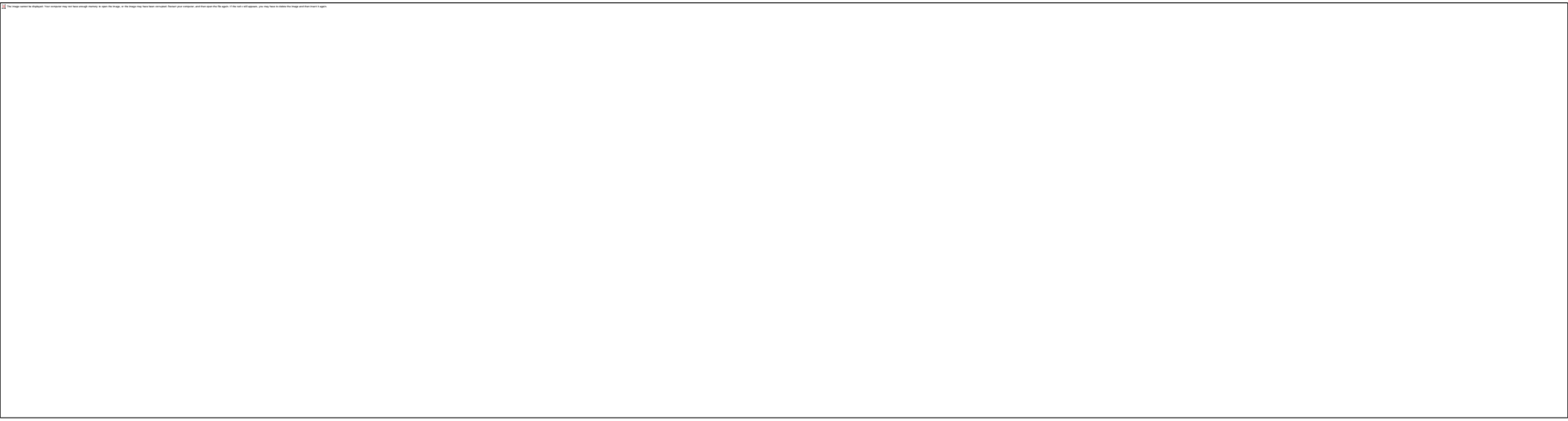
REINHOLD ENVIRONMENTAL Ltd.

2017 APC & Wastewater Round Table & Expo Presentation

July 17 & 18, 2017 in Charlotte, NC / Hosted by Duke Energy



DSI - THE SWISS ARMY KNIFE® OF COAL-FIRED BOILERS WORKSHOP 16

Gerald Hunt, Jim Dickerman

Reinhold Workshop

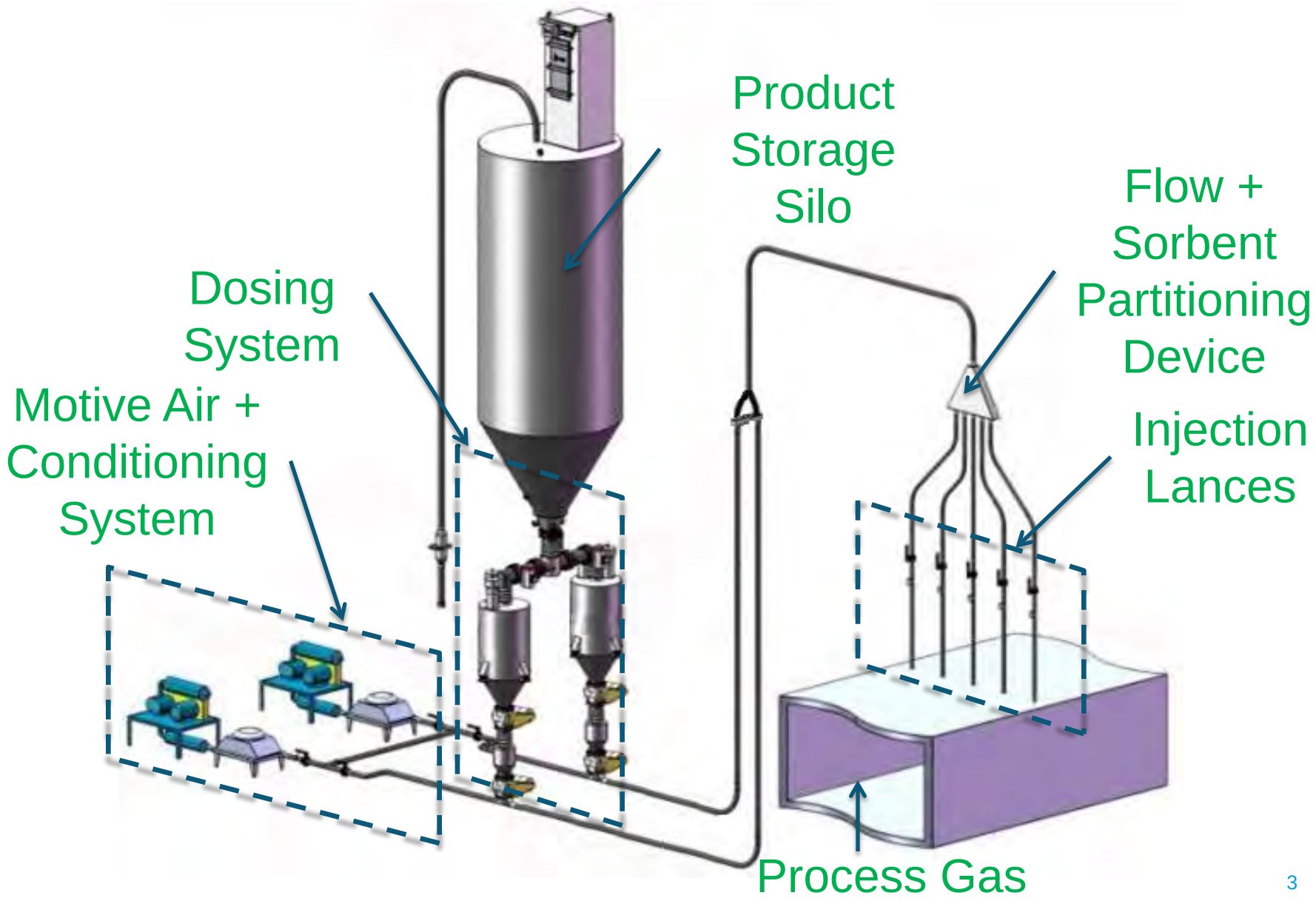
July 18, 2017

“You Can’t Always Get What You Want”

The Rolling Stones

“You can't always get what you want
You can't always get what you want
You can't always get what you want
But if you try sometimes you might find
You get what you need”

DSI Configuration



Features of DSI Technology

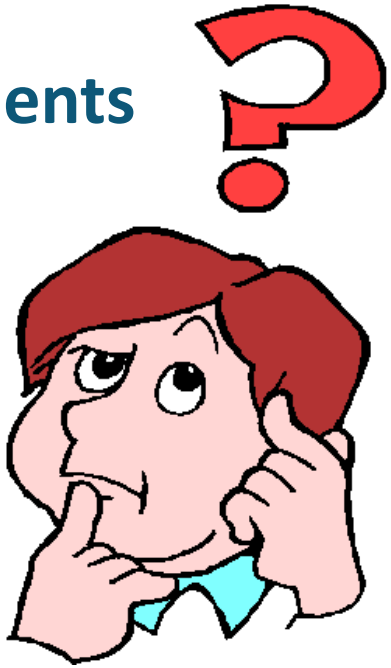
- **Low capital expenditure**
- **≤ 12 month schedule (award to installation)**
- **Simple equipment with a small footprint and easy process retrofit**
- **Simple proof of concept testing**
- **Adaptability to a variety of fuels and pollutants**
- **Technology is mature and proven**
- **Process and regulatory agility**

Everything effects SO_3, and SO_3 effects everything

Chad Donner – Duke Energy

Just What Does SO_3 Really Effect?

- **Removal of other flue gas constituents**
  - NOx, Hg, PM
- **Air Heater Operations**
  - Overall boiler efficiency
  - APH maintenance/cleaning cycles
- **Flue Gas Acid Dew Point**
- **ESP Operations**
- **SCR Minimum Operating Temperature**



DSI – Swiss Army Knife® of APC

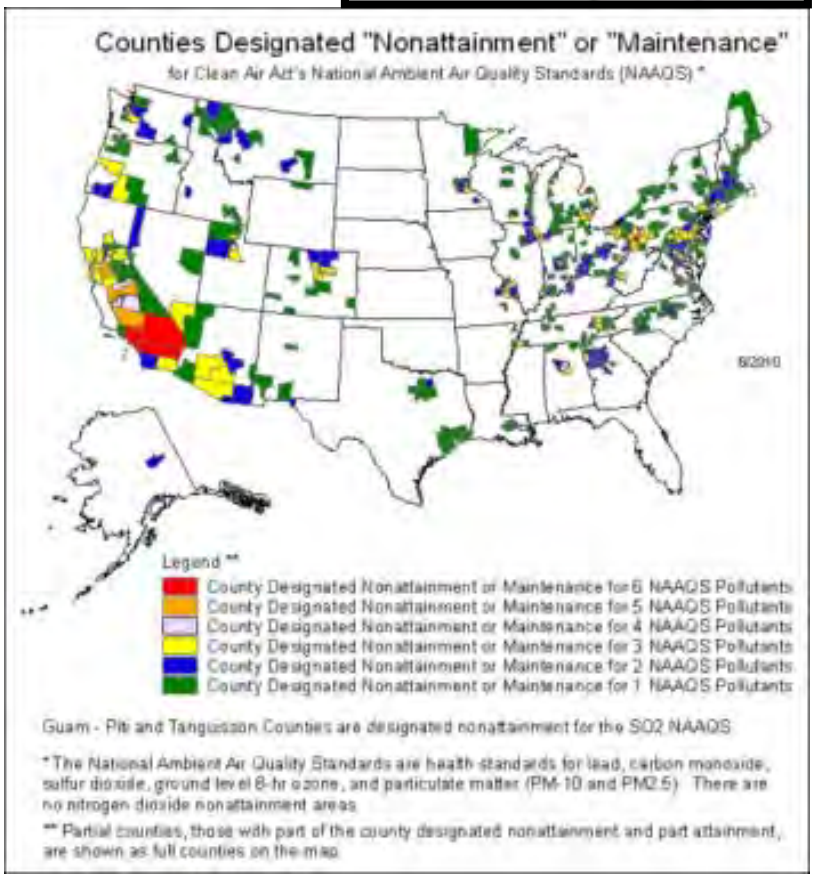
- Acid Gas Removal
- Reduced metals/chlorides to WFGD Purge Stream
- PAC Protection
- Reduce SCR Minimum Operating Temperature (MOT)
- Reduced APH Fouling
- Corrosion Protection
- Heat Efficiency Improvement

Acid Gas Removal

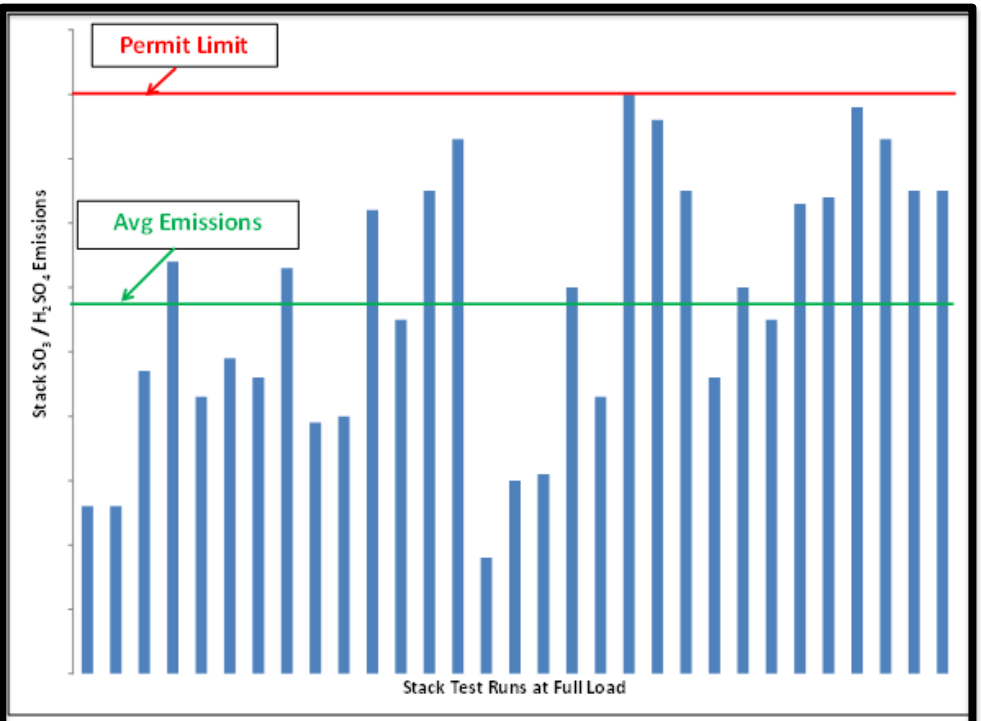
- Regulatory compliance
  - Visible blue plume control
  - Industrial Boiler MACT & MATS → HCl, SO_3, SO_2
  - Consent Decrees
  - NAAQS & Regional Haze → SO_2

mercury & air toxics standards

BOILER MACT



Acid Gas Removal



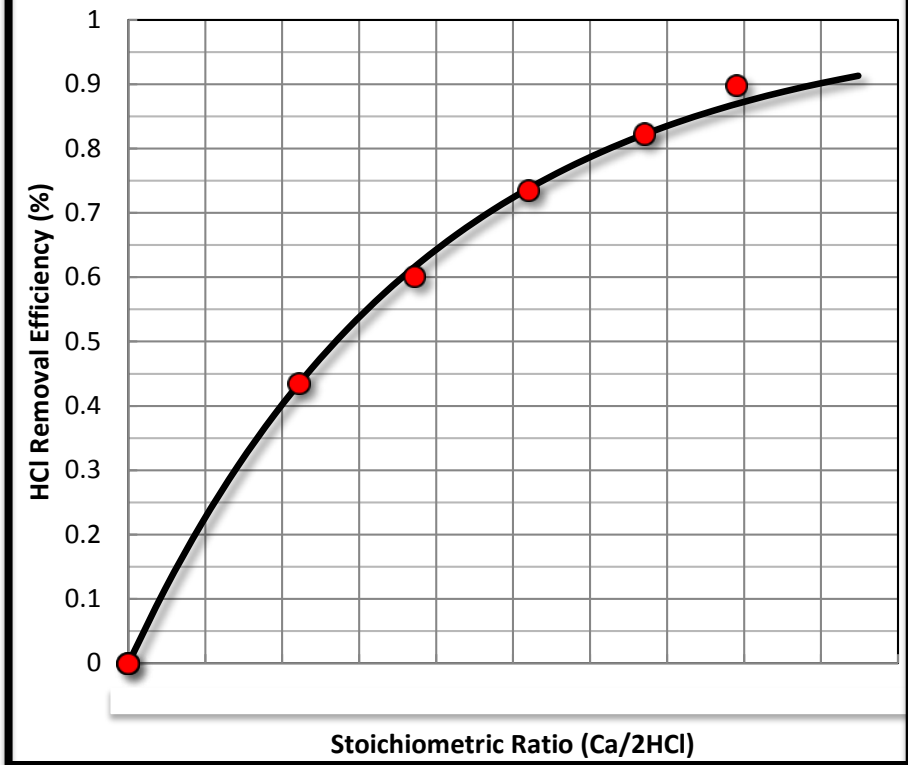
SO_3 / H_2SO_4 Emissions at Full Load

- Coal fired utility with following configuration: SCR → AH → ESP → WFGD
- DSI to reduce stack SAM to ~2 ppmv
- Data for Sorbacal® SP

SO_3 / H_2SO_4 Removal

HCl Removal

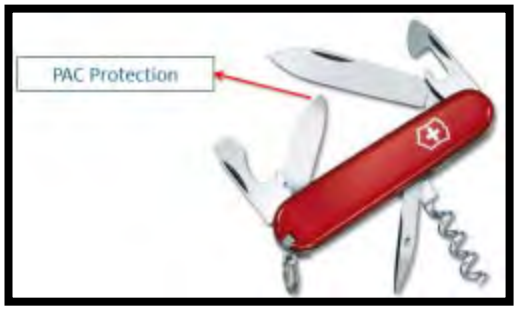
- Industrial site burning coal, bark and pellets
- DSI for IB MACT HCl compliance
- Target 75% HCl removal
- Curve for Sorbacal® SP



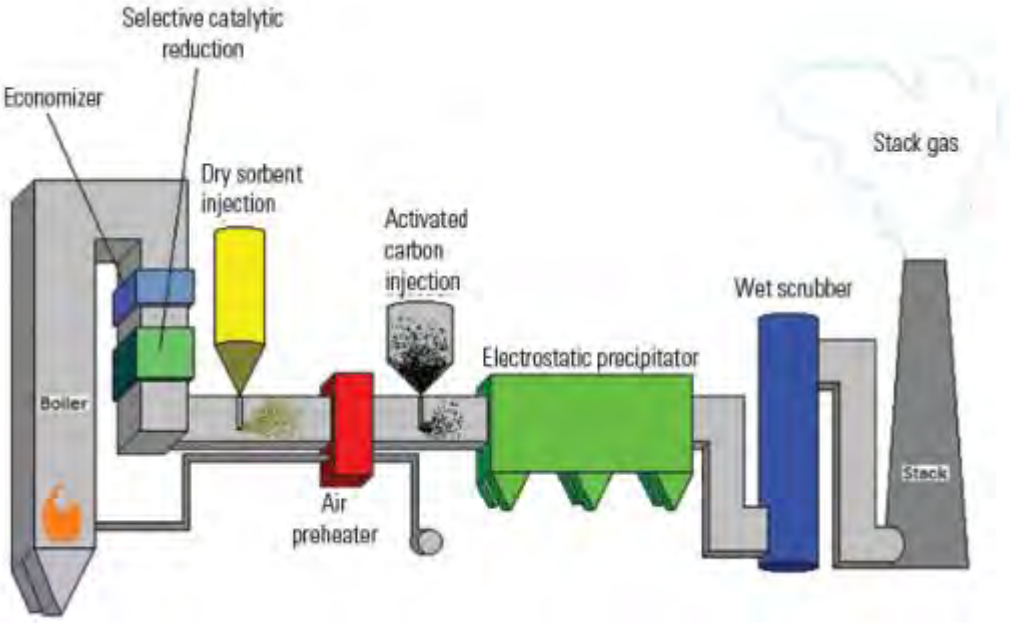
Acid Gas Removal for Reduced Particulate Matter Emissions

- **Customer had PM Emissions over the limit**
  - Testing indicated high emissions were due to SO_3 being condensed on PM monitor
  - Performed demonstration tests to inject hydrated lime
  - PM Emissions decreased from > 0.03 lb/MMBtu to 0.021 lb/MMBtu

PAC Protection



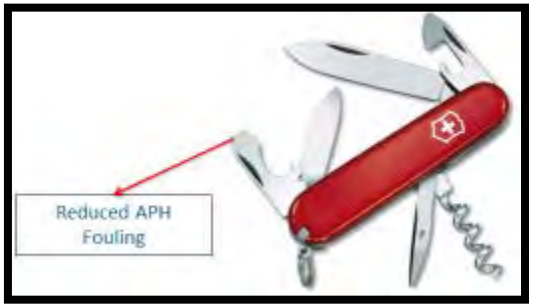
- SO_3 present in gas stream "poisons" PAC and negatively impacts Hg removal.
- SO_3 generated by oxidation of SO_2 to SO_3 in coal combustion as well as across SCR.
- Using DSI to reduce SO_3 to < 5 ppm upstream of PAC proven to improve Hg removal and reduce PAC consumption.
- Common for plants burning high sulfur coals that need Hg control to also install DSI simply to benefit the PAC performance and Hg removal efficacy.

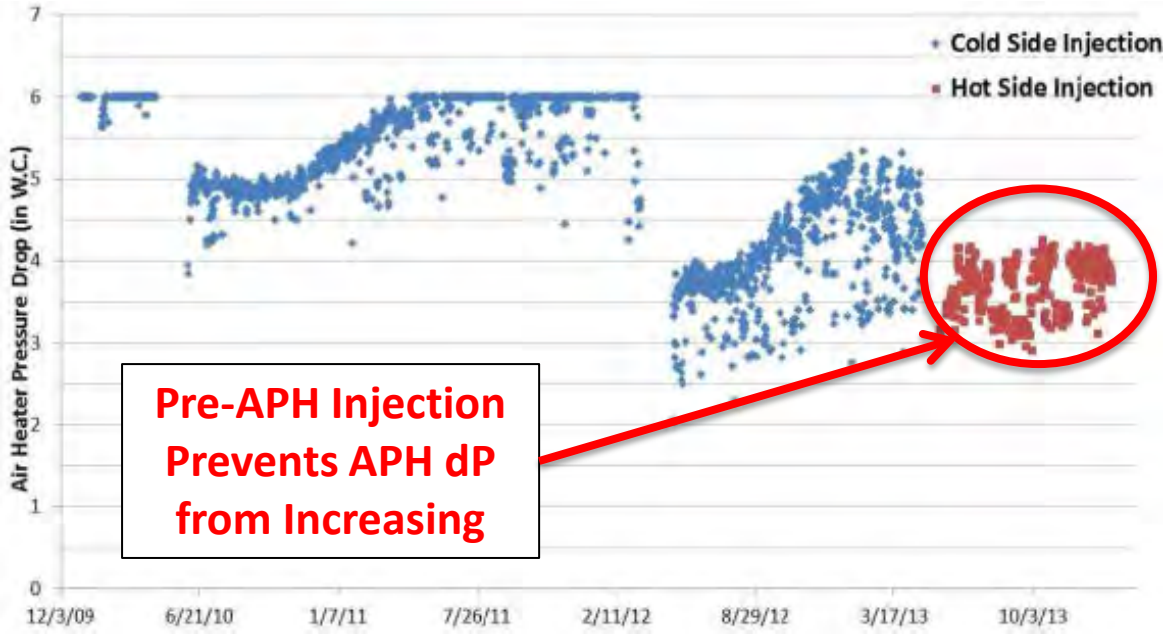


http://www.powermag.com/the-role-of-activated-carbon-in-a-comprehensive-mats-strategy/

Reduced APH Fouling

- Reaction between SO_3 and ammonia creates ABS which is sticky byproduct and undesirable.
- Using DSI to reduce SO_3 emissions upstream of APH eliminates a component necessary for ABS formation.
- Preventing ABS formation reduces build-up and fouling within APH baskets.
- No longer observe steadily ↑ APH differential pressure.





Biehn, C.; "Pre-APH Injection of Hydrated Lime Update on Recent Testing"; Dry Hydrate Users Group; Nashville, TN; 2014.

Corrosion Protection

- Condensation of corrosive compounds can damage back-end of plant (i.e. steel, filter bags, etc.).
- Leakage in duct can create localized cold spots where corrosion can occur.
- Approach to acid dew point can condense sulfuric acid
- DSI can remove corrosive compounds

Photos deleted due to confidentiality with customer

Heat Efficiency Improvements

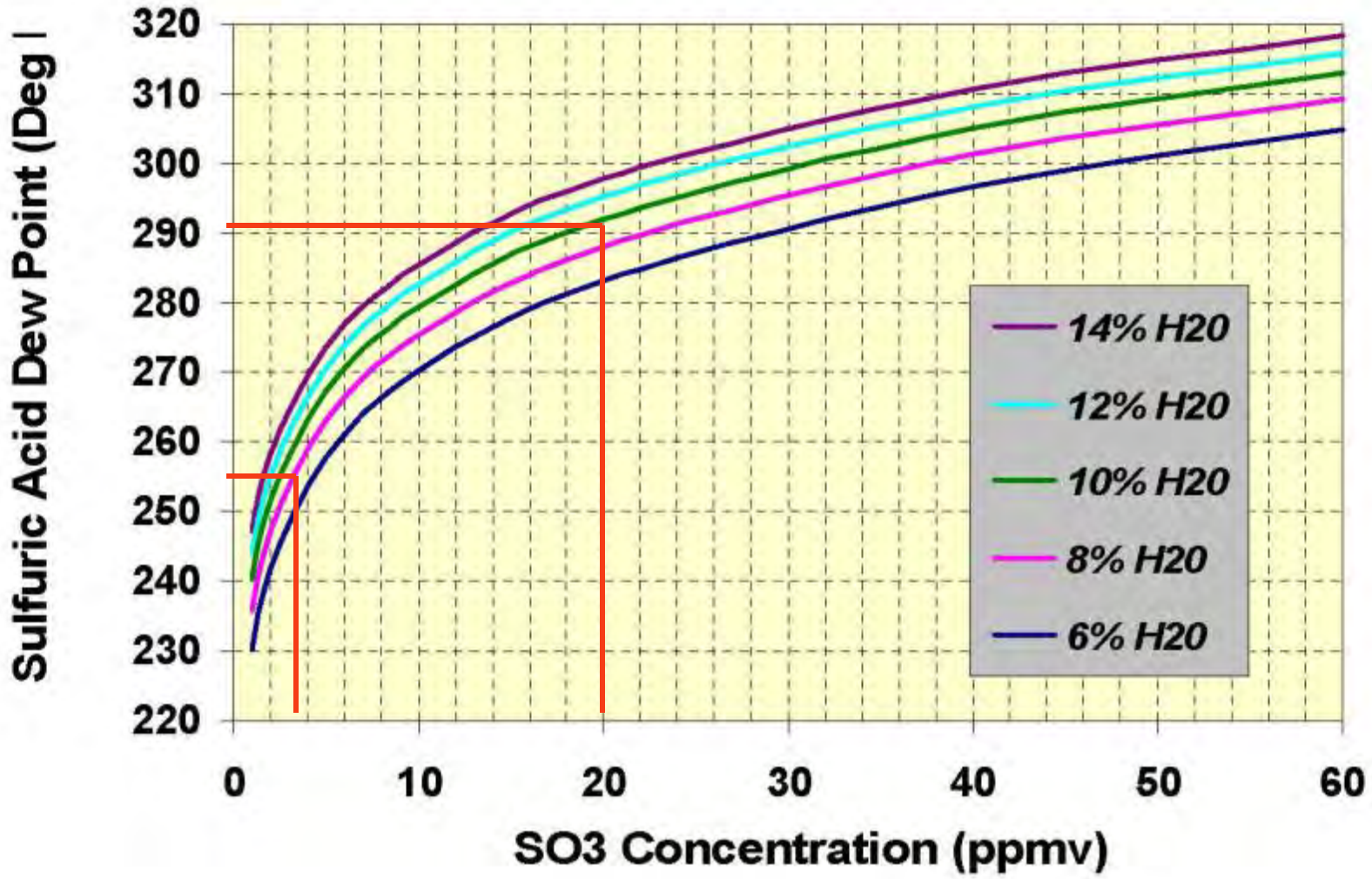
- Reduce SO_3 < 3-5 ppm upstream of APH to lower acid dew point and drop gas exit temperature.
- Reducing gas exit temperature by 30°F ≈ 1% heat efficiency improvement
- Following benefits observed,
  - ↓ fuel consumption
  - ↓ waste / ash generation
  - ↓ pollutant emissions
  - ↓ CO_2 emissions
  - ↑ ESP performance

	Baseline	Less 1% HR	Savings
Heat Rate (BTU/KWh)	10,000	9,900	100
Yearly Fuel (TN's)	1,368,750	1,355,063	13,688
Yearly Ash (TN's)	109,500	108,405	1,095
Coal & Ash Cost ($'000)	87,600	86,724	876
CO_2 Emissions (TN's)	3,367,125	3,333,454	33,671

Donner, C.; "Sorbent Injection for Low Load Operating Flexibility"; Reinhold APC/PCUG Meeting; Dearborn, MI; 2016.

Heat Efficiency Improvements

Acid Dew Point as a Function of SO_3 Concentration



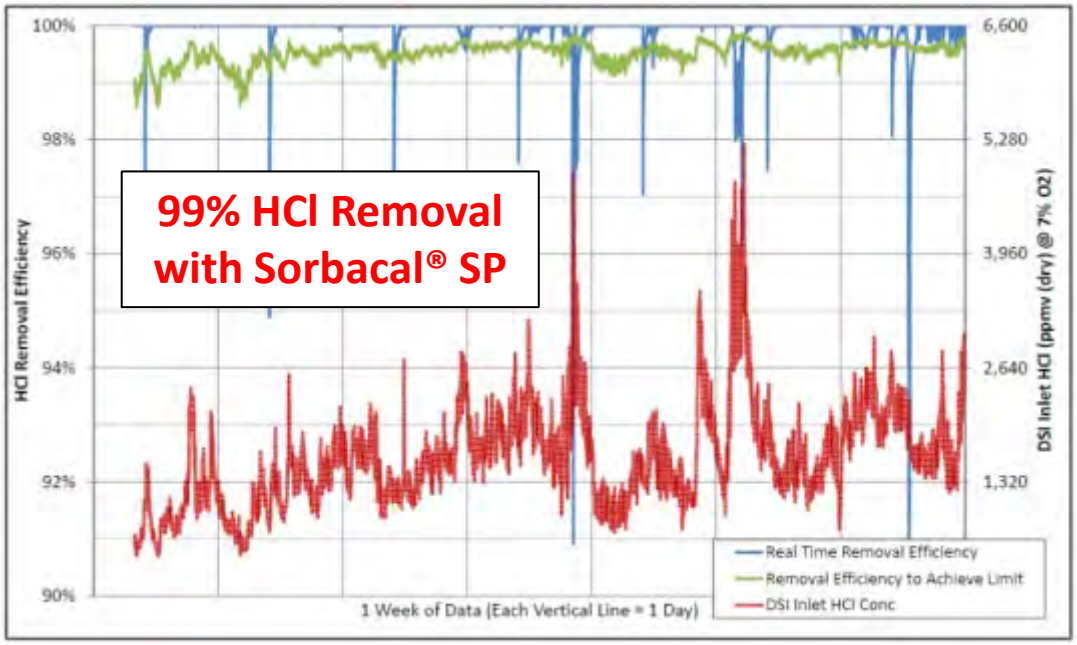
Reduce SCR MOT

- Coal boilers forced to swing load and function more often at low load.
- SCR MOT can limit boiler low load.
- Dynegy Zimmer Station Case Study
  - 1,440 MW boiler
  - SCR added in 2004
  - Injected Sorbacal® SP upstream of SCR at low boiler load since 2013
  - Reduce SO_3 at SCR inlet to ~5 ppm enables plant to lower minimum operating temperatures by ~30°F
  - No accelerated catalyst deactivation or erosion

Thomas, M.; Filippelli, G.; "Benefits, Impacts & Costs of Using DSI to Reduce SCR Minimum Operating Temperatures"; Reinhold NOx Combustion CCR/PCUG Meeting; Cleveland, OH; 2017.

Reduced WFGD Purge

- Reducing HCl upstream of WFGD. Lower chlorides into WFGD = less chloride purge.
- Lower chloride purge reduces operating costs associated with WWT.
- DSI with hydrated lime demonstrated ability to achieve > 95% HCl removal.
- Demonstrated high selenium removal as well (> 90% selenium removal).
- Reducing heavy metals before WFGD reduces treatment in WWT.



Sewell, M.; Hunt, G.; "Dry Sorbent Injection Technology to Improve Acid Gas Control"; 34th IT3 & Hazardous Waste Combustors; Houston, TX; 2015.

Sorbacal® SPS – Swiss Army Knife® of APC Sorbents

Enhanced Hydrated Lime Development

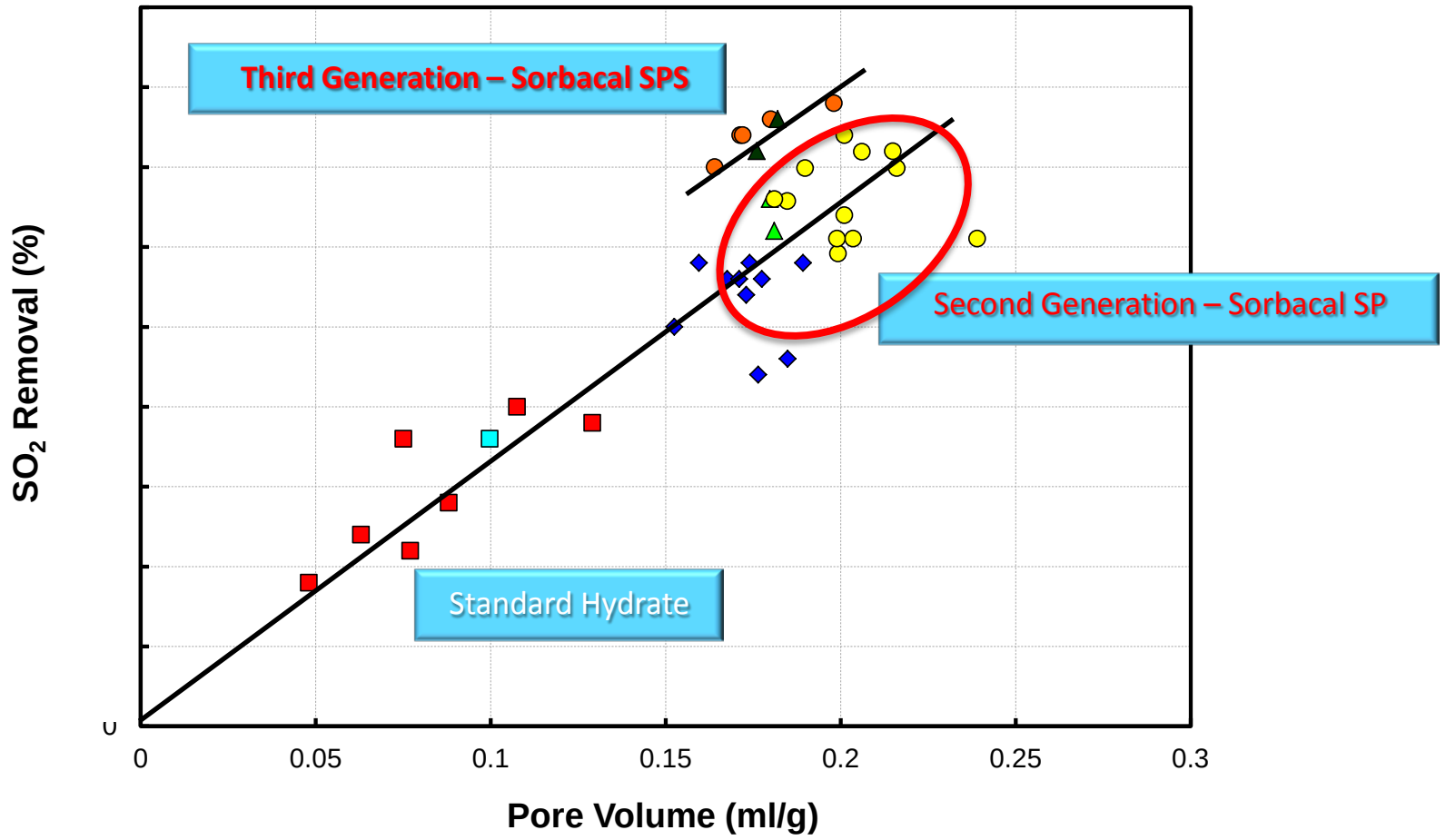
Sorbent	Standard Hydrated Limes	FGT Grade Sorbacal® H	Sorbacal® SP	Sorbacal® SPS
Figure				ACTIVATION 
Typical Available $Ca(OH)_2$ - [%]	92 – 95	93	93	93
Typical Surface Area - [m^2/g]	14 – 18	20	40	40
Typical Pore Volume - [cm^3/g]	~0.07	0.08	0.20	0.20
Typical D_{50} - [microns]	5 – 7	5 – 7	8 – 12	8 – 12

- Various standard and enhanced hydrated lime products will have different physical properties and potentially different BOP impacts

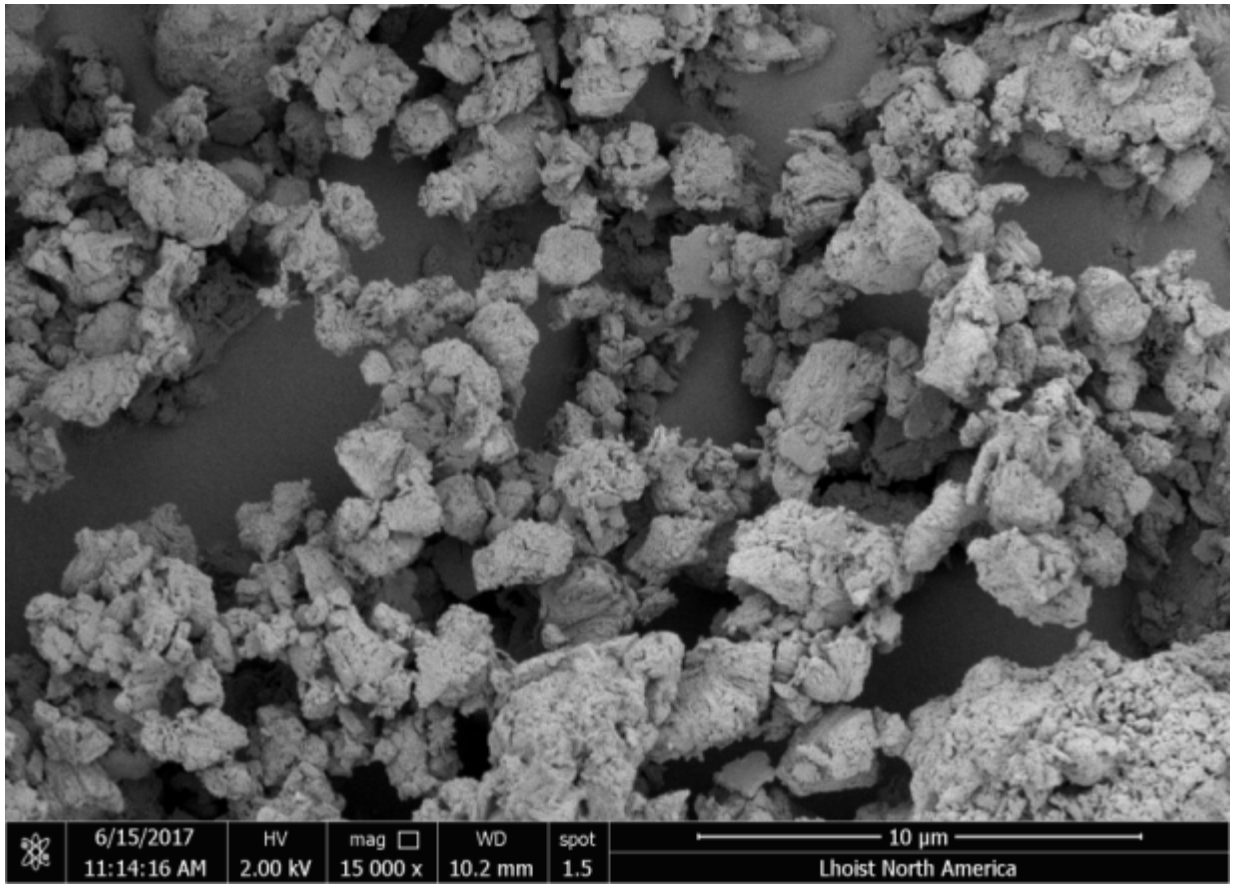
Enhanced Hydrated Lime Development

- **Pore Volume and Lab Scale Activity Test**

  Linear relationship between reactivity and pore volume



Enhanced Hydrated Lime Development



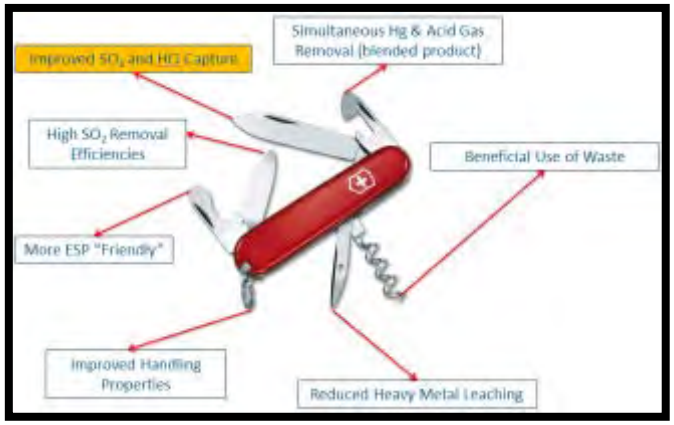
- Gas diffuses within hydrated lime particle and reacts with internal surfaces
- Internal as well as external surface area critical (i.e. total surface area)
- Internal surface area driven by increased porosity / pore volume

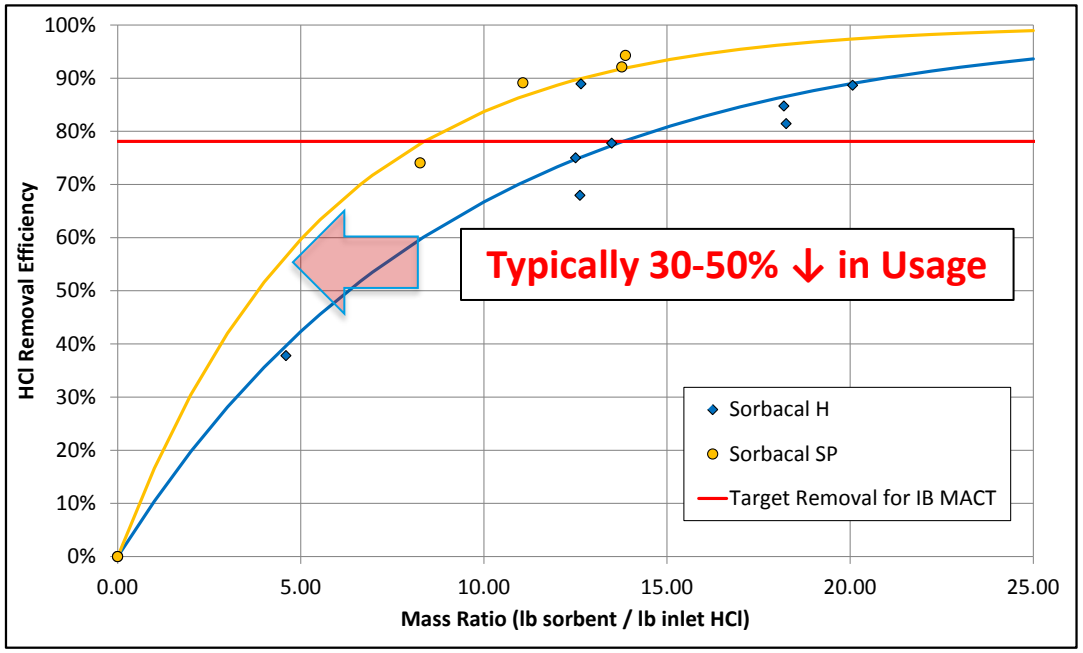
Sorbacal® SPS – Swiss Army Knife® of APC

- Improved SO_3 and HCl Capture
- Simultaneous Hg & Acid Gas Removal (blended product)
- High SO_2 Removal Efficiencies
- Beneficial Use of Waste
- More ESP “Friendly”
- Improved Handling Properties
- Reduced Heavy Metal Leaching

Improved SO_3 and HCl Capture

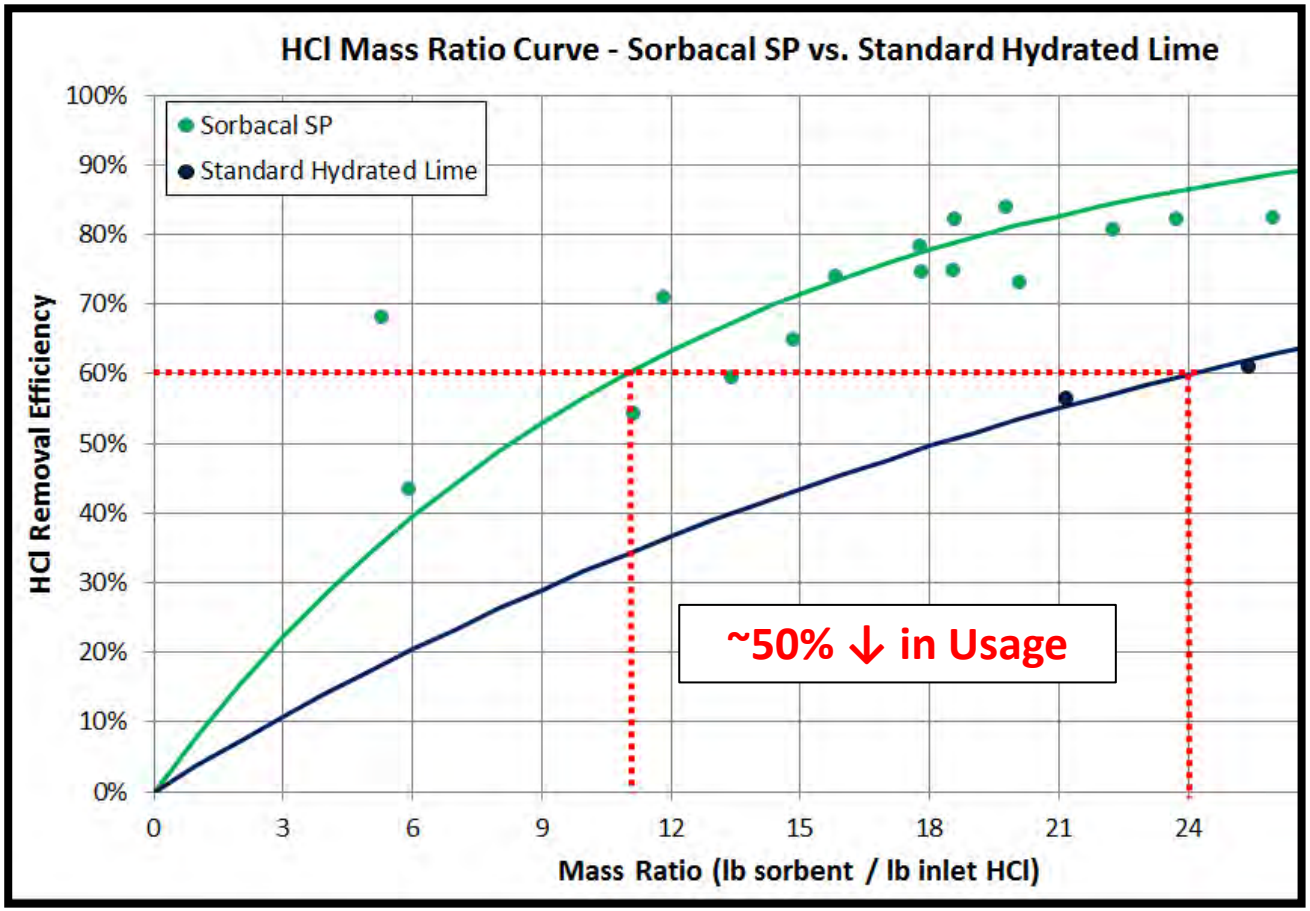
- Sorbacal® SP/SPS proven to achieve comparable SO_3/HCl removal as standard hydrate with 30-50% lower usage.
- Utilities, cement, paper, tile, waste incinerators, universities, biomass, etc.
- Following benefits achieved,
  - Lowest total cost of ownership
  - Increased silo capacity
  - ↓ to ESP/FF and ash handling
  - Fewer truck deliveries





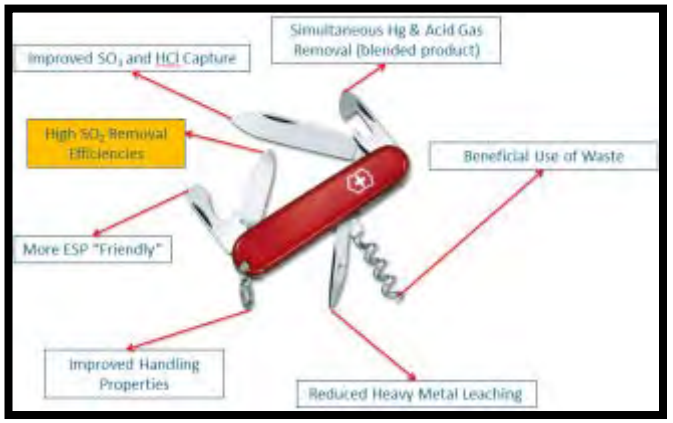
Improved SO_3 and HCl Capture

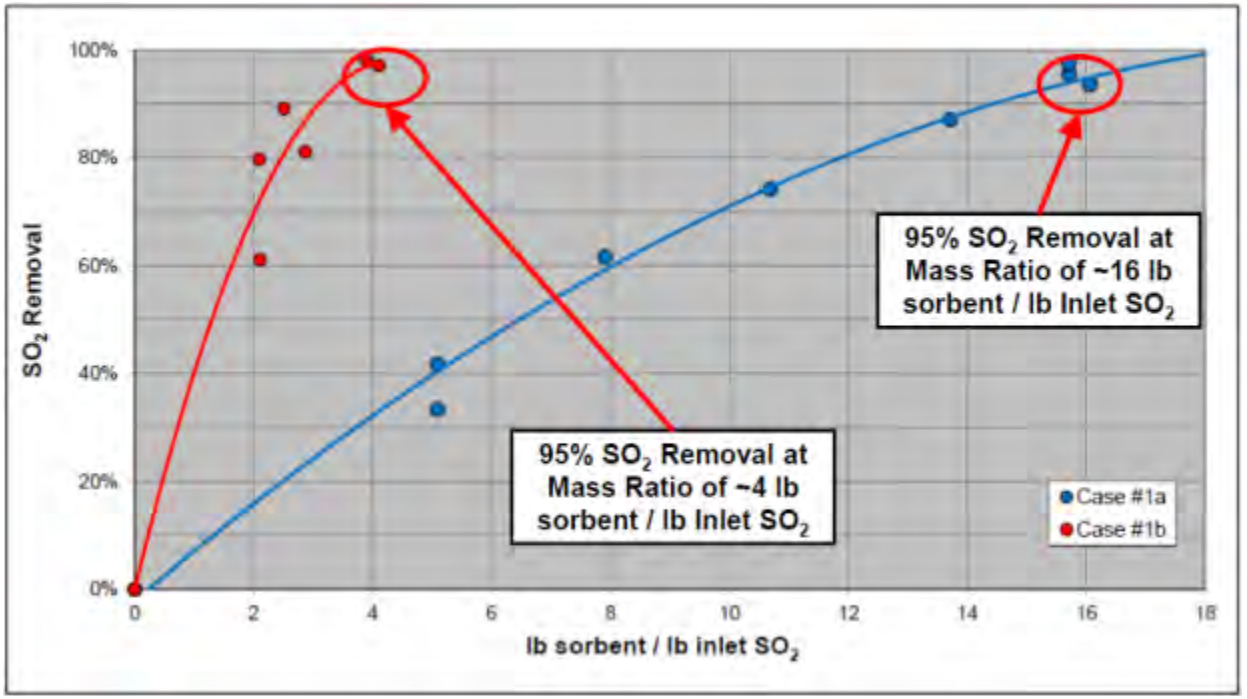
- **Paper mill injected hydrates post AH / pre ESP for HCl control for IB MACT compliance**
- **Plant tested Sorbacal® SP as well as standard hydrated lime**
- **Sorbacal® SP reduced consumption by ~50% over standard hydrated lime**



High SO_2 Removal Efficiency

- Previous perception was DSI with hydrate not effective for SO_2 control.
- Demonstrated ability to achieve > 90% SO_2 removal on variety of applications without humidification.
- No longer "can it get SO_2 removal" rather "how much will it take".
- Utilities, cement, glass, tile, pet coke, biomass, etc.

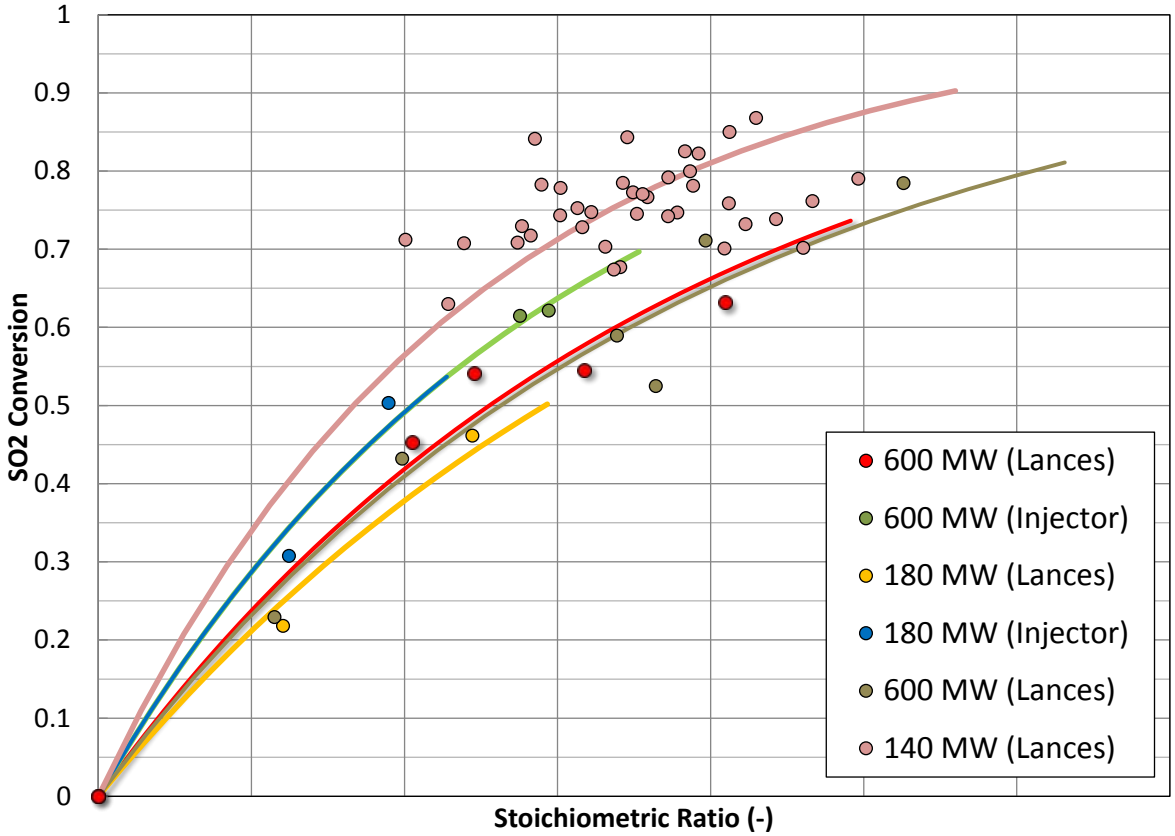




Dickerman, J.; Hunt, G.; "SO_2 Control Using Dry Sorbent Injection Technology with Hydrated Lime"; EUEC; San Diego, CA; 2015.

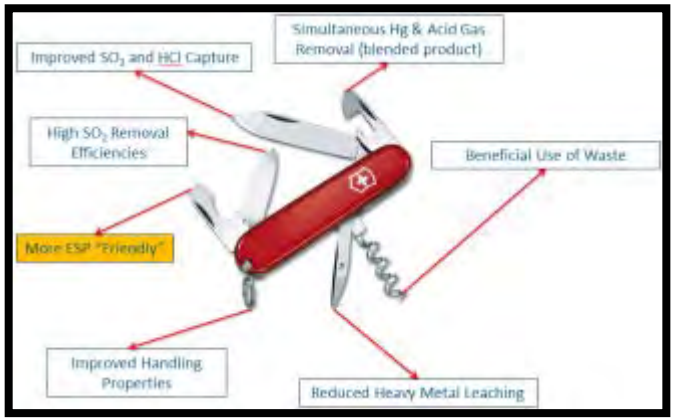
High SO_2 Removal Efficiency

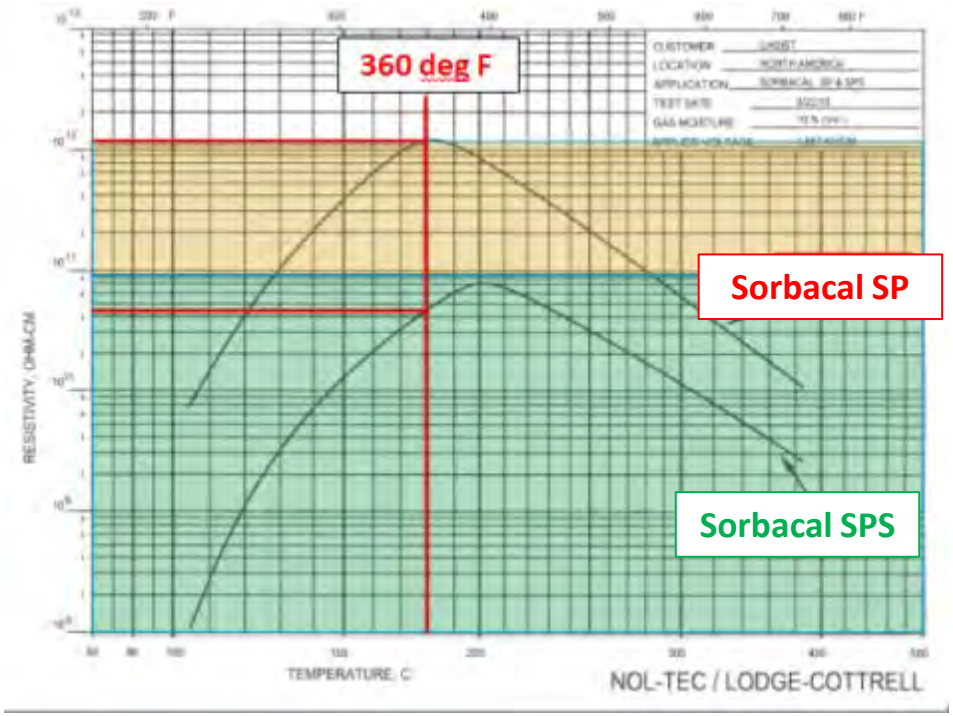
- Collection of full load data from PRB fired units with ESPs testing Sorbacal® SPS for SO_2 control
- In each case desired SO_2 removal was achieved
- Also illustrates importance of "proper" mixing as cases with Sorb-Tec injectors achieved 20-30% improvement in performance



More ESP “Friendly”

- More ESP “friendly” due to,
  - Lower dosage rates, less calcium injected
  - Larger particles are “easier” to collect in ESP
  - Chemical activation results in lower resistivity
- ESP impacts should be evaluated on case by case basis.
- ESP tuning and optimization ideal when changing composition and mass loading of incoming dust.





Foo, R.; Dickerman, J.; Hunt, J.; Heiszwolf, J.; Johnson, L.; “ESP Compatible Calcium Sorbent for SO_2 Capture at Great River Energy’s Stanton Station”; MEGA Symposium; Baltimore, MD; 2016.

More ESP “Friendly”

- **No operational issues with ESP during Sorbacal® SPS injection**
  - **Sorbacal® SPS ~ 50% of the total mass loading in this application**
  - **High SO_2 removal requirement (60-80% depending on coal sulfur)**
- **Small impact on opacity ~ 1% change, but no long term effects**

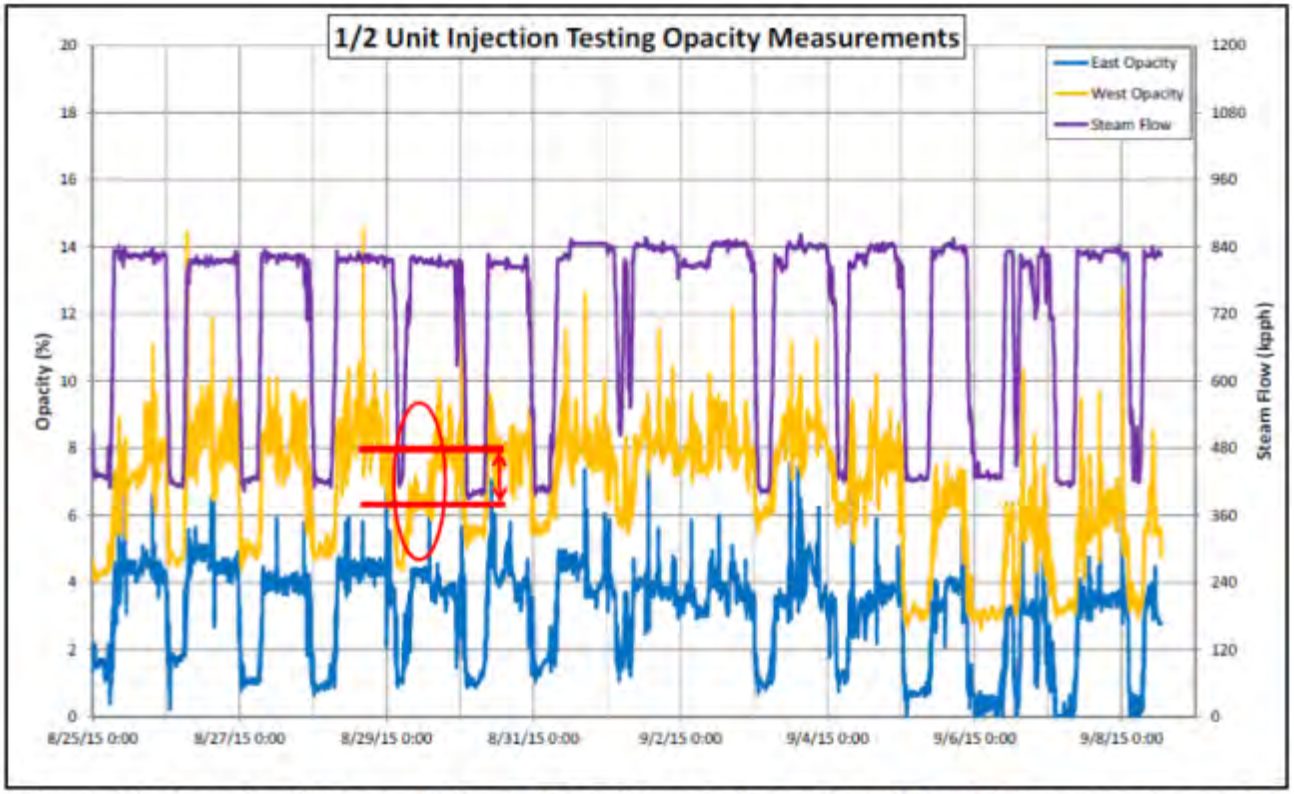
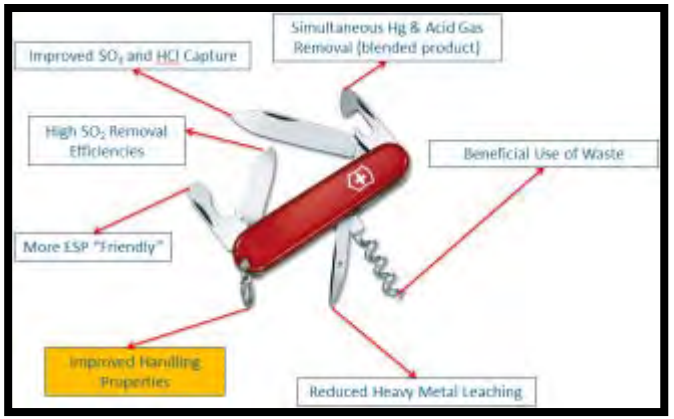
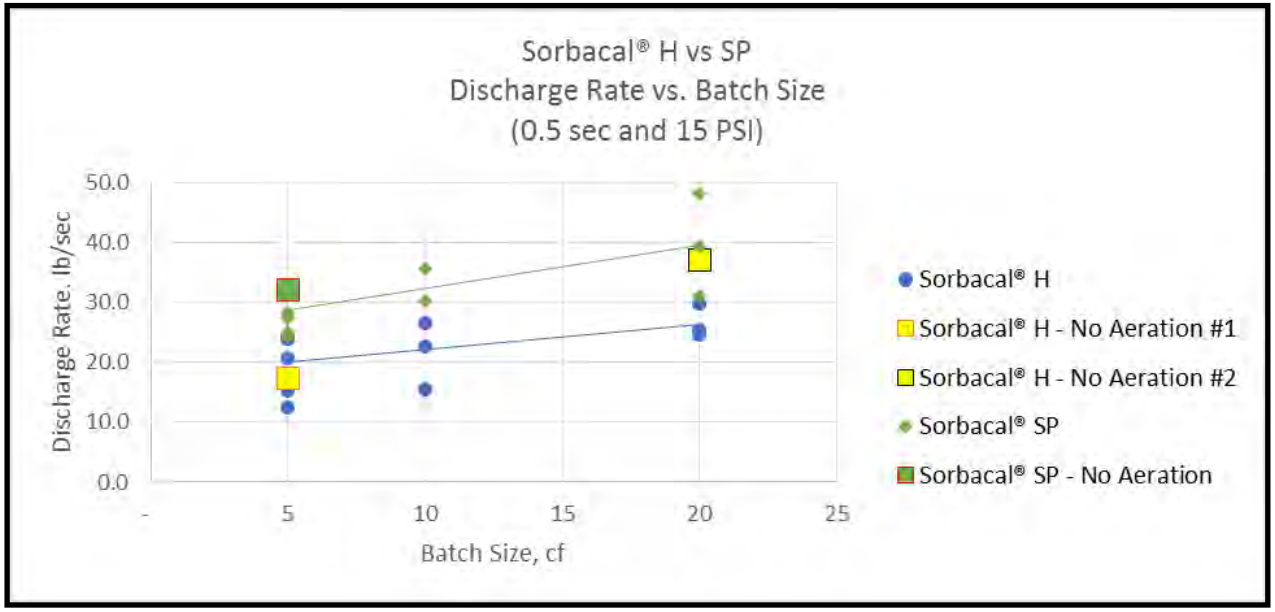


Figure 10: Opacity of West and East side ESP and steam flow. The circle represent a period without Sorbacal® SPS injection.

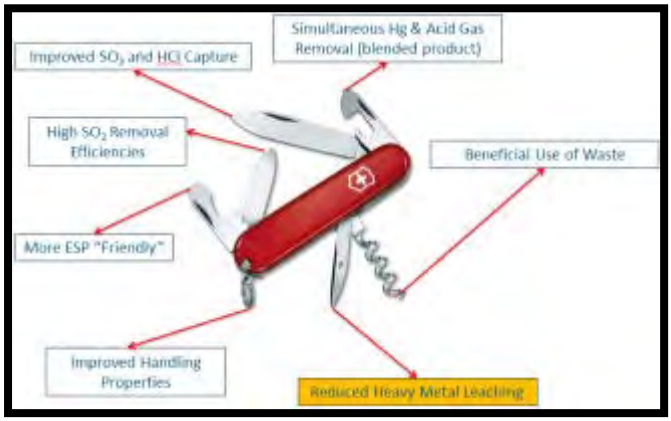
Improved Handling Properties



- Field observations indicated "better" handling with Sorbacal® SP/SPS than finer hydrated limes.
- Lab and pilot testing performed to validate field observations.
- Physical properties dictate handling properties.
- Better handling properties → less O&M → less $.



Reduced Heavy Metal Leaching



- Calcium based reagents stabilize heavy metals in fly ash / residue via pozzolonic reactions.
- Even ash laden with high calcium content (i.e. PRB coal) can mitigate leaching from sodium sorbent injection.
- Leaching of metals could classify residue/ash as hazardous waste ($$$).
- Total dissolved solids will increase with DSI but the $TDS_{CALCIUM} << TDS_{SODIUM}$

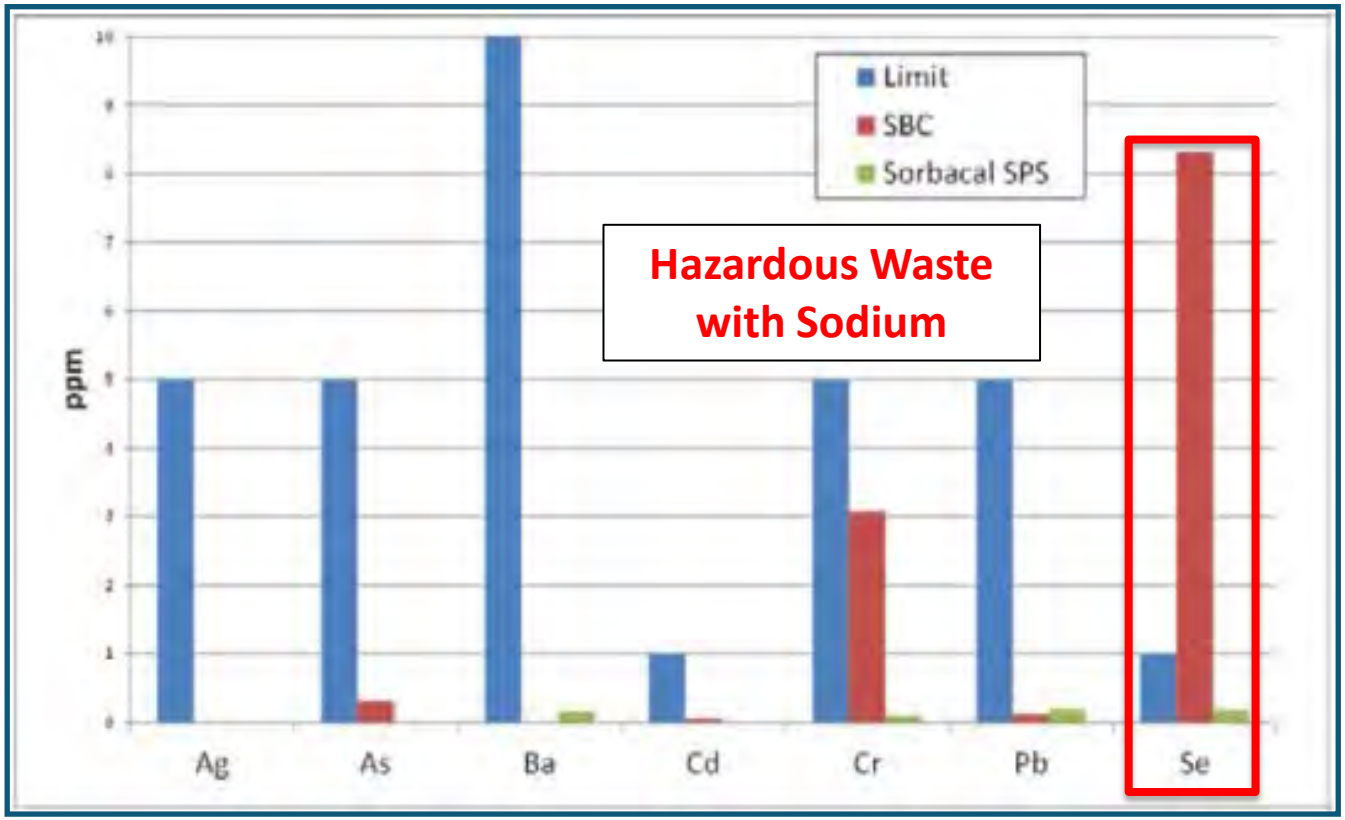
Heavy Metal	RCRA Limits	Baseline Fly Ash	SPS Residue	SBC Residue
Ag	5	<0.01	<0.01	<0.01
As	5	0.11	<0.02	0.04
Ba	100	2.00	7.27	0.32
Cd	1	<0.01	<0.01	<0.01
Cr	5	0.20	0.17	0.04
Pb	5	0.02	0.04	0.03
Se	1	0.18	<0.02	0.15
Total Dissolved Solids (mg/L)	-	960	4,161	26,899

Higher TDS with Sodium Sorbent

Schantz, M.; "The Relative Impacts of the use of Calcium and Sodium Dry Sorbent Injection (DSI) Reagents"; WOCA; 2017.

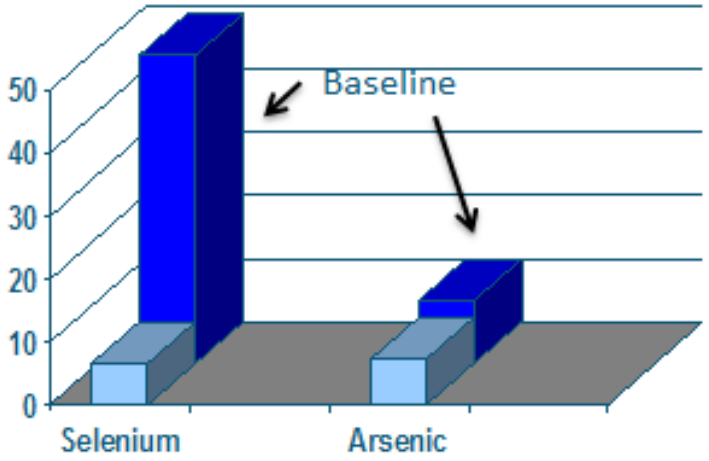
Reduced Heavy Metal Leaching

- Industrial site was injecting sodium bicarbonate for SO_2 and HCl control (still had to inject Sorbacal® SP for HF control)
- Site converted to only Sorbacal® SPS for SO_2, HCl and HF capture
- Residue was hazardous waste with sodium bicarbonate but non-hazardous with Sorbacal® SPS and disposal costs ↓ by order of magnitude

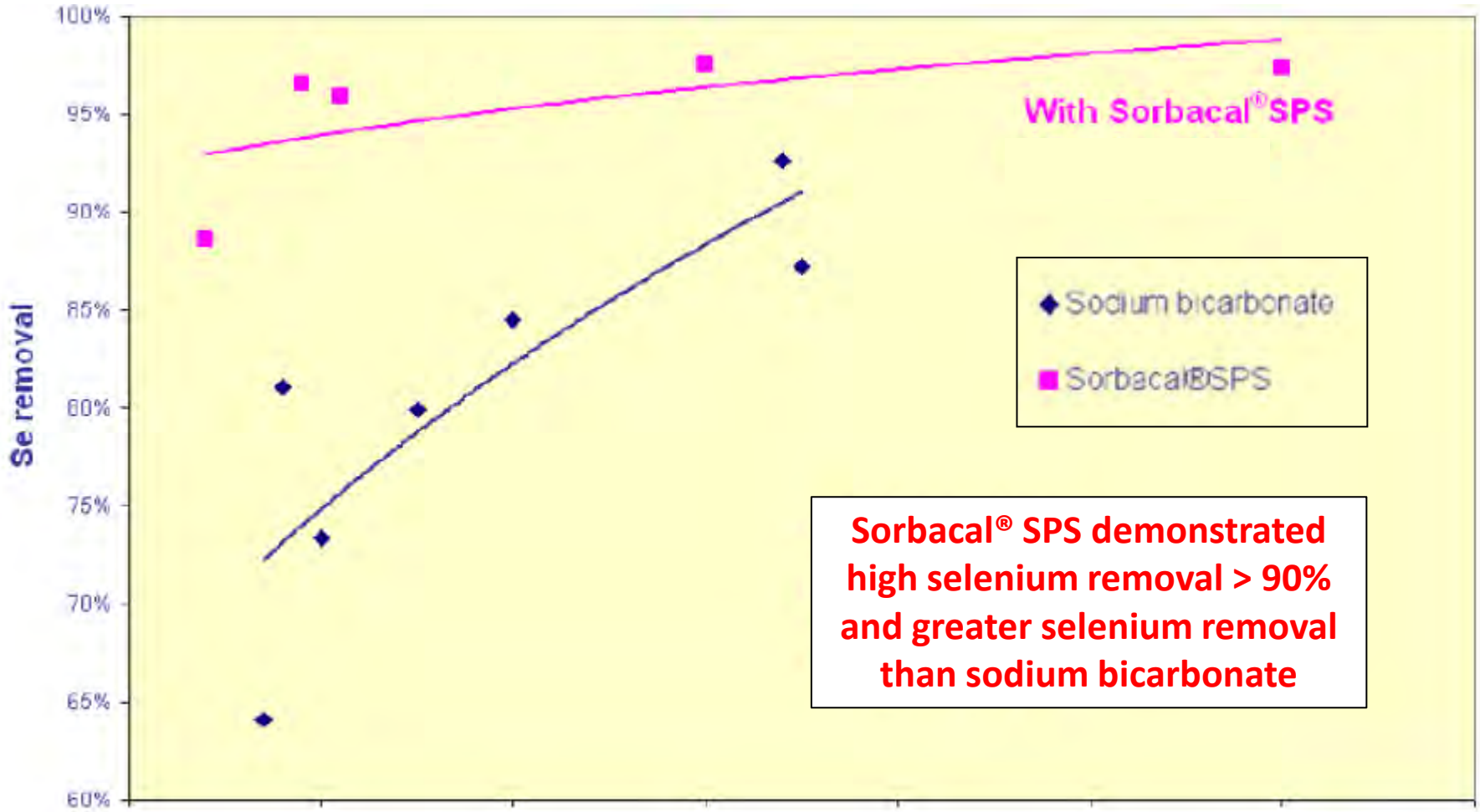


Reduced Selenium Emissions

- Selenium in flue gas gets collected in FGD liquor and requires treatment.
- Selenium can be removed upstream of WFGD via DSI and ESP/Baghouse.
- Testing using showed > 80% selenium capture from flue gas with Sorbacal.
- More data expected in near future due to growing interest to evaluate selenium removal upstream of WFGD.



Reduced Selenium Emissions

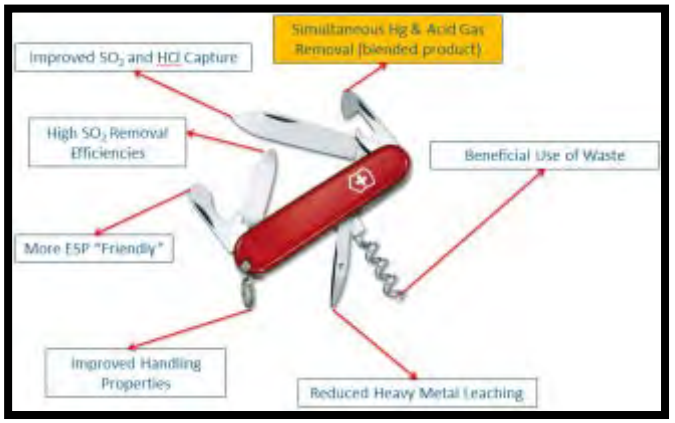


Beneficial Use of Waste

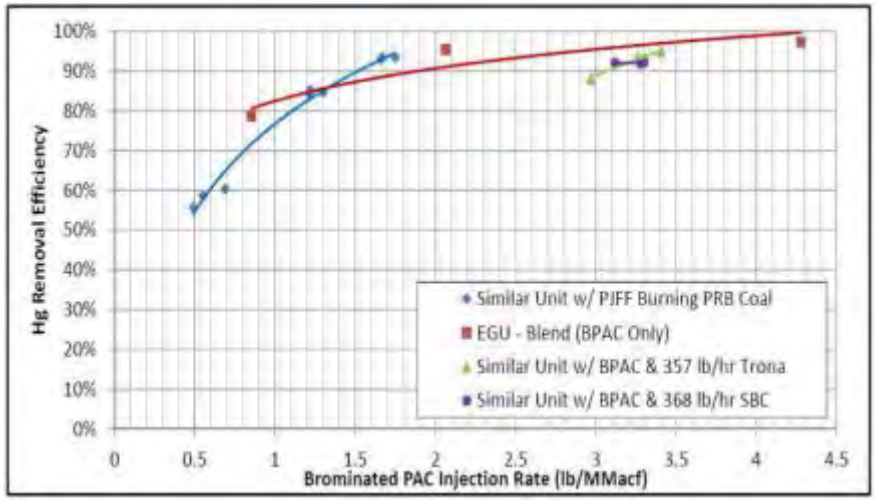
- Calcium based reagents have potential for beneficial use of residue / fly ash.
- DSI HCl and SO_3 applications may still allow ash to be suitable for cement.
- DSI SO_2 applications may require new/different beneficial uses.
- Potential applications include soil stabilization, mine reclamation, waste solidification, synthetic aggregates, agriculture applications, etc.
- Finding a beneficial use of residue / fly ash could significantly impact the lowest total cost of ownership solution.

Minkara, R; "Fly Ash Sustainability, the Impact of Sorbent Injection"; Orlando Air Quality Workshop; October, 2015.

Simultaneous Hg & Acid Gas Removal



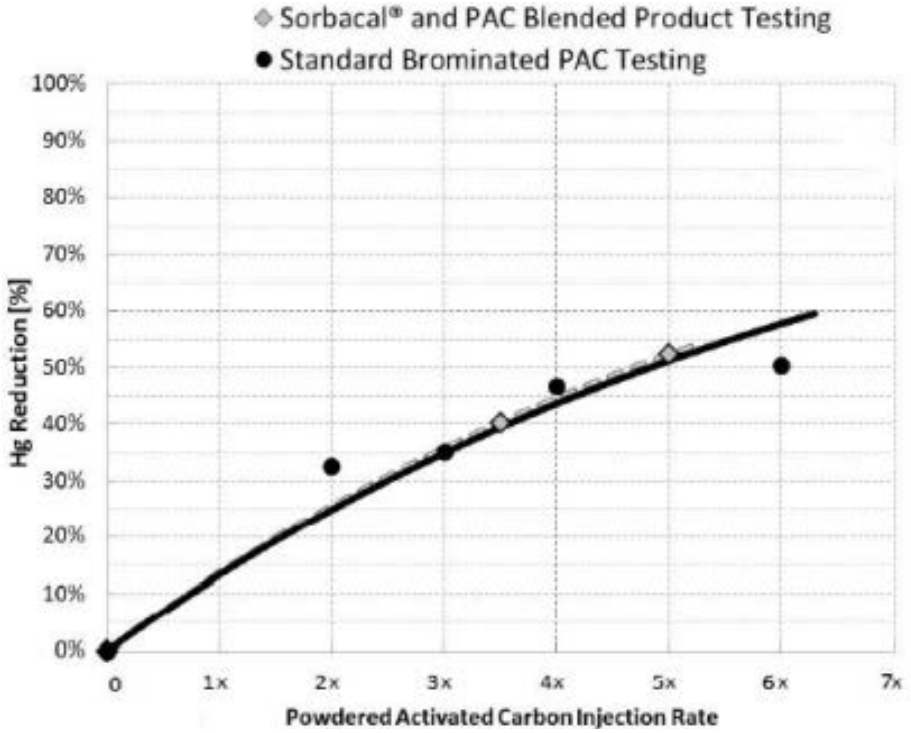
- **Sorbacal® SPS can be blended homogeneously with PAC.**
- **Single sorbent / single dosing system for reducing Hg and HCl/SO_2 emissions.**
  - **Capital $ savings**
- **Customize blend % based on best meeting desired Hg and acid gas emissions control.**
- **Utilities, cement plants, chemical manufacturing facilities, paper mills, etc.**



Dickerman, J.; Hunt, G..; "Simultaneous HCl and Hg Control with a Single Sorbent and DSI System"; Reinhold APC Conference; July, 2015.

Simultaneous Hg & Acid Gas Removal

- **Cement plant evaluating blended product for simultaneous HCl and Hg removal**
- **Comparing against ACI data to evaluate Hg removal performance**
- **HCl compliance achieved and comparable Hg removal achieved using Sorbacal SP/AC as solely PAC**



Ciro, W.; Sewell, M.; Dillon, M.; "Simple and Cost Effective NESHAP Compliance"; World Cement Magazine; October, 2016.

Thanks for your time…

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