
- Matrix of fine particulate and larger, micron sized particles
  - » Matrix contains large amount of fine spherical particulate (<1 μm)
  - » Overall PSD ave. particle size = 1-2 μm (99+% < 5 μm)
  - » Few or no larger particles (>10 μm)
  - » No layering or char particles in deposit
- Observed PSD is NOT typical of a coal fly ash PSD
  - » SC deposit PSD = very narrow band
- Particles are less defined closer to the heat exchanger surface, indicating that particles diffuse and sinter over time



# Deposit Formation Hypothesis

**Metallic Element Release**

- Some metals in fuel released/vaporized during gasification process

**Fume Formation**

- Vapor condenses ➔ sub-micron fume of pure metals, metal sulfides and metal oxides
- Melting point of these species may be near or lower than IGCC syngas cooler temperature
- Gasifiers have long residence times that promote growth of fume particle size

**Initial Deposition**

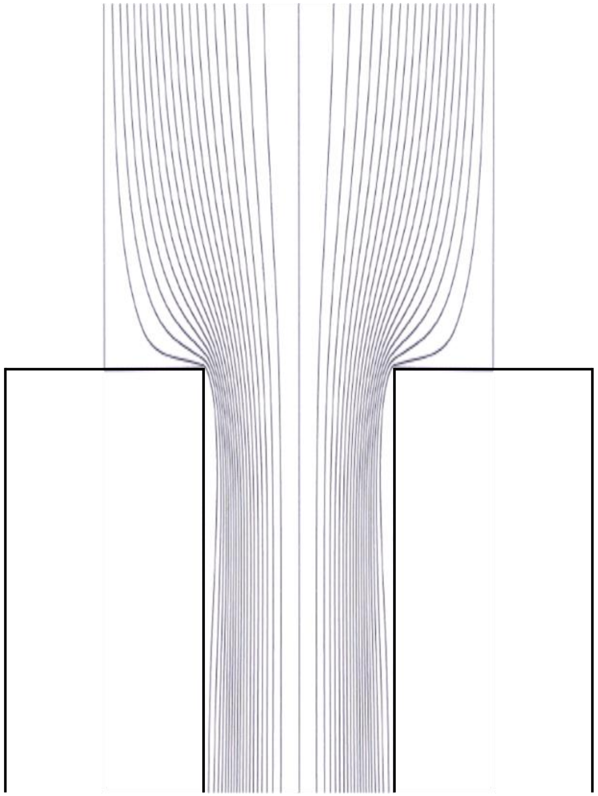
- Submicron particulate & small ash particles deposit onto stagnation points in syngas cooler region (Impaction)
- Forces important for small particles hold material (i.e., electrostatic, Van der Waals)
  - Thermophoresis is small since deposit is forming on an adiabatic surface

**Build-Up and Sintering**

- Particles diffuse & sinter to form amorphous deposits ➔ high structural strength
- Some evidence of char particles depositing
- Deposition mechanism doesn't change as the deposit builds

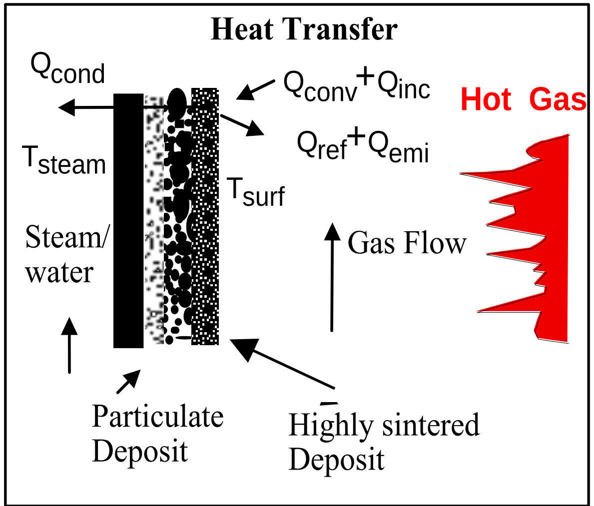
# Impact of Tubesheet Face Geometry

- Streamlines converge and then turn sharply near the lip of each tube inlet resulting in sharp deposits of particles of a relatively narrow range of particle diameters in an annulus just outside the tubes
- This is consistent with field observations that deposits build-up on tubesheet face at tube entrance
- Pseudo-transient CFD modeling indicates that, as the deposit builds, the rate of deposition increases – this is consistent with field observations related to pressure drop



# REI Fouling & Deposit Buildup Model

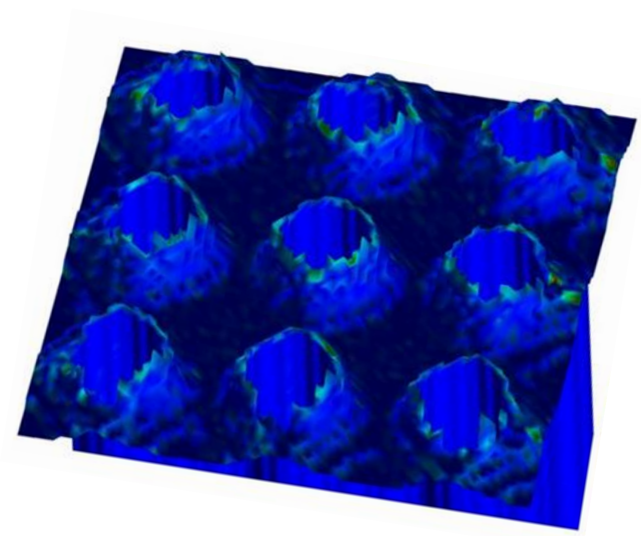
- Mechanistic model that includes the impacts of
  - » ash properties (individual local particle composition, particle size, temperature, density, viscosity, surface tension),
  - » local conditions (gas composition, temperature, heat flux to surfaces)
  - » properties of deposits (composition, temperature, density, viscosity, surface tension (if wet), strength of sintered material)
- Model enhancements for syngas cooler applications
  - » Replaced particle cloud model with stochastic particle tracking to better capture "randomness" due to turbulent effects on particle trajectory
  - » Implemented grid deformation algorithm to better represent buildup of deposited material on surfaces
  - » Implemented more general criteria for particles sticking to surfaces for SC




- Provides predictions for
  - » properties of particles exiting the furnace in-flight
  - » deposition rate (growth rate)
  - » properties of sintered deposits on walls
  - » impacts of fouling on gas phase properties, overall heat transfer, etc.

# Modeling - Deposition

- » Deposition patterns:
  - – deposits concentrate near tube inlets and at distinct stagnation lines near tube inlets
  - – little/no deposition a few tube diameters after inlet
- » Tapered tube inlet
  - – provides smoother flow transition but also ....
  - – provides shape that can collect large pieces of deposits that originated upstream

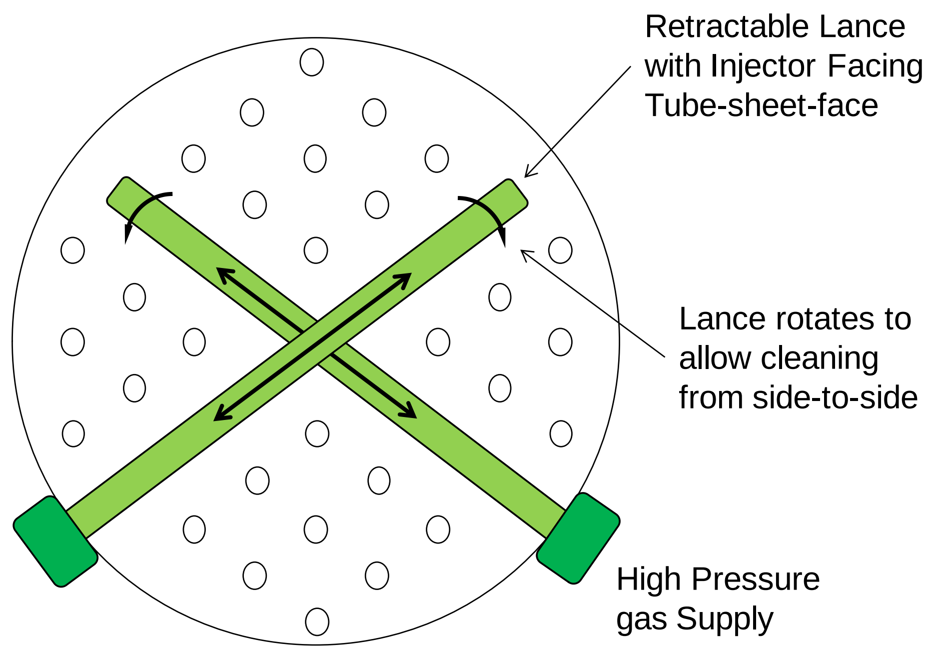


# Mitigation Strategies Investigated

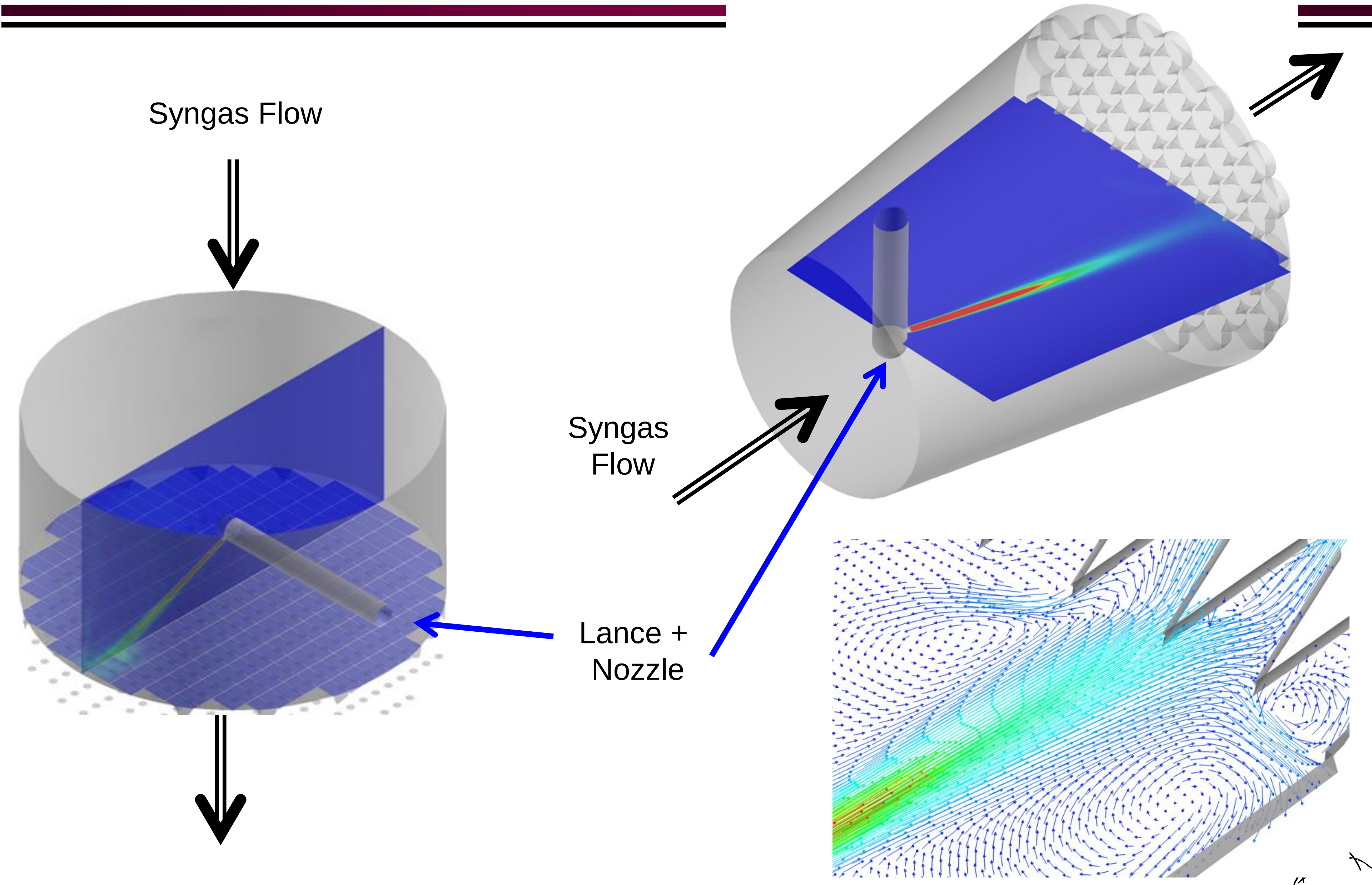
- Sootblowers
  - » Use of a jet or acoustic sootblower to keep surfaces free from deposits
- Coatings for Syngas Cooler Surfaces
  - » Coated surfaces (e.g., particle traps, tube sheet face) could reduce adhesion strength of the deposits
- Sorbents and/or fuel additives to capture/bind the "bad actors"
  - » Laboratory tests ➔ sorbents can sequester vanadium, sodium, sulfur, and other potential "bad actors" [Gale and Wendt, Mwabe and Wendt, Linak]

# Conceptual Design - Soot Blower

- Use soot blowers to periodically clean surfaces and avoid fouling buildup
- REI collaborating with OEM on conceptual design and performing CFD modeling to evaluate/optimize soot blower performance.
- Possible sootblower jet media
  - » (recycled) syngas; N2;
    high pressure steam from SC
- Components of design demonstrated for high pressure process furnace
- IGCC plant pressure ~ 30-60 atm ➔ must minimize vessel penetrations.
- Field test planned for IGCC plant syngas cooler




# CFD Modeling - Syngas Cooler



# Deposit Bond Strength Tests - Coatings

- Approach
  - » Form deposits of ash/particles on plates under laboratory conditions
  - » Analyze physical and chemical characteristics of deposits
  - » Assess strength of adhesion between deposit and plate by measuring velocity of impinging gas jet required to remove deposit from the plate
- Variables
  - » Feedstock
  - » Deposit plate temperature (550C-820C)
  - » Deposit plate material (Carbon steel, SS steel, coated plates)
  - » Time deposit exposed to high temperature (heat soak time)
- Findings
  - » Bond strength between deposit and plate
    - – Increases with plate temperature and heat soak time
    - – Overall ➔ relative bond strength:
      - coal < petcoke+fluxant < plant "char"
  - » Coatings required less (~15%) energy to clean surface but coating toughness a concern

Coated Deposit Plate

# Sorbents to Mitigate Fouling

- Use sorbents to capture "bad actors" in syngas
  - » "bad actors" ~ metal sulfides, vanadium, sodium
  - » Modeling (thermodynamic equilibrium; CFD ) indicated deposition reduced if the "bad actor" compounds are eliminated.
- Sorbents considered
  - » Limestone - has high capture efficiency for sulfur
  - » Kaolinite - captures sodium and vanadium
  - » Focus ➔ Aurora = "engineered" kaolinite
    - – commercially available
    - – demonstrated to have good performance at relevant conditions

# Sorbent Pilot Scale Test

Deposit Sample

- Co-feed sorbent and fuel in a "drop tube" reactor to evaluate ability of Aurora (commercial sorbent) to remove vaporized metals from the effluent
  - » Fuels: coal and petcoke
  - » Oxidizing vs. reducing conditions
  - » Sorbent feed rate = 0-2 wt% of solid feed
    ➔ 0X, 2X, 4X, 8X wt% of ash in solid fuel
- Reactor instrumented with two probes (APS, SMPS) that measure concentration of fine particulate and an uncooled deposition probe
  - » SMPS = [<1 μm], APS = [1-20μm]
  - » Reactor is used to investigate aerosol formation for coal combustion applications

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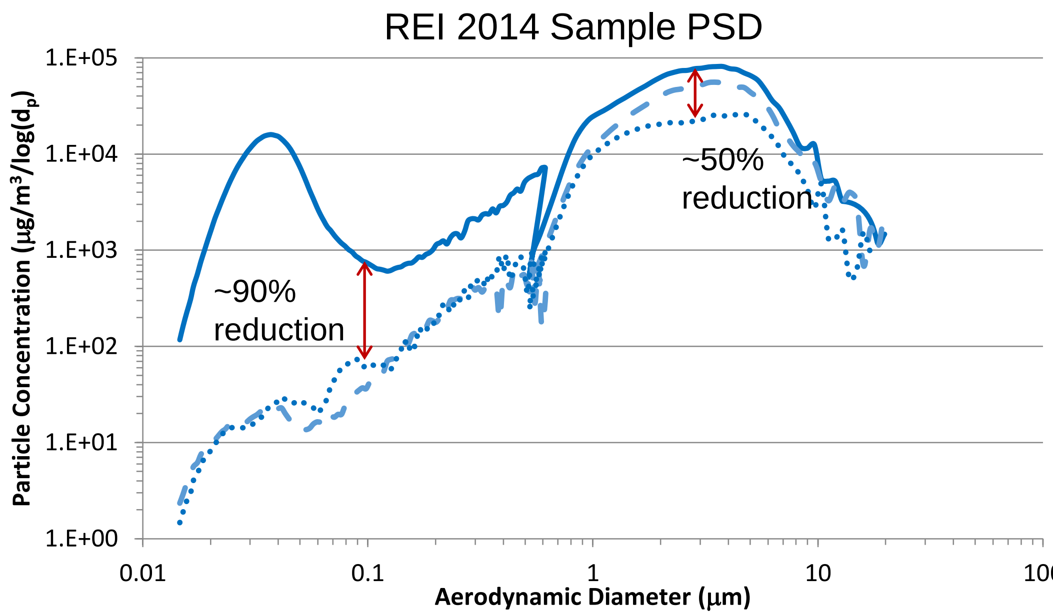
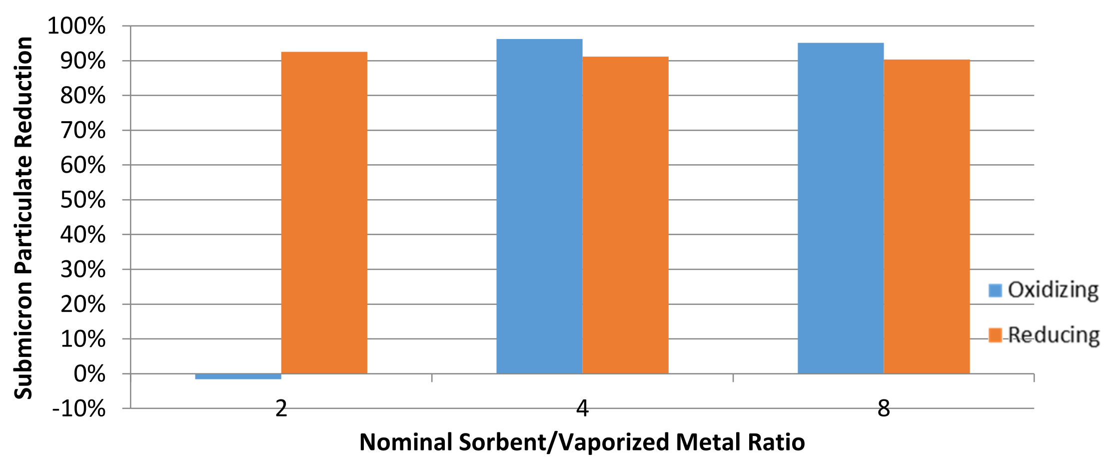
# Sorbent Pilot Scale Test - Results

- Results for baseline showed good agreement with literature data [Linak et. al, 2002, 2004]
- Sorbent reduced mass of submicron particulate > 90%
  - Mass of larger particles also significantly reduced.
- Results similar for all sorbent concentrations tested
- Impact on Ash Fusion Temp ?
  - +2700F => add fluxant
- Re-emit captured metals ?
  - TGA test ~ 3% mass loss at 1500C
- Data indicates can use lower sorbent ratio

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# Summary

- Syngas Cooler Deposit form via:
  1) Vaporization of organically associated metals in the fuel form submicron particulate
  2) Impaction, electrostatic and van der Waals forces cause particulate to deposit onto flow surfaces
  3) Sintering of low-melting point deposit components increases bond strength
- Potential Mitigation Strategies
  - » Inject Sorbents to capture vaporized metals
  - » Targeted soot blowing
  - » Coatings ???
- Modeling tools and Lab/Pilot Scale facilities available to evaluate mitigation strategies for new plants and syngas cooler retrofits

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