EMO®

August 1, 2013

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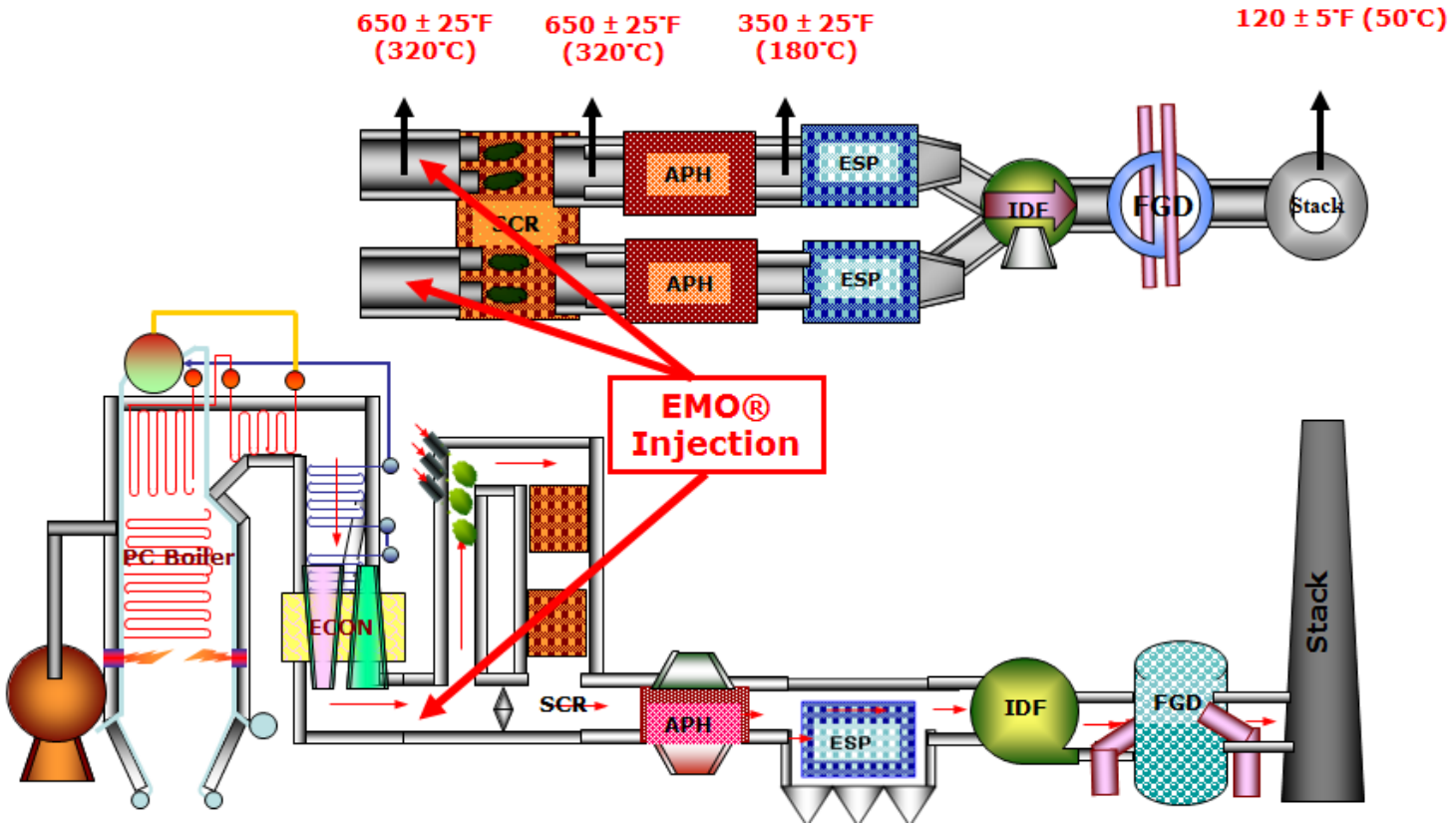
Client Program Manager

MATS Overview

Subcategory	Total Filterable Particulate Matter **(PM)**	Hydrogen Chloride **(HCl)**	Mercury **(Hg)**
Existing coal-fired unit designed for coal **> 8,300** Btu/lb	**0.030** lb/MMBtu (**0.30** lb/MWh)	**0.0020** lb/MMBtu (**0.020** lb/MWh)	**1.2** lb/TBtu (**0.010** lb/GWh)
Existing coal-fired unit designed for coal **< 8,300** Btu/lb	**0.030** lb/MMBtu (**0.30** lb/MWh)	**0.0020** lb/MMBtu (**0.020** lb/MWh)	**4.0** lb/TBtu (**0.040** lb/GWh)

- Mercury and Air Toxics Standard (MATS) published on 2/16/2012, which became effective 60 days later. Compliance needs to be demonstrated by the 1st quarter of 2015
- Final PM limit for Filterable PM only (per EPA Method 5)
- Use of the alternate SO_2 limit is not allowed if EGU does not have some form of FGD system and SO_2 CEMS installed.
- Where alternate limits are designated with "or" in Table 2 Section 1 of MATS, these pollutants may be used in lieu of pollutants listed in same subsection (e.g. Total non-HAPs may be used in lieu of Filterable PM).
- The Hg limit is **based on a 30-day boiler operations rolling average**

EMO® Injection General Arrangements



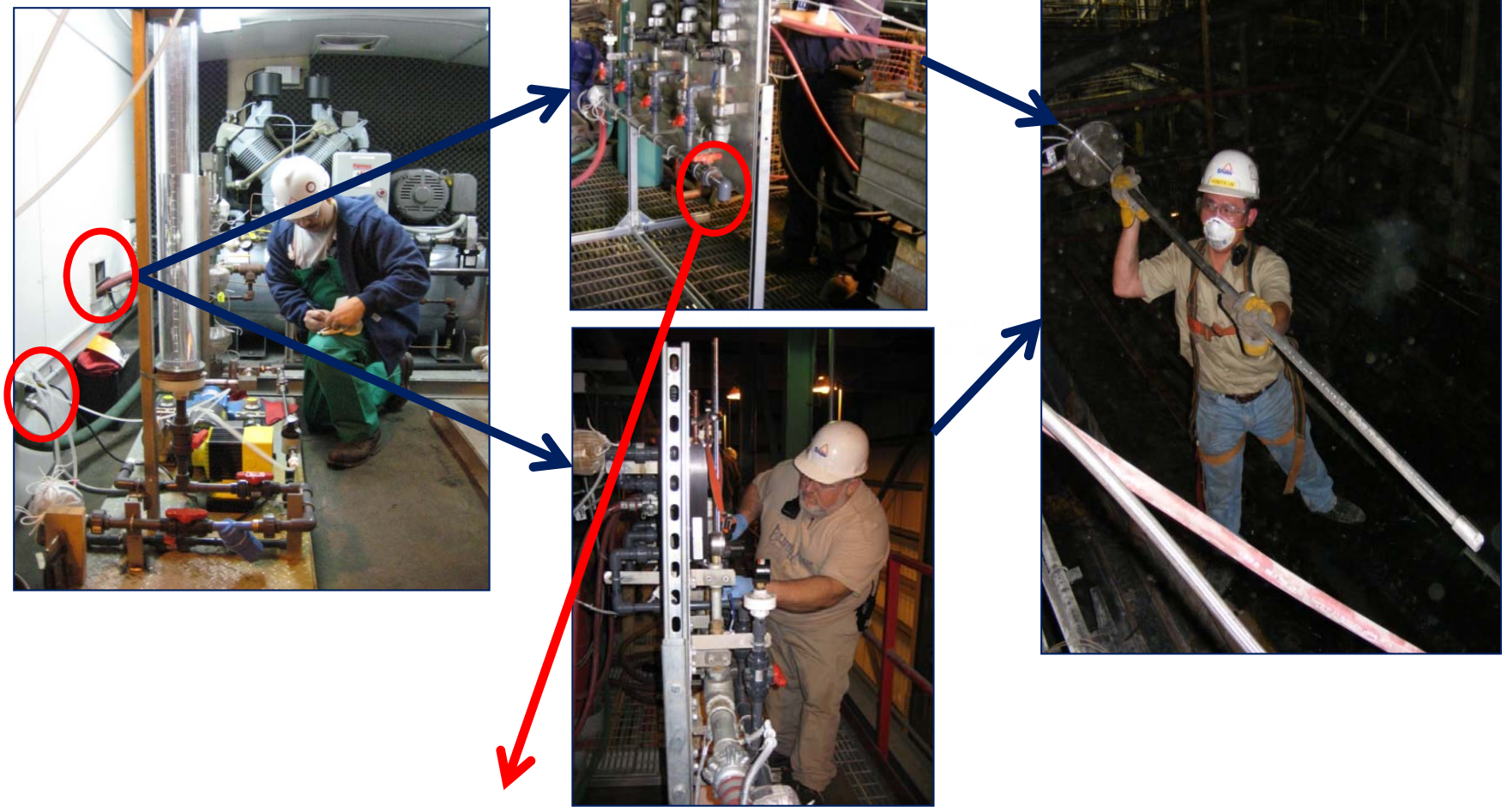
- Injecting chemical: EMO® chemical additives

  Mercury Oxidization: **Hg(0)** → **$Hg^{(2+)}$**

  Mercury Absorption/Adsorption: in the existing PCD and scrubber

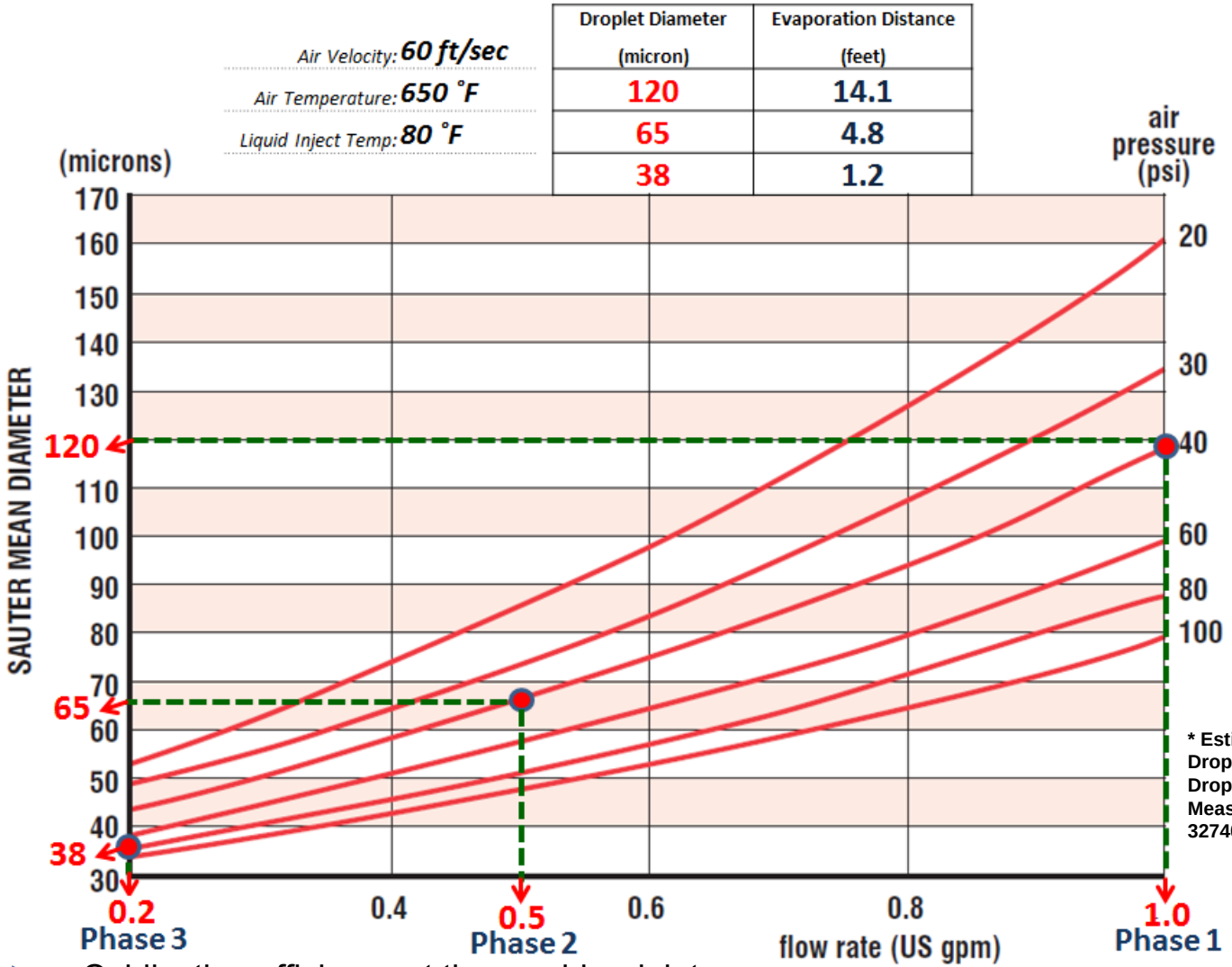
- Injection location and temperature: Economizer outlet (**> 650**°F) or PCD outlet (**320**°F)

EMO® Injection General Arrangements



- the **X** ppmv of EMO® injection rate was precisely determined by direct sample titration

Flue Gas Flow Analysis

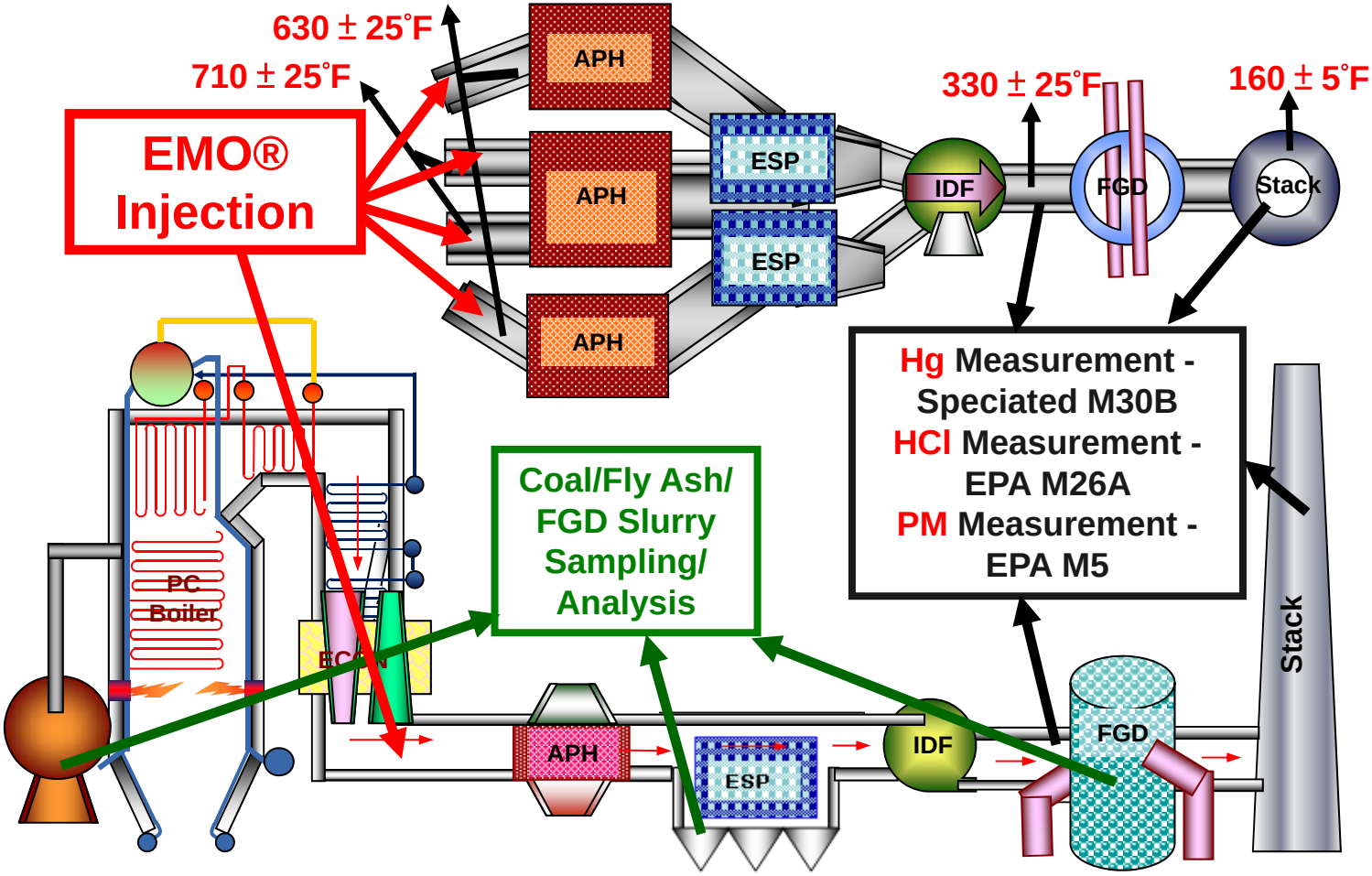


- Oxidization efficiency at the scrubber inlet:

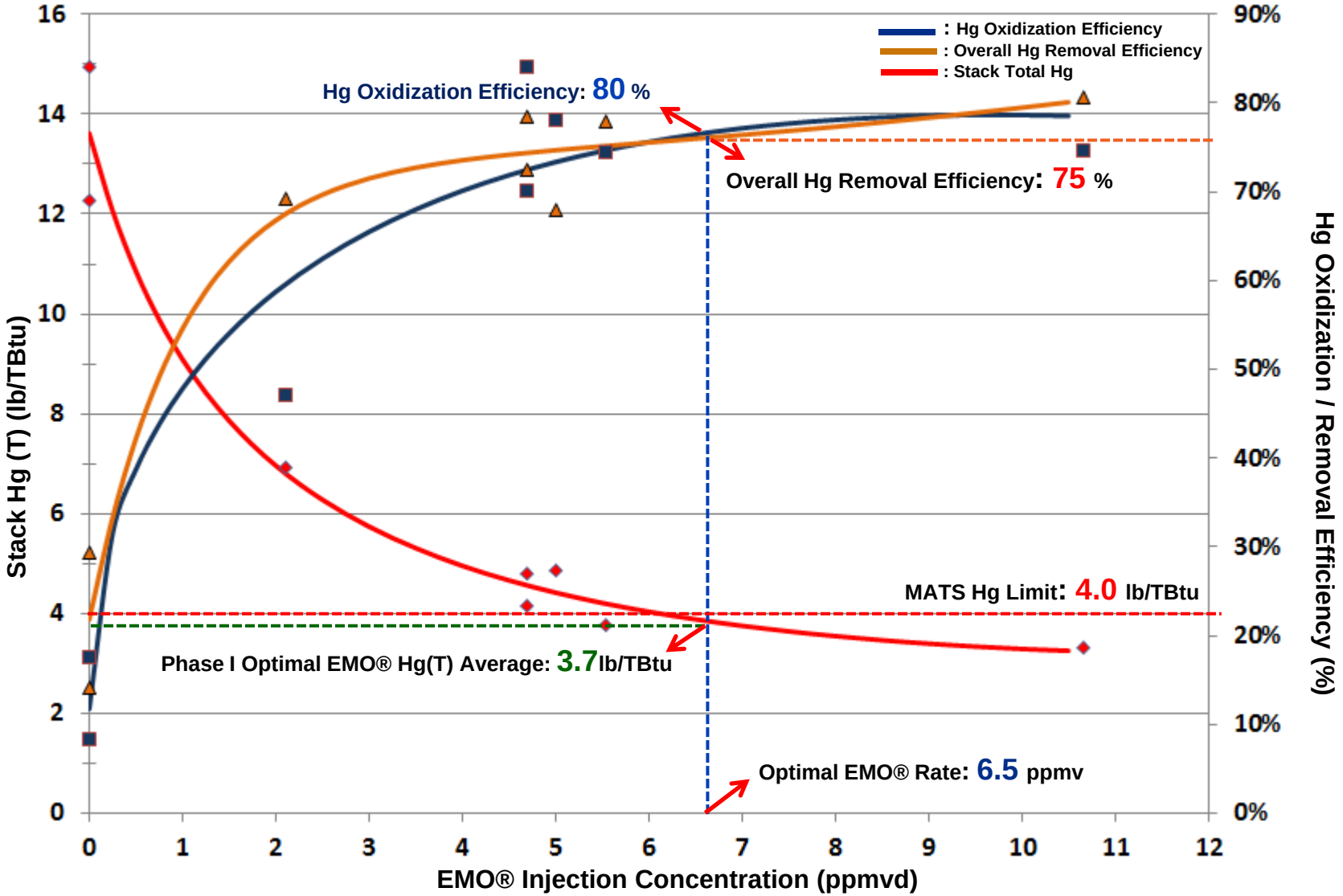
Phase 3: **98**%; Phase 2: **88**%; Phase 1: **80**%;

Reference Unit 1 Testing Arrangement

- 440 MW, ESP +FGD, 100% Lignite

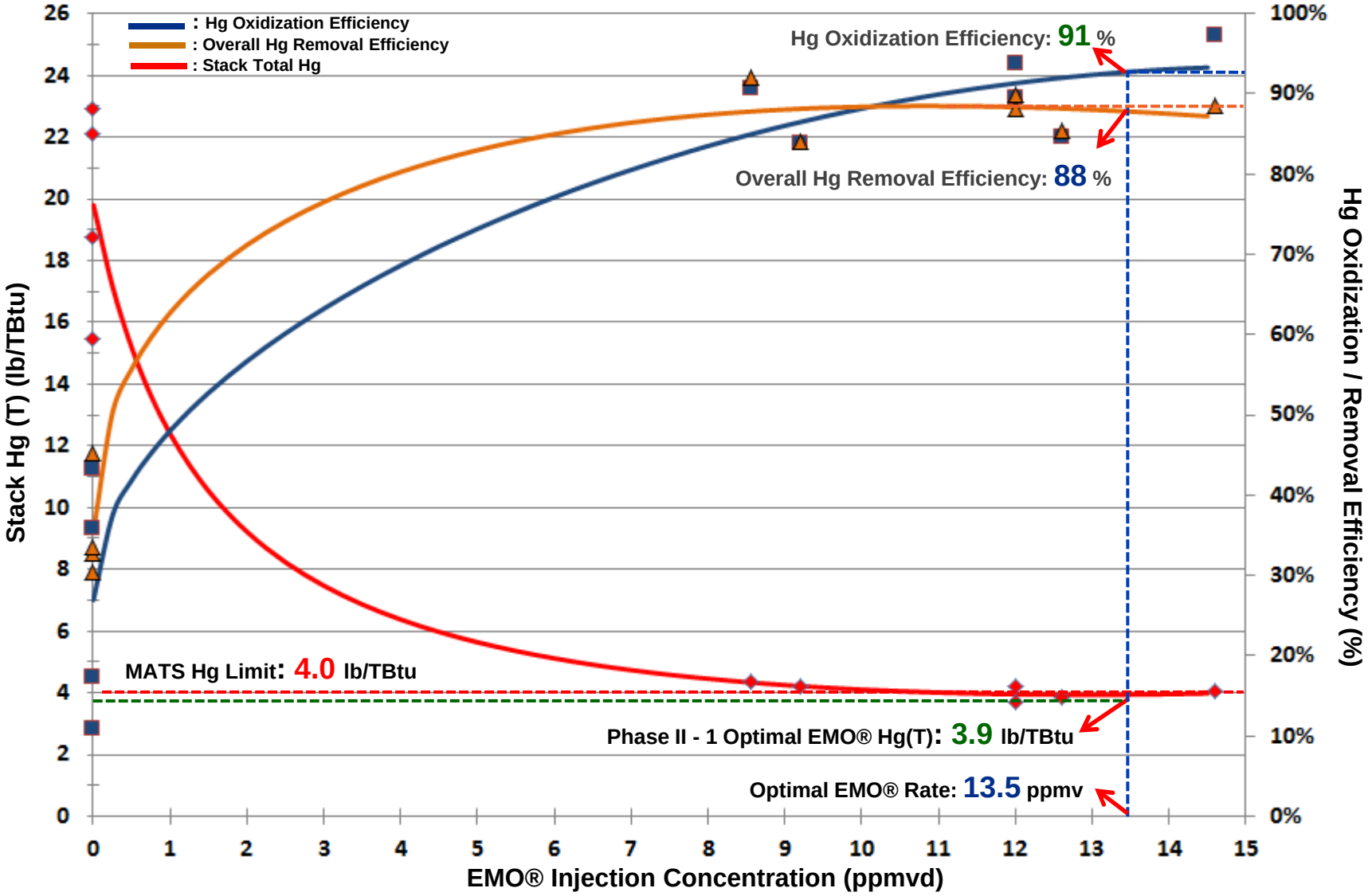


EMO® Phase I Overview (11/14/2011-11/17/2011)



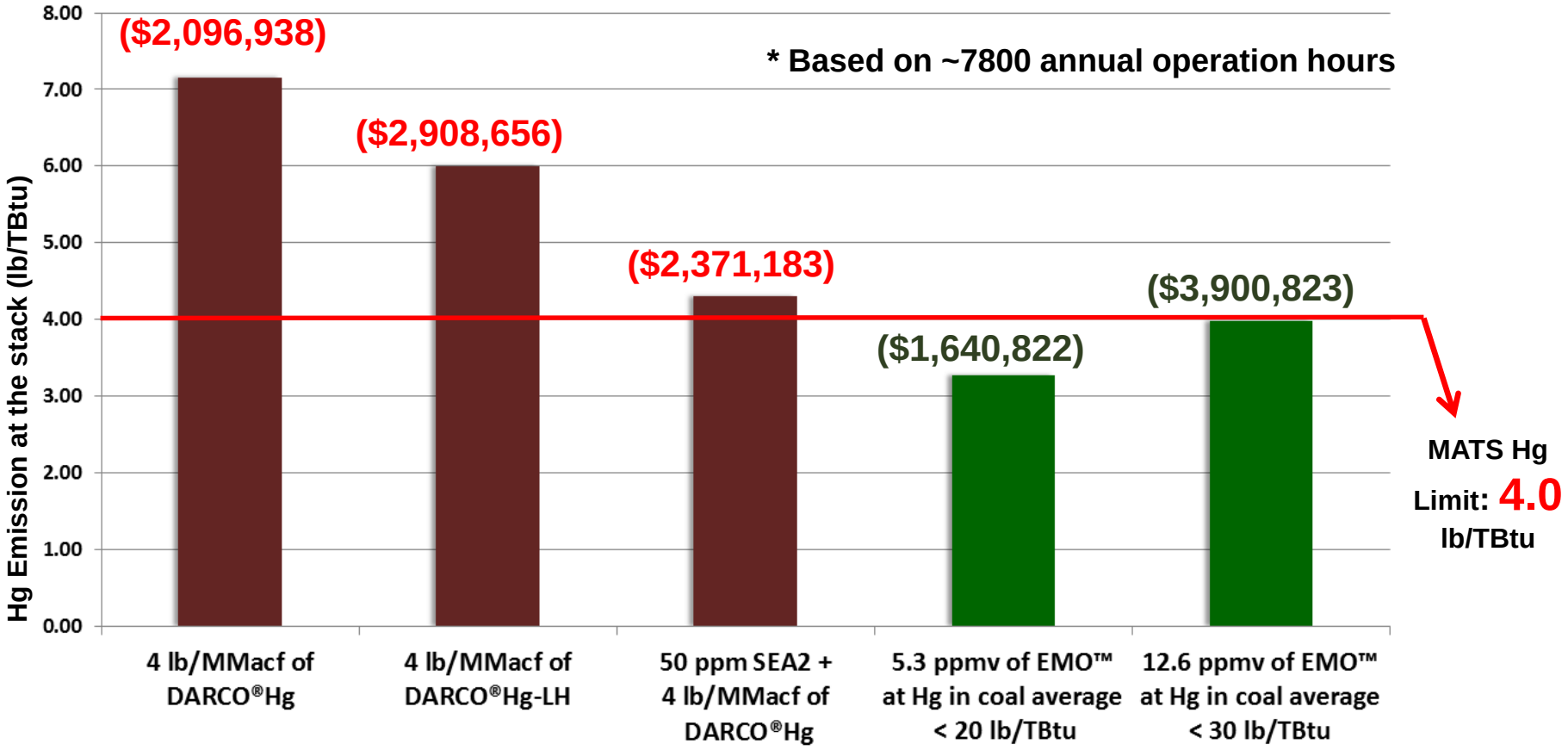
- Hg content in coal varied between **15.1** and **22.4** lb/TBtu, averaged at **18.0** lb/TBtu

EMO® Phase II Overview (5/22/2012 – 6/12/2012)



- Hg content in coal varied between **26.6** and **54.1** lb/TBtu, averaged at **33.7** lb/TBtu, Phase 1: **18.0** lb/TBtu

Reference Unit 1 Economics Analysis



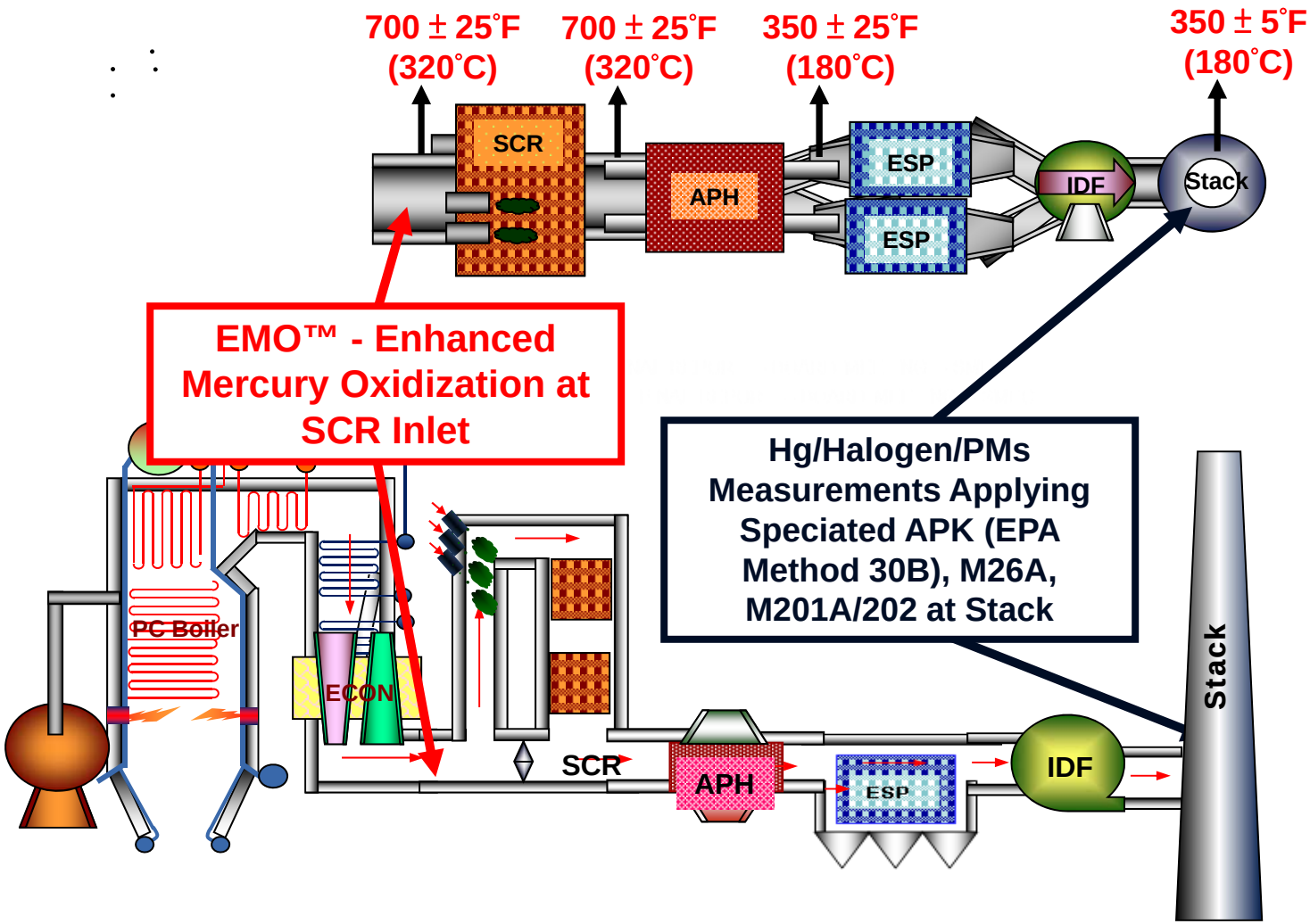
- The cost estimates for **the first 3 non-EMO™ injection options** were based on Hg Content in coal **~20** lb/TBtu. **None of them demonstrated MATS compliance!**

Stack Visible blue plum – SO_3 Interferences

- From various CB&I EMO field trial, SO3 has been observed to inhabit Hg oxidization Hg2+ adsorption across the ESP, and Hg2+ absorption across the FGD

SO_3 Interferences on Hg - Unit 1 ESP

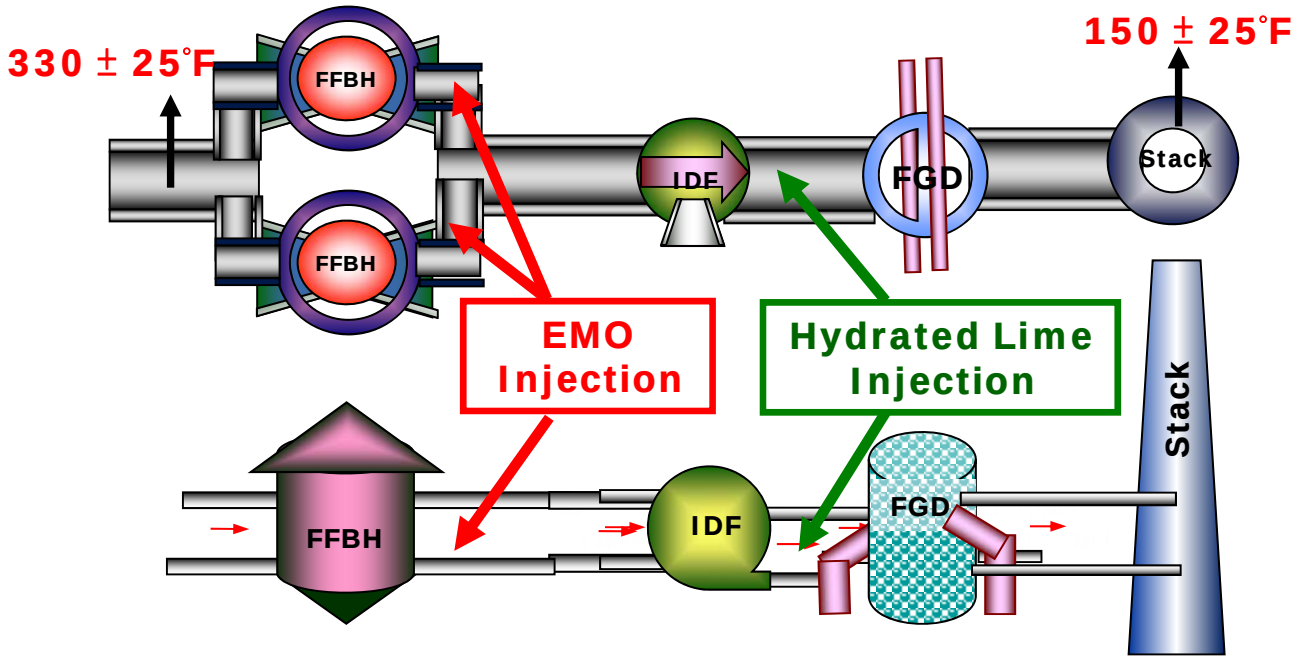
Unit Configuration: 320 MW burning 100% PRB. SCR + CESP



SO_3 Interferences on Hg - Unit 1 ESP

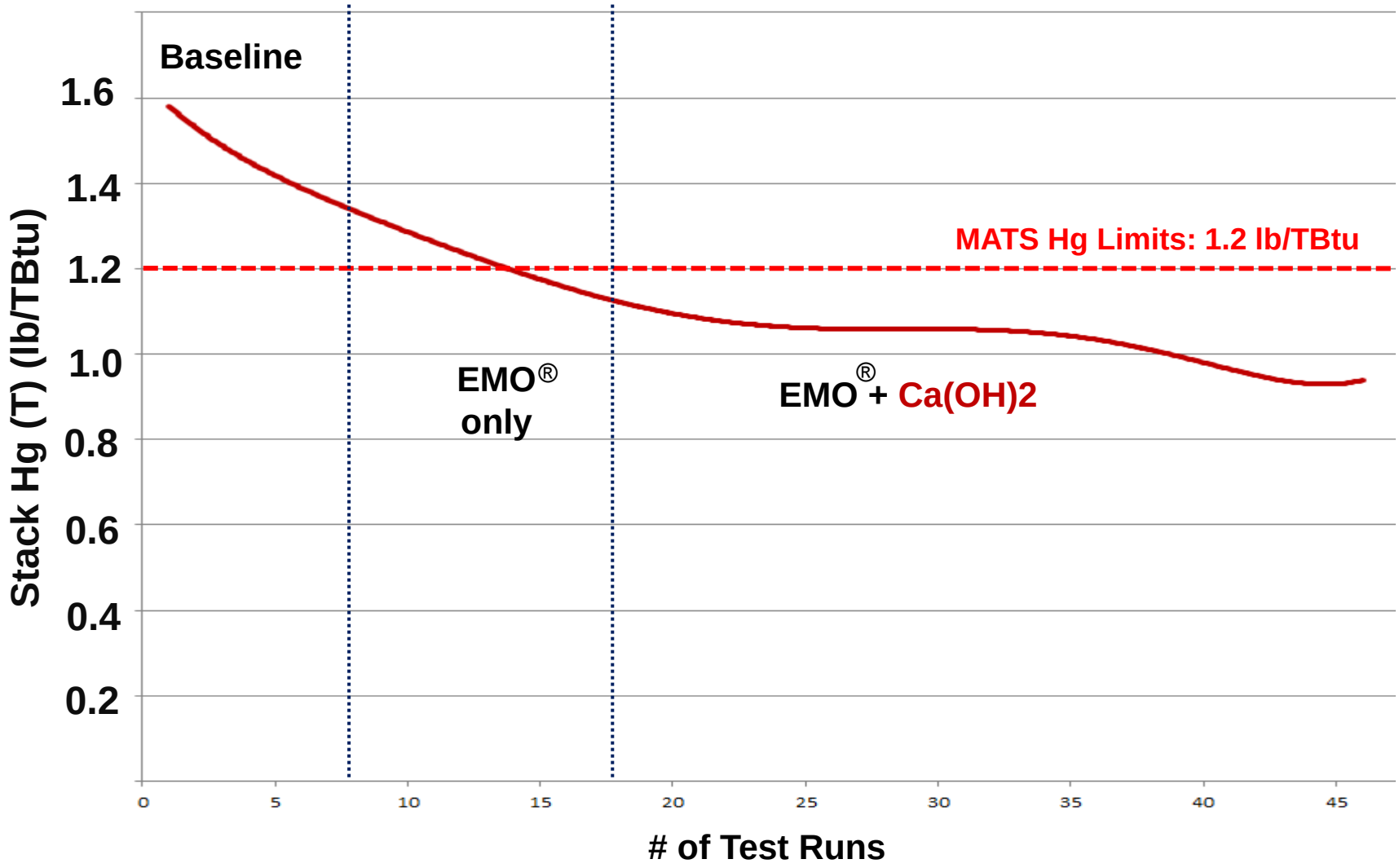
Date	Unit Load	Max. Hg From PRB	EMO™ Injection Rate	PAC Injection Rate	SO3 Injection Rate	NH3 Injection Rate	Stack Hg	Stack Hg	Hg Oxidization at Stack	Overall Hg Removal	NOx	Opacity
mm/dd/yy	(MW)	(lb/TBtu)	(ppmvd)	(lb/mmacf)	(ppmvd)	(lb/hr)	(lb/TBtu)	(lb/GWh)	(%)	(%)	(lb/MMBtu)	(%)
5/2/11	329	7.8	0.0	0	4	223	3.20	0.03122	59.0%	59.0%	0.044	23.9
	329	7.8	0.0	0	4	216	3.40	0.03317	56.4%	56.4%	0.042	23.7
5/3/11	338	11.3	7.6	0	4	232	0.91	0.00888	93.1%	91.9%	0.043	19.0
	338	11.1	5.2	0	0	236	0.77	0.00751	94.5%	93.1%	0.045	17.4
	338	11.3	10.1	0	0	250	0.65	0.00634	95.8%	94.2%	0.045	15.0
5/4/11	348	6.0	4.3	0	0	252	0.50	0.00488	93.1%	91.6%	0.045	17.0
	317	6.0	7.5	0	0	214	0.56	0.00546	93.1%	90.6%	0.045	16.2
5/5/11	342	7.2	3.3	0	0	230	0.78	0.00761	91.3%	89.1%	0.047	20.8
	342	7.2	2.5	0	0	233	1.15	0.01122	85.6%	83.9%	0.046	21.8
5/6/11	345	5.0	5.3	0	0	252	0.43	0.00420	91.4%	91.4%	0.047	20.4
	346	5.0	4.8	0	0	249	0.47	0.00459	90.6%	90.6%	0.048	21.0
5/6/11	315	5.0	4.8	0	0	207	0.38	0.00371	92.8%	92.4%	0.048	16.8
5/7/11	346	7.0	6.0	0	0	226	0.78	0.00761	89.1%	88.9%	0.047	22.0
	341	7.0	5.2	0	0	225	1.04	0.01015	85.7%	85.1%	0.046	26.4
5/8/11	204	6.6	4.9	0	0	142	0.74	0.00722	92.4%	88.8%	0.039	6.3
	204	6.6	5.3	0	0	141	0.34	0.00332	97.4%	94.8%	0.038	5.6
5/9/11	340	8.9	6.6	0	4	207	1.52	0.01483	84.2%	83.0%	0.048	21.6
	340	8.9	8.1	0	4	201	2.02	0.01971	78.9%	77.4%	0.050	25.2
	341	8.9	6.1	0	4	207	2.06	0.02010	77.7%	77.0%	0.051	24.1
5/10/11	281	10.1	6.7	0	6	160	1.36	0.01327	87.0%	86.5%	0.048	15.7
	341	10.1	12.9	0	0	201	1.76	0.01717	83.3%	82.6%	0.048	25.5
5/11/11	299	7.4	13.6	0	0	158	0.73	0.00712	90.2%	90.2%	0.047	15.8
	299	7.4	13.2	0	0	171	0.67	0.00654	91.1%	90.9%	0.047	14.3
5/11/11	335	7.4	12.9	0	0	187	1.40	0.01366	82.7%	81.1%	0.051	23.1
	339	7.4	9.7	2	0	205	0.60	0.00585	94.1%	91.9%	0.051	26.2
5/12/11	338	9.6	0.0	10	4	194	0.58	0.00566	95.8%	94.0%	0.048	24.5
	324	9.6	0.0	10	4	185	0.59	0.00576	95.6%	93.9%	0.048	26.1

SO_3 Interferences on Hg - Unit 2 FGD – Phase 1

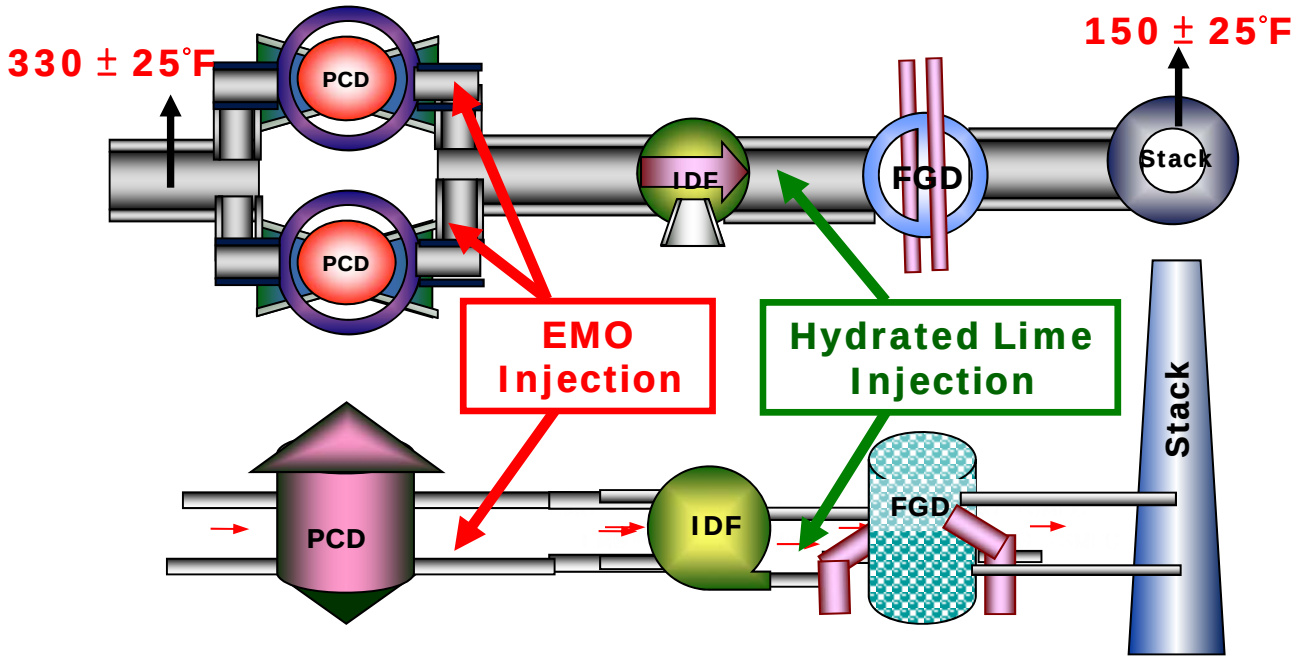


- ✓ Hg in coal: 10 lb/TBtu, Sulfur in coal: 3.5%, Stack SO_3 was visible – more than 20 ppmv
- ✓ Baseline stack Hg (T): **1.5 lb/TBtu,**
- ✓ **3.0** ppmv of EMO at FFBH outlet, Hg (T): **1.1 lb/TBtu**
- ✓ Hydrated Lime was injected 60’ downstream of the EMO injection, the main purpose was for SO3 mitigation
- ✓ **1.5** ppmv of EMO at the FFBH outlet and **800** lb/hr of HL at the ID outlet Hg (T): **0.9 lb/TBtu, $458K/year**

SO_3 Interferences on Hg - Unit 2 FGD - Phase 1

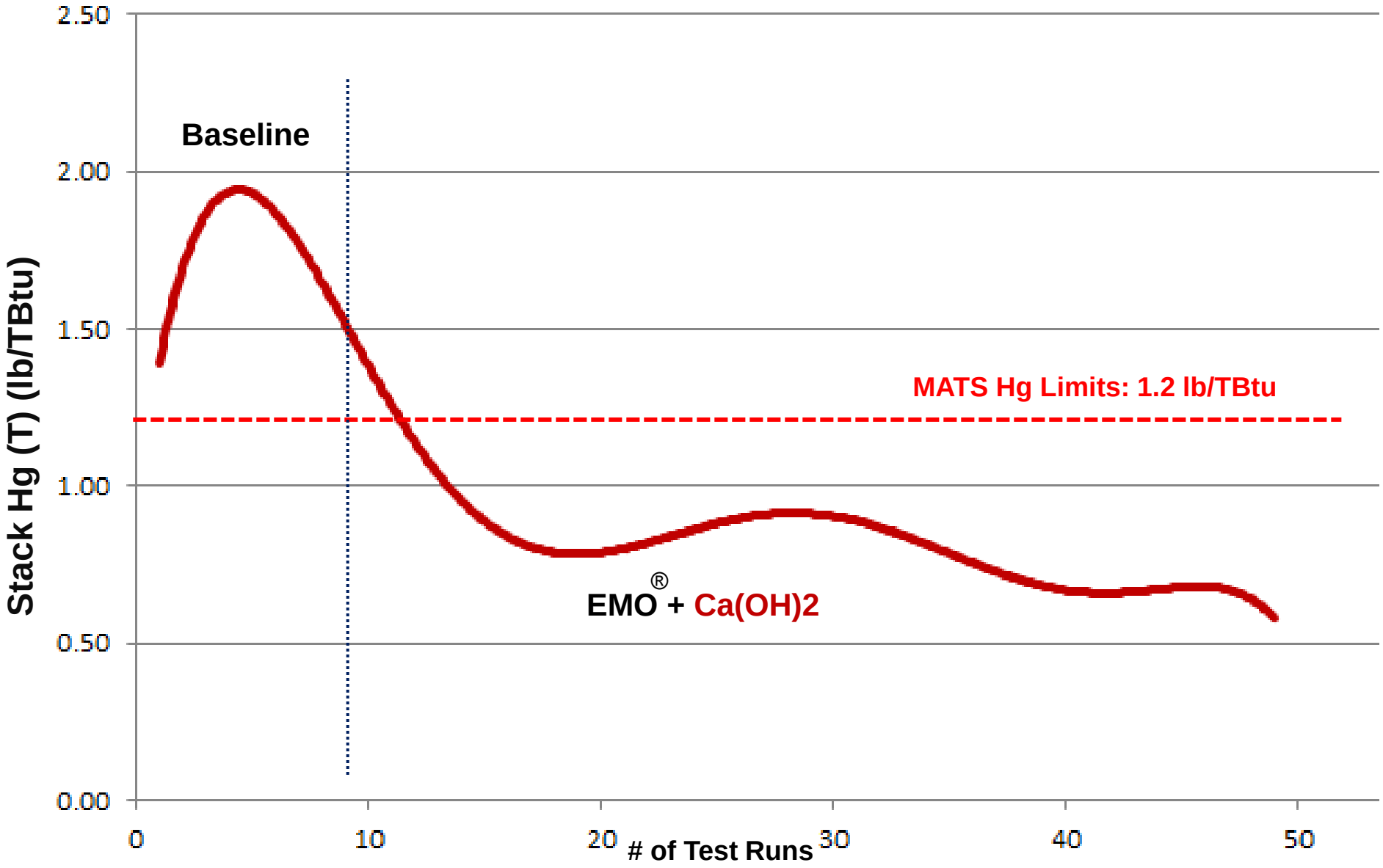


SO_3 Interferences on Hg - Unit 2 FGD - Phase 2

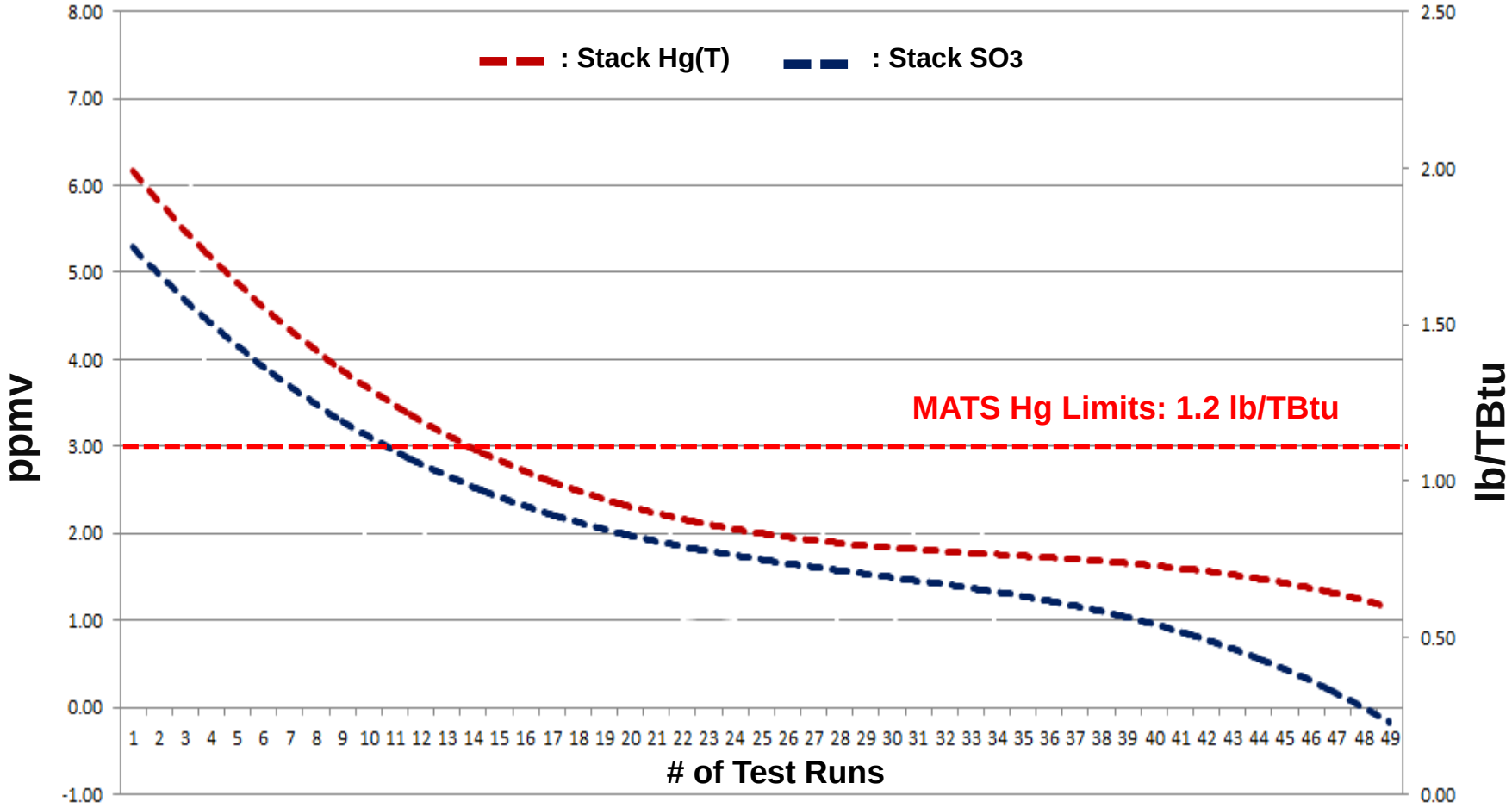


- ✓ Hg in coal: 10 lb/TBtu, Sulfur in coal: 3.5%, Stack SO_3 was visible – more than 20 ppmv
- ✓ Baseline stack Hg (T): **1.8 lb/TBtu,**
- ✓ Hydrated Lime was injected 60' downstream of the EMO injection, the main purpose was for SO_3 mitigation
- ✓ **1.5** ppmv of EMO at the FFBH outlet and **800** lb/hr of HL at the ID outlet Hg (T): **0.7 lb/TBtu ,$458K/year**

SO_3 Interferences on Hg - Unit 2 FGD - Phase 2



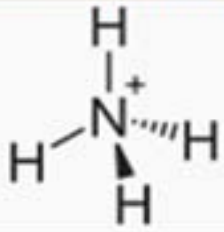
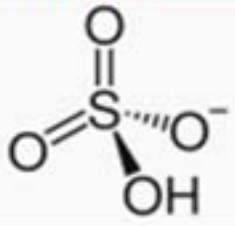
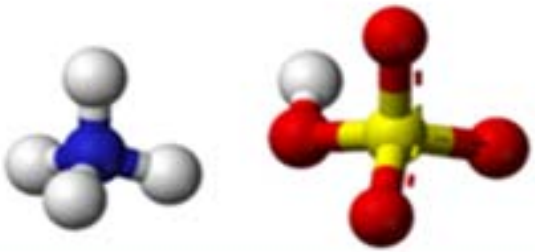
SO_3 Interferences vs. Stack Hg



- ✓ The Ca(OH)2 injection has been varied to keep the Stack SO3 < 3 ppmv
- ✓ EMO injection has been kept at 1.5 ppmv on average throughout the entire project, **$458K/year**

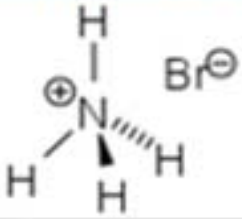
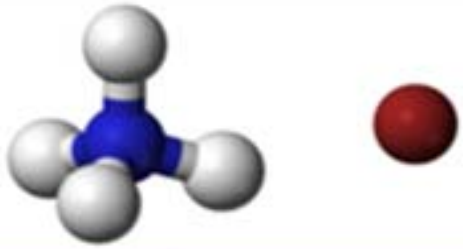
EMO's Co-benefit for Reducing ABS across APH

Ammonium bisulfate

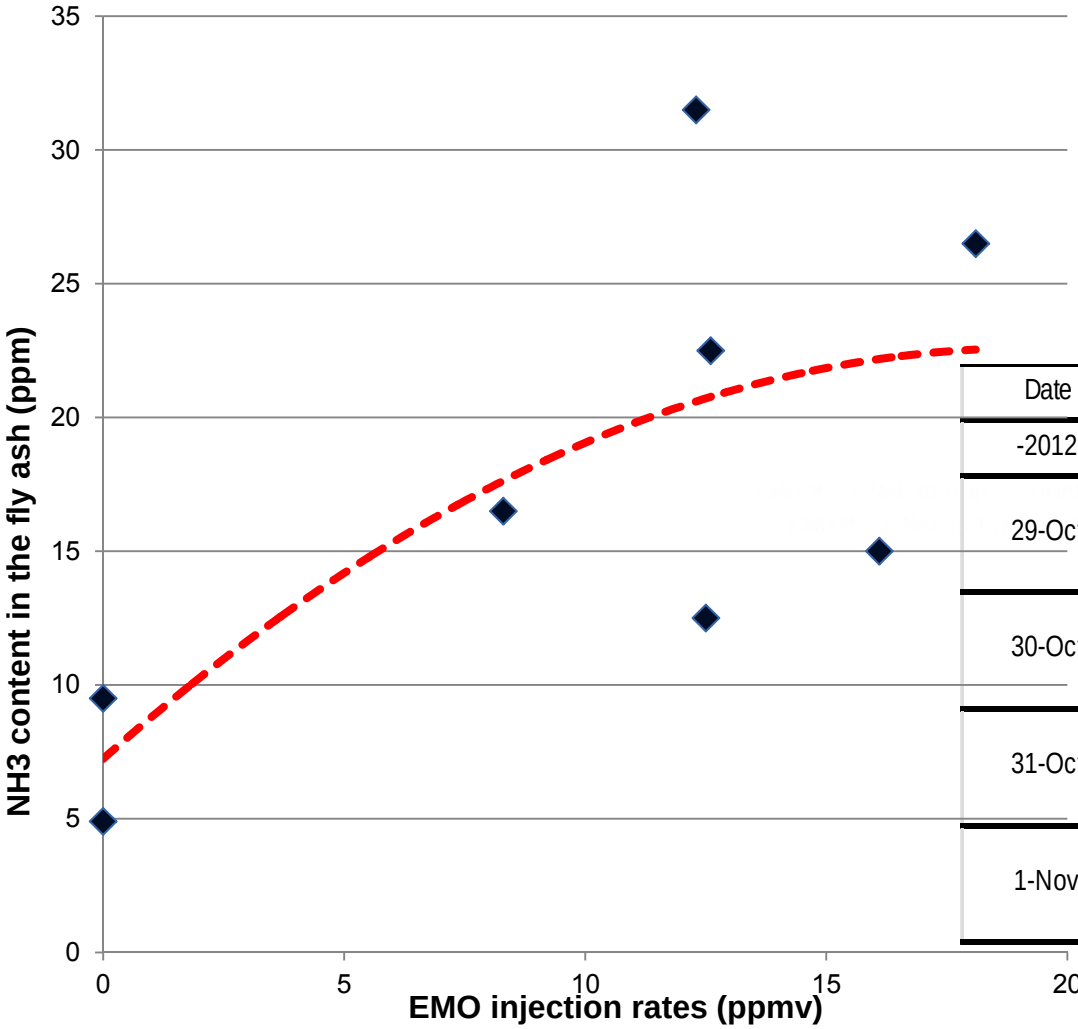
Properties	
Molecular formula	$(NH_4)HSO_4$
Molar mass	115.11 g/mol
Appearance	White solid
Density	1.78 g/cm^3
Melting point	147 °C, 420 K 297 °F
Solubility in water	Very soluble
Solubility in other solvents	Soluble in methanol insoluble in acetone

Ammonium bromide

Properties	
Molecular formula	NH_4Br
Molar mass	97.94 g/mol
Appearance	white powder, hygroscopic
Density	2.429 g/cm^3
Melting point	452 °C, 725 K 846 °F
Solubility in water	60.6 g/100 mL (0 °C) 78.3 g/100 mL (25 °C) 145 g/100 mL (100 °C)
Refractive index (n_D)	1.712

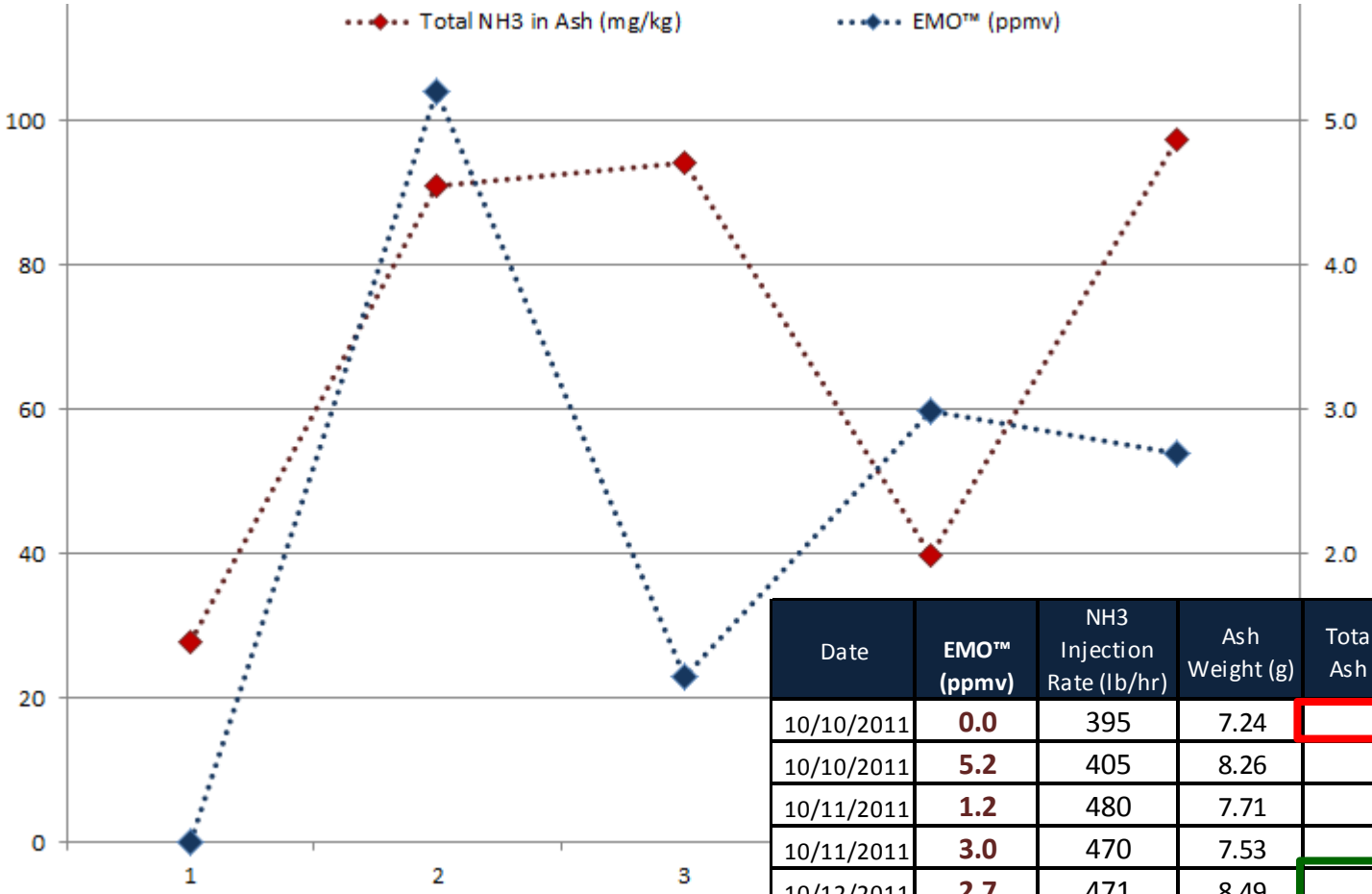
EMO's Co-benefit for Reducing ABS across APH



Date	Run	Condition	EMO Dose	NH_3
-2012			ppmv	mg/kg
29-Oct	1	Baseline	0	9.5
	2	Baseline	0	4.9
30-Oct	1	Parametric	8.3	16.5
	2	Parametric	16.1	15
31-Oct	1	Parametric	12.5	12.5
	2	Parametric	18.1	26.5
1-Nov	1	Optimal	12.3	31.5
	2	Optimal	12.6	22.5

- Ammonia (NH_3) content of fly ash increased concurrent with EMO injections. At **12.4** ppmv of EMO injection, the NH3 in the fly ash was observed to increase by **200%**

EMO's Co-benefit for Reducing ABS across APH



Date	EMO™ (ppmv)	NH3 Injection Rate (lb/hr)	Ash Weight (g)	Total NH3 in Ash (mg/kg)	Slurry Cake Weight (g)	Total NH3 in Slurry (mg/kg)
10/10/2011	**0.0**	395	7.24	**28**	26.45	**3.71**
10/10/2011	**5.2**	405	8.26	**91**	26.15	**3.39**
10/11/2011	**1.2**	480	7.71	**94**	27.77	**3.43**
10/11/2011	**3.0**	470	7.53	**40**	26.79	**3.48**
10/12/2011	**2.7**	471	8.49	**97**	26.76	**3.13**

- As EMO™ increased, the total NH3 in ash increased, Baseline: **28** ppm; EMO Optimal: **97** ppm; increased by **246**%

Can Ca(Br)2 Produce the Same Results? Not Really

Sampling Date	Test Condition	Start Time	End Time	CaBr2 Target	EMO Target	Hydrogen Bromide		Relative Deviation	Hg Oxidization Efficiency	Stack Hg Removal Efficiency
						M26A FGD inlet	M26A Stack			
				ppm	ppmvd	ppmvd	ppmvd	%	%	%
7/12/2012	EMO - Baseline	9:00	10:00	0	0	0.18	0.10		17%	25%
7/12/2012	EMO - Baseline	11:15	12:15	0	0	0.09	0.10		6%	21%
7/12/2012	EMO Parametric	17:00	18:00	0	2.9	4.48	0.10	21%	54%	57%
7/13/2012	EMO Parametric	10:40	11:40	0	5.5	5.78	0.10	3%	71%	60%
7/16/2012	Trona - Baseline	8:00	9:00	260	0	3.27	0.10		61%	51%
7/16/2012	Trona - Baseline	9:30	10:30	260	0	3.47	0.10		61%	50%

✓ Blending **260** ppm of $Ca(Br)_2$ blending in coal requires 57 lb/hr $Ca(Br)_2$ (110 lb/hr of 52% Ca(Br)2 solution). This equates to 0.28 lb-mol of $Ca(Br)_2$, which generates **0.56** lb-mol available Br material in flue gas in the form of Br2 or HBr.

✓ For **3.3** ppmv EMO™ injection at 195 MW gross generation, it would require 23.1 lb/hr of HBr injection (48 lb/hr of 48% HBr solution). This equates to **0.29** lb-mol of HBr, which generates 0.29 lb-mol available Br in flue gas.

✓ Hence applying $Ca(Br)_2$ could put approximately **50%** of the Br material to waste (**0.29** lb-mol **vs.** **0.56** lb-mol),

✓the difference in annual cost is approximately **$120K** for a 200 MW unit

✓HBr is a more effective material promoting Hg oxidization

Observations & Recommendations

- EMO® Injection successfully demonstrated Hg compliance to MATS **>90%** plus stack Hg oxidization efficiency), for **Lignite, Bituminous, & Sub-Bituminous**
- The flue gas SO_3 level has a direct negative impact on the Stack Hg control through ESP and FGD
- EMO® injection does not create impact for the fly ash beneficial use/disposal (No metal leaching issues observed)
- EMO reduced ABS formation across the APH to prevent plugging issues – **AS a means of neutralizing the NH3 slip to prevent the APH plugging**
- EMO® was proven to be **~70%** more cost-effective than PAC injection and **~50%** more cost-effective than other fuel halogen additives, such as Ca(Br2)

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