Gas Turbines: Sub 2 ppm NOx Compliance Challenges…CARB Update

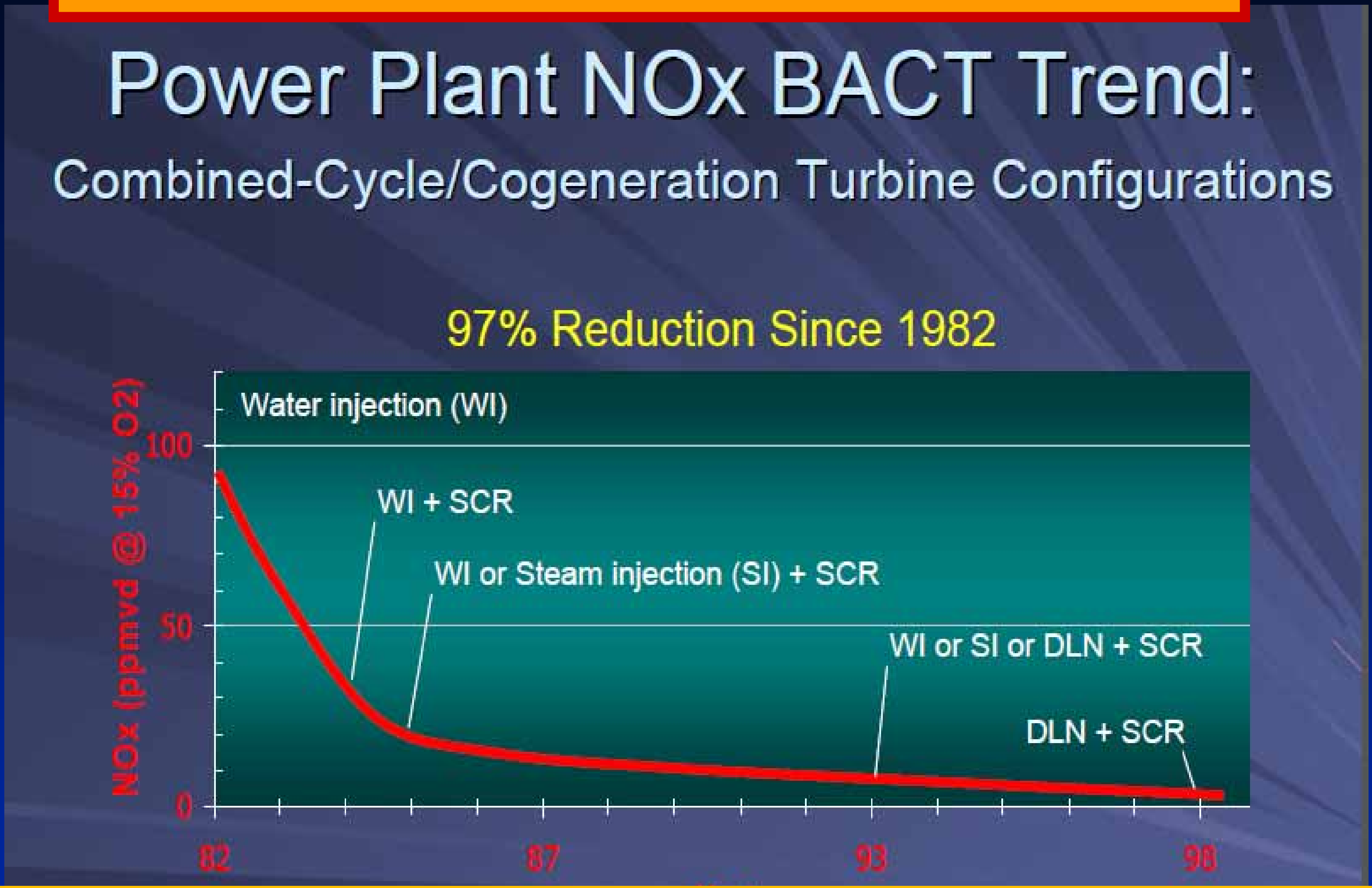
CEMTEK User Group Meeting
Costa Mesa, CA

Presented by Ben Sehgal
California Air Resources Board
September 2016

Objectives

- Comprehend gas turbine technological feasibility of sub 2ppm NOx Levels regulations and its national impact on BACT
- Identify compliance challenges to achieve <2ppm
- Distinguish the control efficiencies & operational parameters between SCR & CO catalysts
- Describe excess emissions and causes of failure

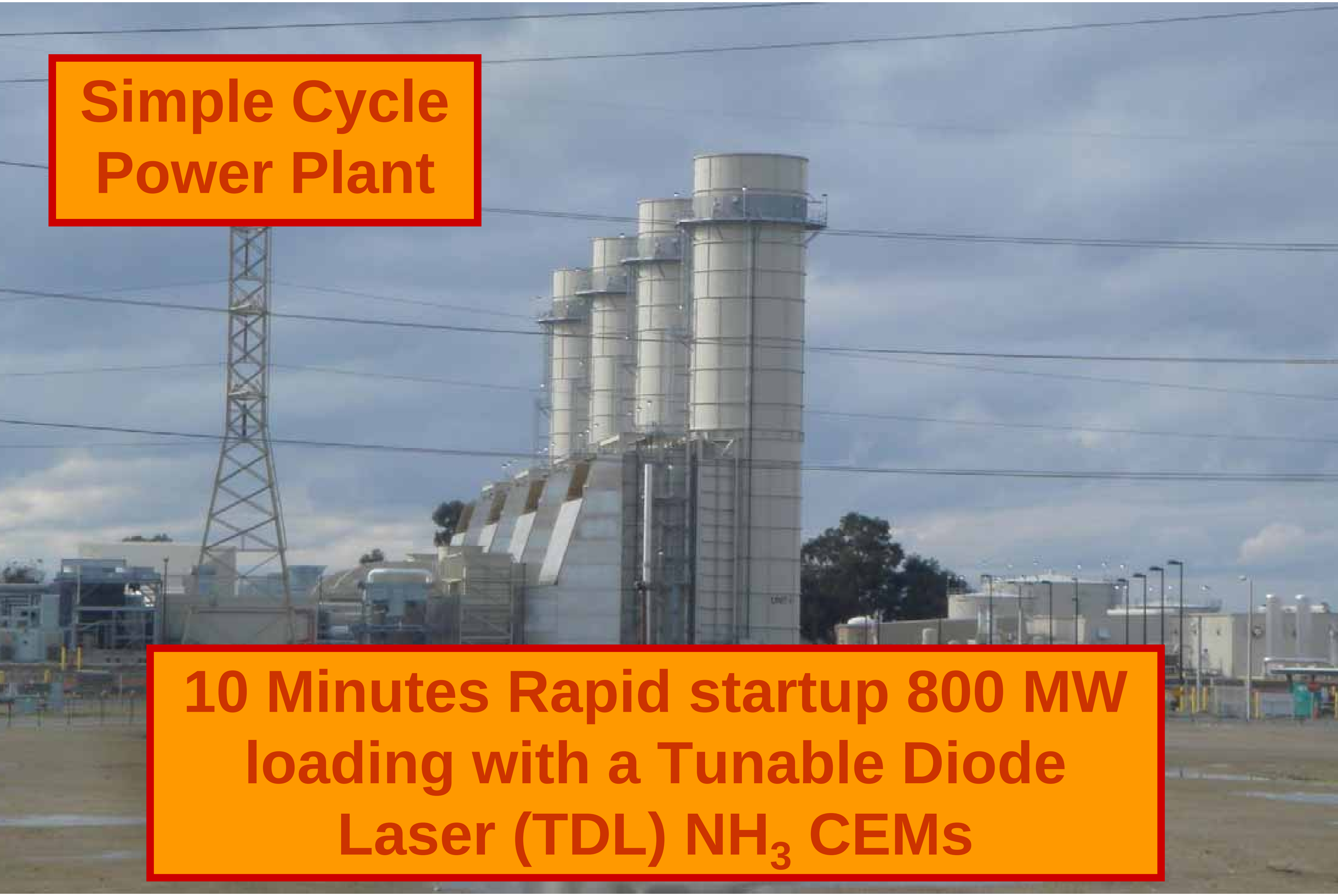
NOx BACT Trends in CA



BACT for power plants in 2000: 5 ppm
BACT for power plants in 2005: 2.5 ppm
BACT for power plants in 2012: 2 ppm

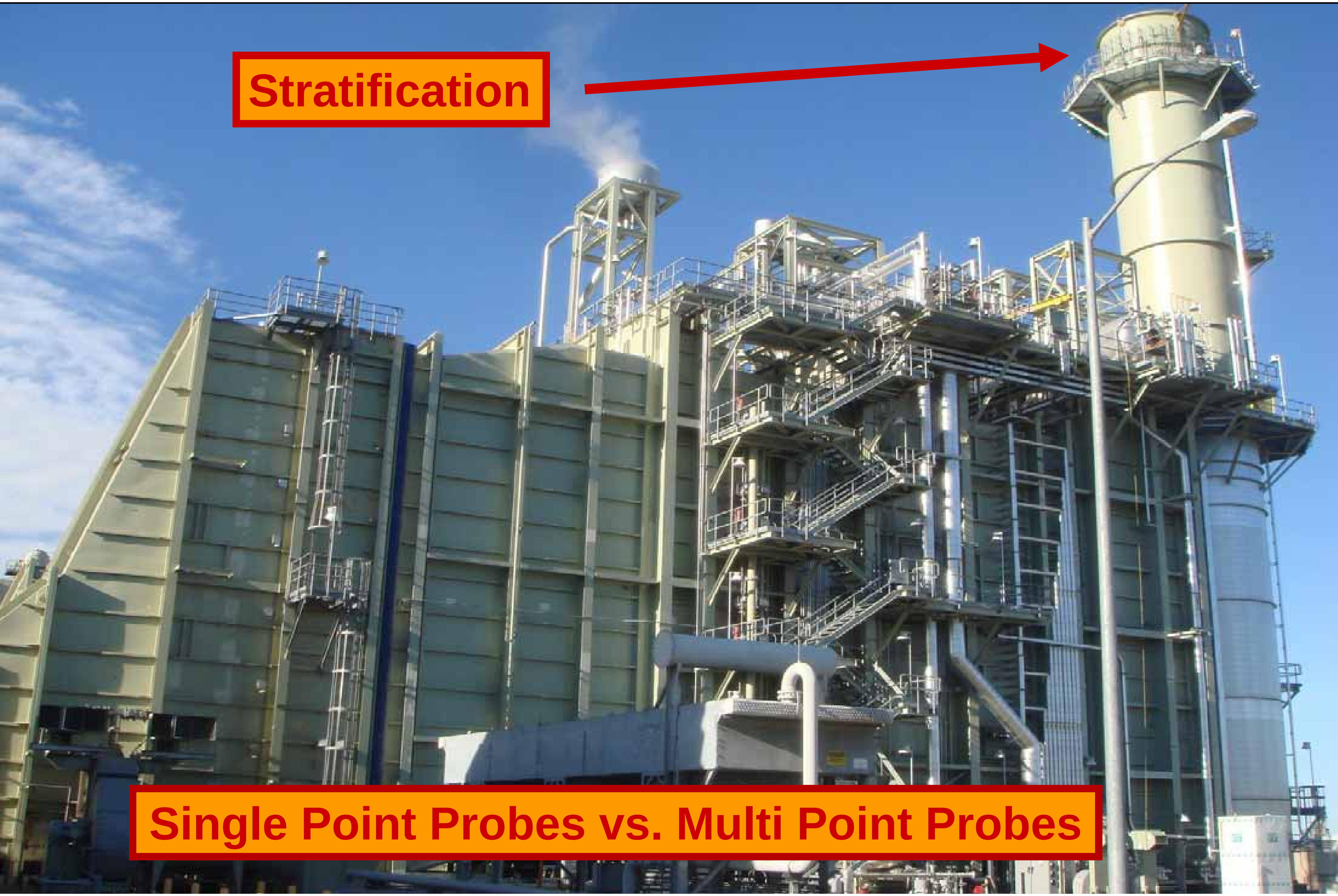
Future BACT Summary for Stationary Gas Turbines

	NO_x	CO	VOC	PM_{10}	SO_x
Simple-Cycle & Combined Cycle & Cogen	1 - 2 ppm @ 15%O2 & < 2 - 5 ppm NH3 slip	1 - 2 ppm	1 ppm OR 0.0027 lbs/MMBtu (HHV)	Equiv. to natural gas with fuel sulfur < 1 grain/100 scf. Now NH_3 is constituent of $PM_{2.5}$	Equiv to natural gas with fuel sulfur < 1 grain/100 scf (< 0.55 ppmvd) Now SOx is constituent of $PM_{2.5}$


Simple Cycle Power Plant
10 Minutes Rapid startup 800 MW loading with a Tunable Diode Laser (TDL) NH_3 CEMs

Compliance Challenges: <2ppm

- Single point probes vs. multi point probes
- Stratification (NOx, NH_3 & CO)
- Inlet & outlet NOx
- Differential NOx vs. calculated NH3
- Ammonia slip challenge
- Suspect cal gases
- Instrument air for O_2 cal
- NOx converter, NH_3 scrubber
- Moisture in sample line


Stratification
Single Point Probes vs. Multi Point Probes

Case Study #1: Stratification on a LMS100 Power Plant
16 point test on the stack. Results showing *26% stratification* in NOx. 20.5% RATA : Overall Failure

Port	Point	O2	CO2	NOx	CO
N	4	13.19	4.42	1.99	-0.42
N	3	13.19	4.42	1.93	-0.43
N	2	13.20	4.42	1.86	-0.43
N	1	13.20	4.42	1.86	-0.43
E	4	13.15	4.45	1.79	-0.43
E	3	13.15	4.46	1.68	-0.45
E	2	13.15	4.46	1.61	-0.44
E	1	13.17	4.45	1.64	-0.45
S	4	13.15	4.46	1.67	-0.44
S	3	13.15	4.47	1.62	-0.45
S	2	13.15	4.47	1.65	-0.46
S	1	13.27	4.40	1.71	-0.46
W	4	13.15	4.47	1.54	-0.47
W	3	13.16	4.47	1.61	-0.47
W	2	13.17	4.47	1.63	-0.48
W	1	13.17	4.47	1.63	-0.48
	Average	13.17	4.45	1.71	-0.45
	Max	13.27	4.47	1.99	-0.42
	Min	13.15	4.40	1.54	-0.48
	diff	0.12	0.07	0.45	0.06
	Strat	0.9%	1.7%	26.3%	-12.7%

Port	Point	O2	CO2	NOx	CO
N	4	13.19	4.42	1.99	-0.42
N	3	13.19	4.42	1.93	-0.43
N	2	13.20	4.42	1.86	-0.43
N	1	13.20	4.42	1.86	-0.43
E	4	13.15	4.45	1.79	-0.43
E	3	13.15	4.46	1.68	-0.45
E	2	13.15	4.46	1.61	-0.44
E	1	13.17	4.45	1.64	-0.45
S	4	13.15	4.46	1.67	-0.44
S	3	13.15	4.47	1.62	-0.45
S	2	13.15	4.47	1.65	-0.46
S	1	13.27	4.40	1.71	-0.46
W	4	13.15	4.47	1.54	-0.47
W	3	13.16	4.47	1.61	-0.47
W	2	13.17	4.47	1.63	-0.48
W	1	13.17	4.47	1.63	-0.48
	Average	13.17	4.45	1.71	-0.45
	Max	13.27	4.47	1.99	-0.42
	Min	13.15	4.40	1.54	-0.48
	diff	0.12	0.07	0.45	0.06
	Strat	0.9%	1.7%	26.3%	-12.7%

RELATIVE ACCURACY AND BIAS CALCULATION

Test	Date	Start Time	End Time	RM NO_x ppm	CEMS NO_x ppm	Difference NO_x ppm	Valid Run (1=yes, 0=no	% Diff.
1				2.590	1.800	0.790	1	30.5%
2				2.460	1.630	0.830	1	33.7%
3				2.450	1.560	0.890	1	36.3%
4				2.150	1.650	0.500	1	23.3%
5				1.400	0.820	0.580	1	41.4%
6				1.500	0.980	0.520	1	34.7%
7				1.550	1.100	0.450	1	29.0%
8				1.760	1.330	0.430	1	24.4%
9				2.230	1.690	0.540	1	24.2%
10							0	-
11							0	-
12							0	-
Average				2.010	1.396	0.614		30.8%

Emission Standard	2.5	ppm	
% of Standar	80.4%		
Ref. Method Average:	2.01	ppm	
Average Difference:	0.61	ppm	
Number of Tests:	9		
Standard Deviation:	0.17	ppm	
t Value:	2.306		
Confidence Coefficient:	0.13	ppm	
Relative Accuracy:	**37.23**	%	Reference Method
Allowable RA	**20**	%	Reference Method
Bias Adjustment Factor:	1.111		
Status	Fail		

Case Study #2: LM6000 April 2016

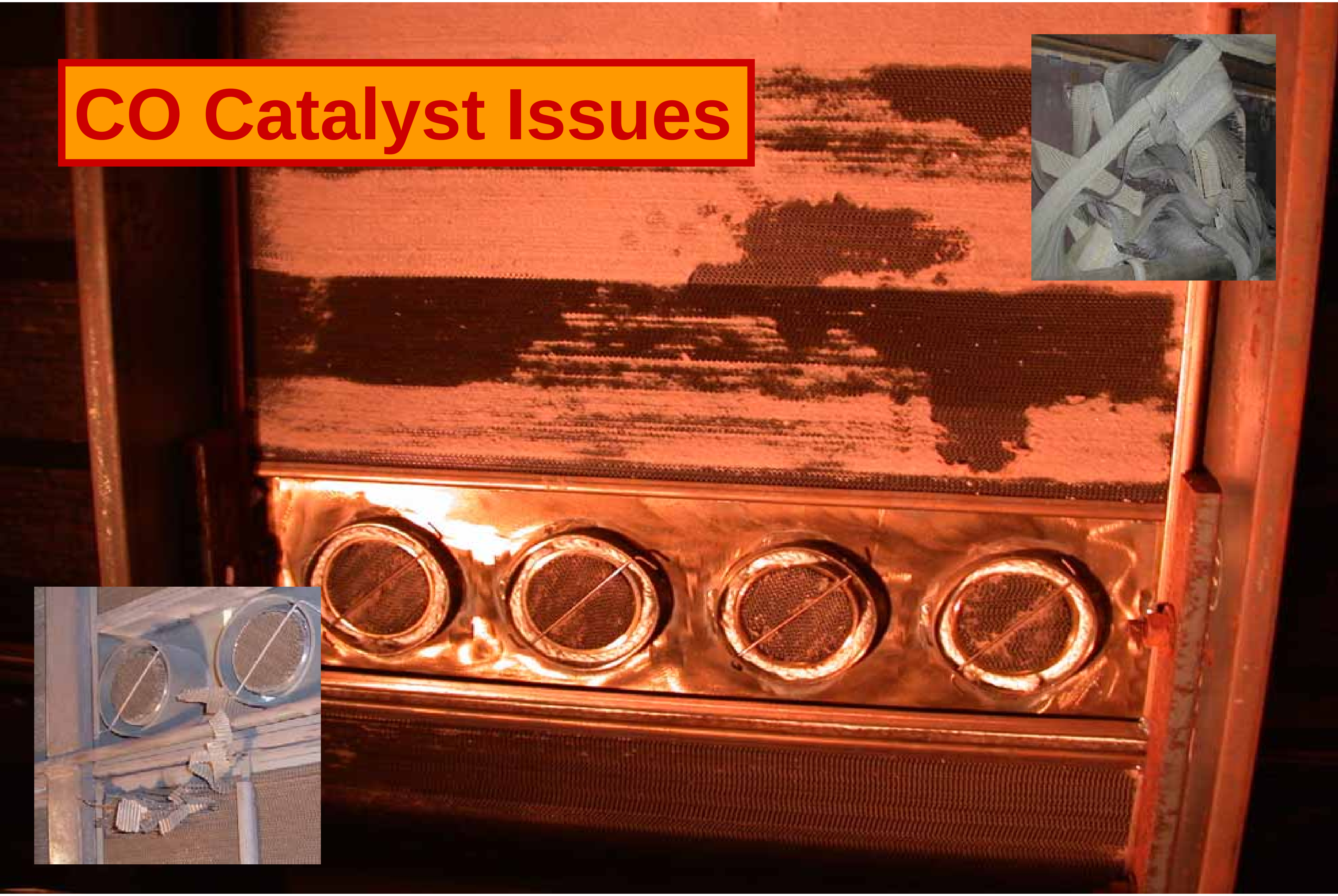
Case Study #2: LM6000 Gas Turbine

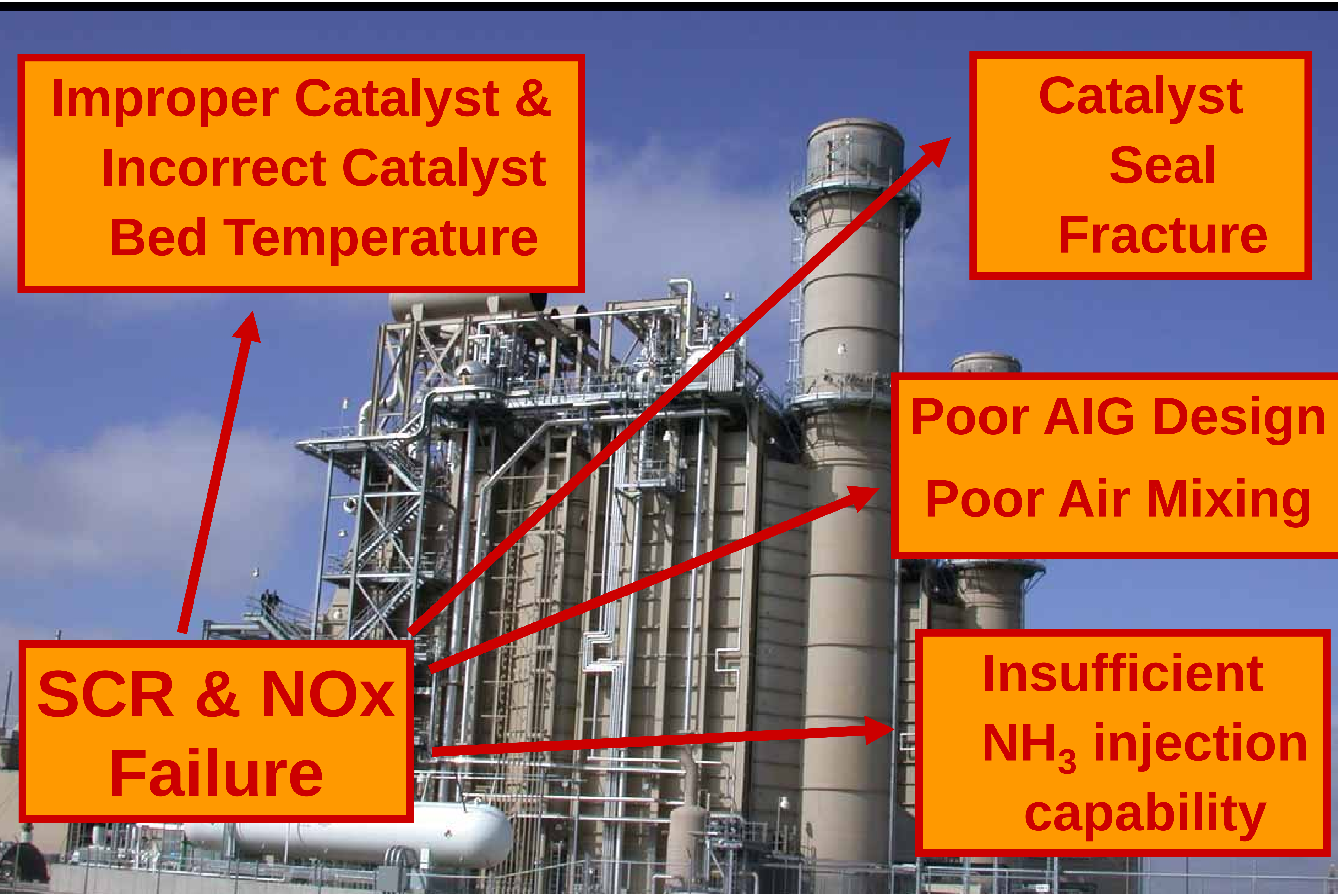
- NO_x Compliance limit: 2.5 ppmvd @ 15% O_2
  - Test result @ 2.5 ppmvd @ 15% O_2: Pass
- NOx Part 75 Relative Accuracy (RA): 10% or alternate criteria of ±0.02 lbs/MMBtu (RM vs CEM)
  - Test result of 37% RA (Fail) and 0.02 lbs/MMBtu (Pass)
- NOx Part 60 Relative Accuracy (RA): 20% (No alternate criteria)
  - Test result of 37% RA (Fail)
- NH_3 Compliance limit: 10 ppmvd @ 15% O_2
  - Test result @ 8.2 ppmvd @ 15% O_2: Pass

Single Point Probes vs. Multi Point Probes

- Stratification in plant will exist
- SCR seals will fail & NH_3 distribution (AIG) change
- SCR & CO configuration in plant changes
- Test van traverses the stack in an “X” - Collects “Representative Sample”
- CEMS probe likely to be a single point, may not match up on day of RATA

CO Catalyst Issues




Improper Catalyst & Incorrect Catalyst Bed Temperature
Catalyst Seal Fracture
Poor AIG Design
Poor Air Mixing
Insufficient NH_3 injection capability
SCR & NOx Failure

RELATIVE ACCURACY AND BIAS CALCULATION

Test	Date	Start Time	End Time	RM NO_x ppm	CEMS NO_x ppm	Difference NO_x ppm	Valid Run (1=yes, 0=no	% Diff.
1				1.890	1.740	0.150	1	7.9%
2				1.640	1.700	-0.060	1	-3.7%
3				1.310	1.320	-0.010	1	-0.8%
4				1.420	1.590	-0.170	1	-12.0%
5				1.270	1.360	-0.090	1	-7.1%
6				1.500	1.500	0.000	1	0.0%
7				1.370	1.370	0.000	1	0.0%
8				1.450	1.440	0.010	1	0.7%
9				1.400	1.380	0.020	1	1.4%
10							0	-
11							0	-
12							0	-
Average				1.472	1.489	-0.017		-1.5%

Emission Standard	2.5	ppm	
% of Standar	58.9%		
Ref. Method Average:	1.47	ppm	
Average Difference:	-0.02	ppm	
Number of Tests:	9		
Standard Deviation:	0.09	ppm	
t Value:	2.306		
Confidence Coefficient:	0.07	ppm	
Relative Accuracy:	**5.70**	%	Reference Method
Allowable RA	**20**	%	Reference Method
Bias Adjustment Factor:	1.000		
Status	Pass		

Case Study #2: LM6000 June 2016 (post fix)

RELATIVE ACCURACY AND BIAS CALCULATION

Test	Date	Start Time	End Time	RM NO_x ppm	CEMS NO_x ppm	Difference NO_x ppm	Valid Run (1=yes, 0=no	% Diff.
1				1.250	1.480	-0.230	1	-18.4%
2				1.230	1.470	-0.240	1	-19.5%
3				1.490	1.770	-0.280	1	-18.8%
4				1.210	1.510	-0.300	1	-24.8%
5				1.240	1.480	-0.240	1	-19.4%
6				1.220	1.470	-0.250	1	-20.5%
7				1.260	1.610	-0.350	1	-27.8%
8				1.220	1.500	-0.280	1	-23.0%
9				1.220	1.470	-0.250	1	-20.5%
10							0	-
11							0	-
12							0	-
Average				1.260	1.529	-0.269		-21.4%

Emission Standard	2.5	ppm		
% of Standar	50.4%			
Ref. Method Average:	1.26	ppm		
Average Difference:	-0.27	ppm		
Number of Tests:	9			
Standard Deviation:	0.04	ppm		
t Value:	2.306			
Confidence Coefficient:	0.03	ppm		
Relative Accuracy:	**23.67**	%	Reference Method	
Allowable RA	**20**	%	Reference Method	
Bias Adjustment Factor:	1.000			
Status	Fail			

Case Study #3: GE 7FA 175 MW Turbine

Case Study #2: LM6000 Gas Turbine

- NO_x Compliance limit: 2.5 ppmvd @ 15% O_2
  - Test result @ 2.5 ppmvd @ 15% O_2: Pass
- NOx Part 75 Relative Accuracy (RA): 10% or alternate criteria of ±0.02 lbs/MMBtu (RM vs CEM)
  - Test result of 24% RA (Fail) and 0.02 lbs/MMBtu (Pass)
- NOx Part 60 Relative Accuracy (RA): 20% (No alternate criteria)
  - Test result of 24% RA (Fail)
- NH_3 Compliance limit: 10 ppmvd @ 15% O_2
  - Test result @ 5.5 ppmvd @ 15% O_2: Pass

Gas Turbine
Inlet & Outlet NOx

Gas Turbine Inlet & Outlet NOx

- Outlet NOx is mandatory
- Inlet NOx maybe optional
- Measuring both will represent better identify compliance target
- Is NH_3 slip a mathematical calculation using a bias #?
- Differential NOx vs. calculated NH_3 slip

NH_3 Slip Bias Calculation

Unit 1 - Max				
Ammonia Slip				
NH_3 Test No.	**1-NH3-MAX-1**	**2-NH3-MAX-1**	**3-NH3-MAX-1**	**Averages**
Date	**2/27/15**	**2/27/15**	**2/27/15**	**--**
Time	**1701-1750**	**1817-1847**	**1854-1924**	**--**
Process Data:				
NH_3 Solution Injection Rate, lb/hr	**260.99**	**256.22**	**259.10**	**258.77**
lb NH_3 per lb of solution	**0.28**	**0.28**	**0.28**	**0.28**
Fuel Flow rate, MMBtu/hr	**2,028.8**	**2,027.4**	**2,027.2**	**2,027.8**
NH_3 injected, equivlent as ppm vol. dry	**34.64**	**33.94**	**34.33**	**34.30**
Gaseous Emissions (Inlet)				
NO_X Inlet, ppm volume dry	**32.4**	**31.8**	**32.3**	**32.2**
Gaseous Emissions (Outlet)				
O_2 Outlet, % volume dry	**13.18**	**13.20**	**13.20**	**13.19**
NO_X Outlet, ppm volume dry	**2.48**	**2.56**	**2.62**	**2.55**
Measured NH_3 Slip, ppm volume dry @ 15% O_2	**3.25**	**2.67**	**2.28**	**2.73**
NH_3 Slip raw calc, ppm volume dry @ 15% O_2	**3.61**	**3.60**	**3.56**	**3.59**
NH_3 Slip Correction Factor	**0.90**	**0.74**	**0.64**	**0.76**

Unit 1 - Max				
Ammonia Slip				
NH_3 Test No.	1-NH3-MAX-1	2-NH3-MAX-1	3-NH3-MAX-1	Averages
Date	2/27/15	2/27/15	2/27/15	--
Time	1701-1750	1817-1847	1854-1924	--
Process Data:				
NH_3 Solution Injection Rate, lb/hr	260.99	256.[illegible]2	259.10	258.77
lb NH_3 per lb of solution	0.28	0.28	0.28	0.28
Fuel Flow rate, MMBtu/hr	2,028.8	2,027.4	2,027.2	2,027.8
NH_3 injected, equivlent as ppm vol. dry	34.64	33.94	34.33	34.30
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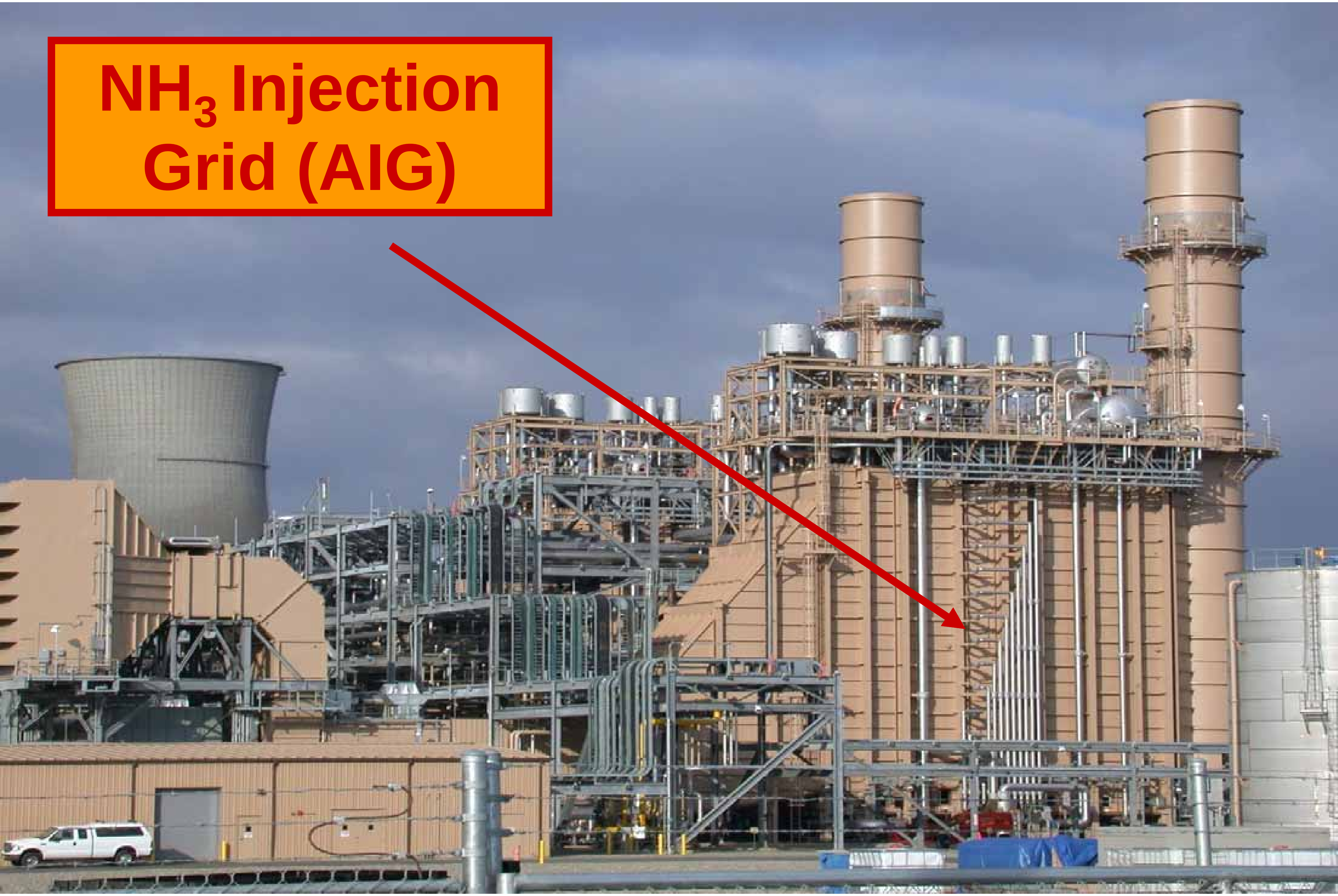

NH_3 Injection Grid (AIG)

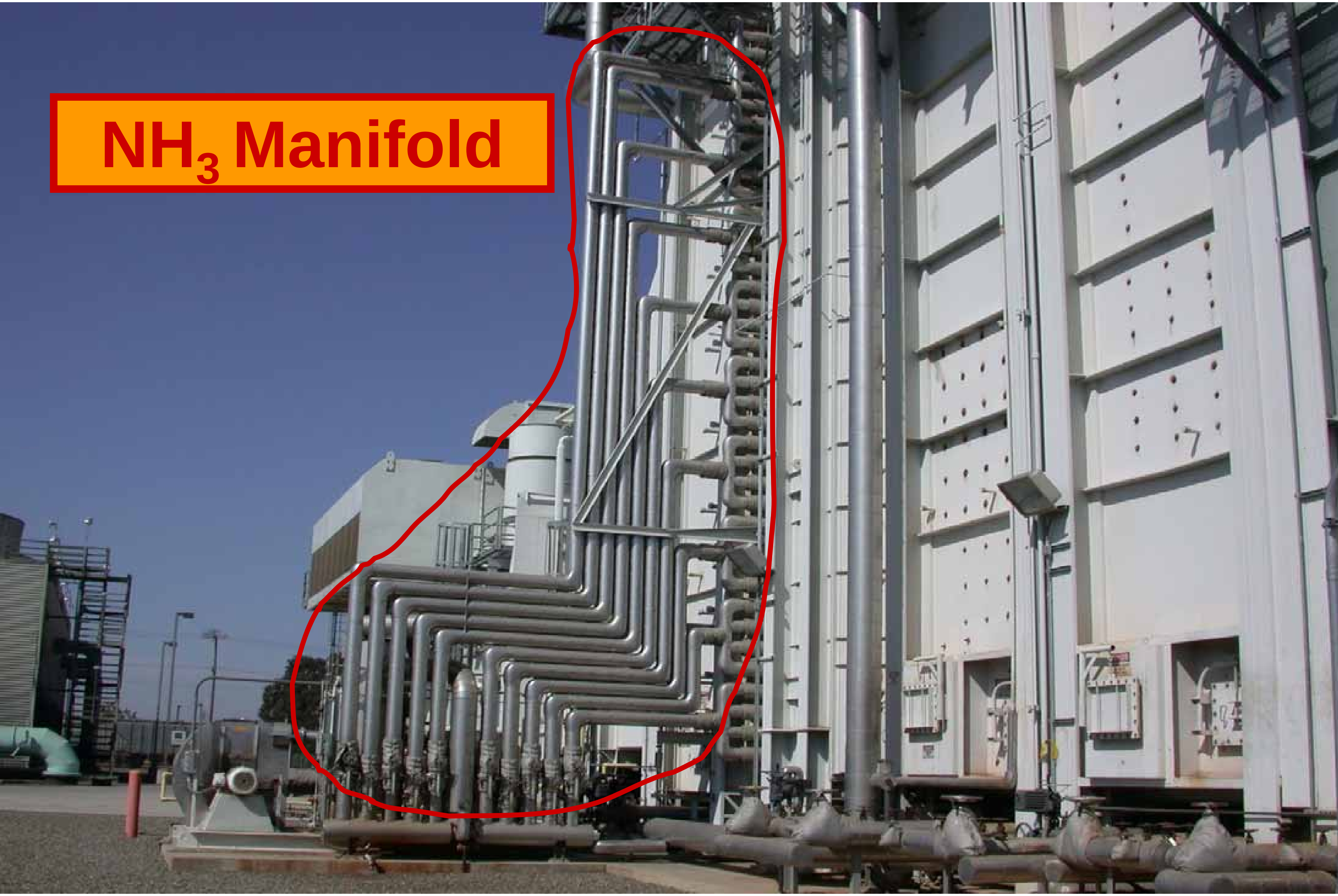
New Permits for Anhydrous NH_3 Maybe be Challenging

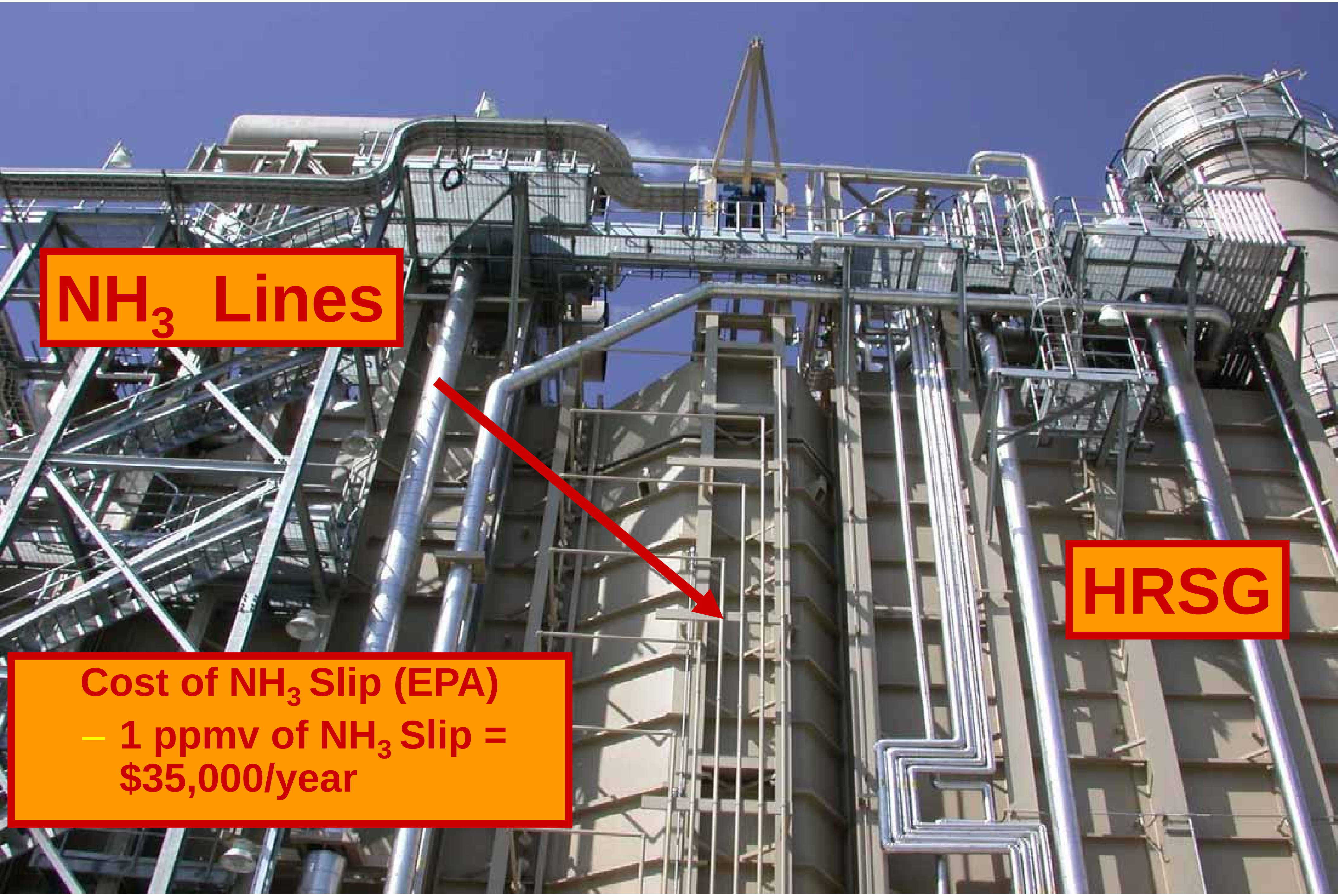
NH_3 Injection Vaporizer Skid

NH_3 Vaporizer Skid: Redundant Backup Electric Heaters

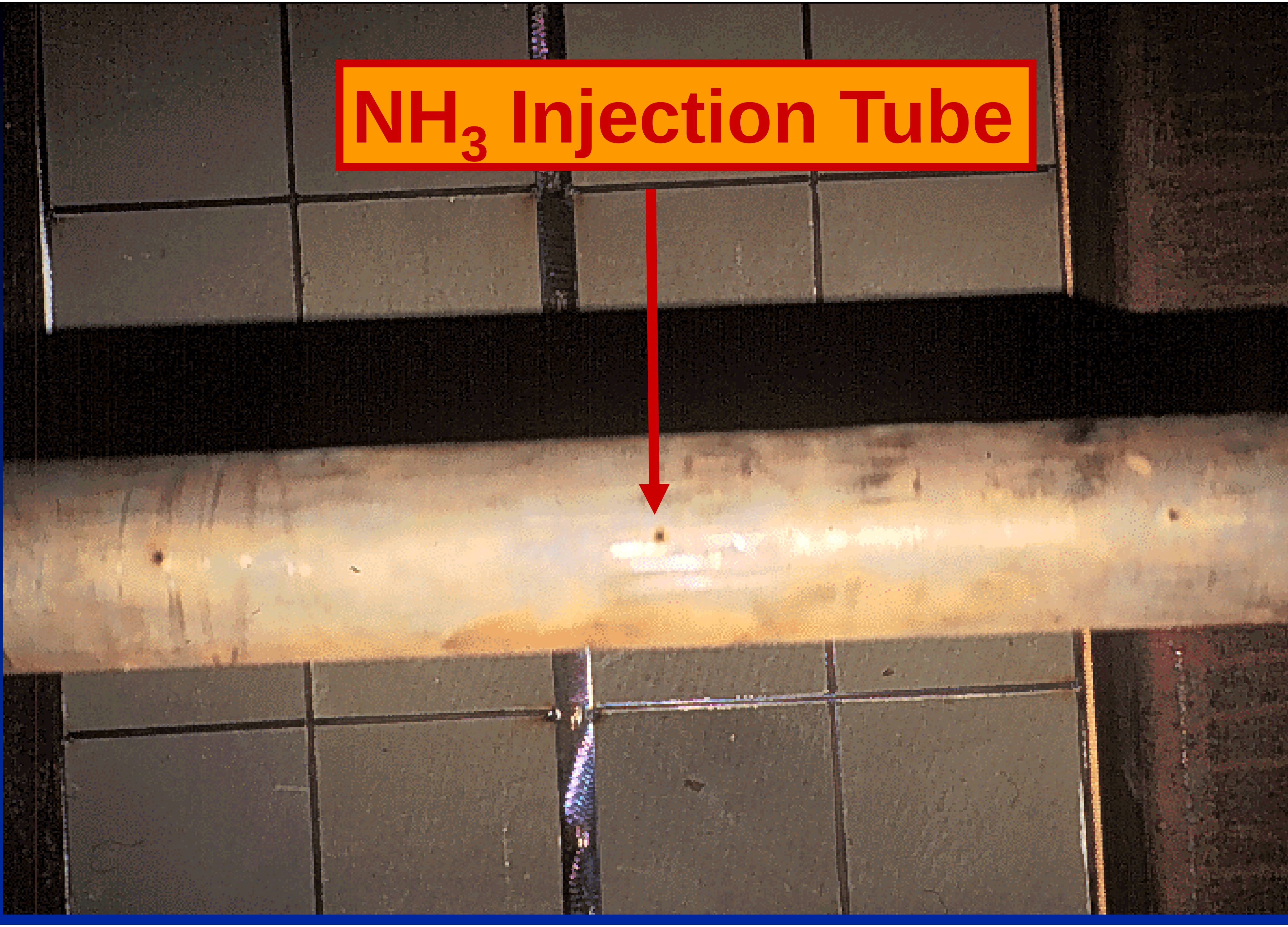
NH_3 Lines
AMMONIA

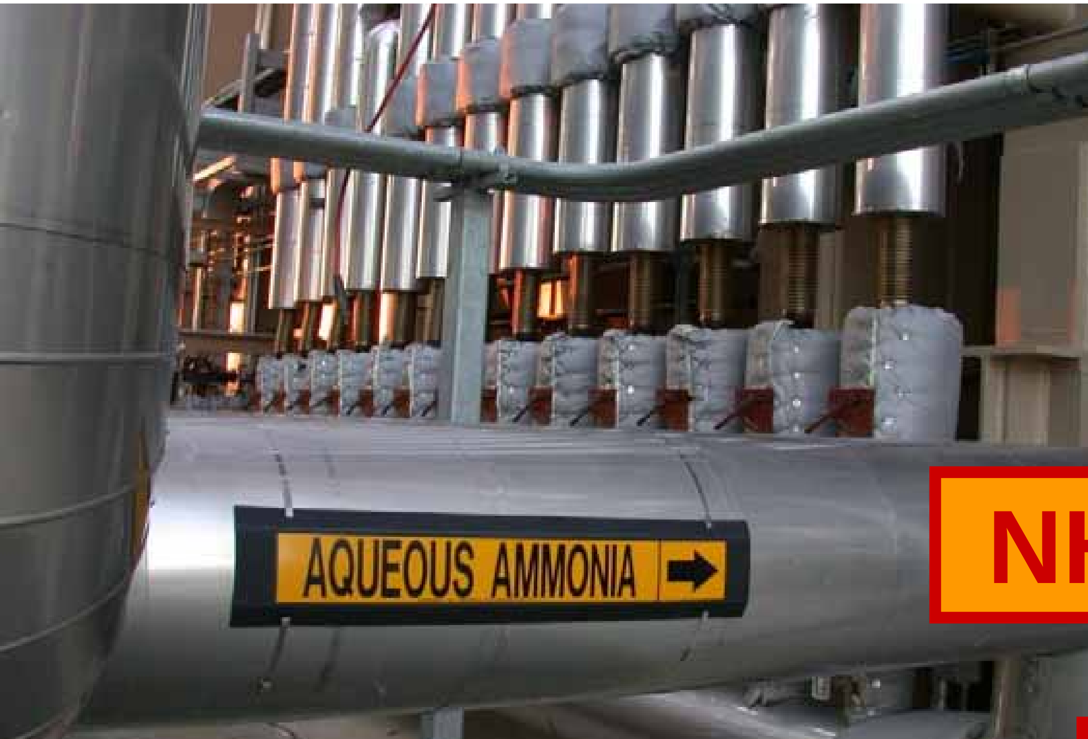
NH_3 Manifold



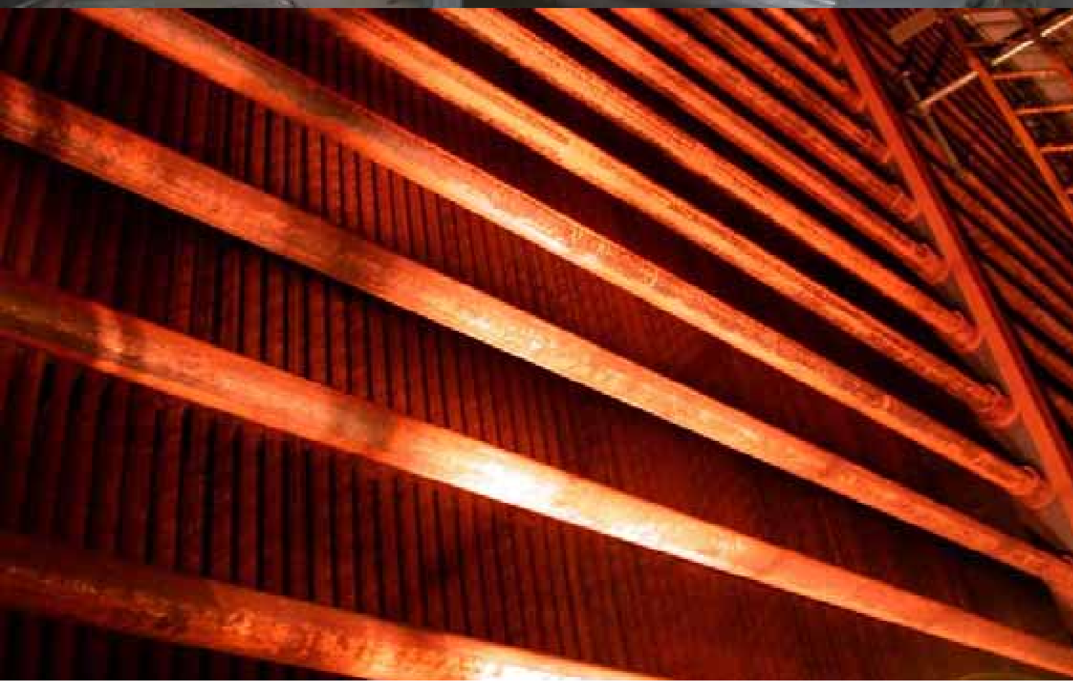


NH_3 Lines
HRSG
Cost of NH_3 Slip (EPA)
– 1 ppmv of NH_3 Slip = $35,000/year


NH_3 Injection Tube



NH_3



- **Issues With NH_3**
  - **Even Distribution**
  - **Proper Mixing Temp.**
  - **Fast start-up**
  - **Thermal Expansion**
  - **Balancing manifold**
  - **Access & maintenance**

What Constitutes Excess Emission Events (>2ppm NOx) and Breakdown?

Excess Emission Events (>2 ppm NOx) and Breakdown

- **CEM analyzer and sample train failure**
- **Ammonia deposits due to poor water quality from the ammonia supply vendor (nozzle plugging)**
- **Ammonia electric heater failure (degradation in the spray nozzle and / or deflector plate leading to poor vaporization)**
- **Ammonia pump failure**

Excess Emission Events (>2 ppm NOx) and Breakdown

- Ammonia dilution blower failure
- Ammonia hot exhaust blower failure
- 650F exhaust, 5’ blower fan radius @ 3600 rpm
- SCR heater controller cabinet overheats because it’s getting baked in the sun
- On hot days, when anhydrous NH3 tank is low, it is possible for pumps to vapor lock, shutting down NH3 injection

Excess Emission Events and Breakdown

- NOx water injection pump & valve failure
- Engine vibrations & harmonics lead to trips
- Emissions spikes (due to load change) after CEMS are put back into service after maintenance or calibration
- Turbine bearing and blade failures
- Retrofit from peaker to combined cycle but keep same SCR…now ask for a variance!!

Excess Emission Events and Breakdown

Extremely low emission limits and/or short averaging periods lead to events.

Any small hiccups to the turbine, control system, or monitoring system can lead to small emission spikes that can make it impossible to meet limits.

Excess Emission Events and Breakdown

It is increasingly important that permits be configured to allow for these type of events

(X number of allowable excursions, Y number of Start-ups and Shut-downs per hour and per day, Z number of allowable lbs of NOx per hour and day etc.)


RATA Tips & Points of Failure

RATA Tips & Points of Failure

- Peaking plants don’t run all the time – run it the week / day before the test to check things out
- Perform preventative maintenance on the analyzers and CEMS system before RATA
- Check the Water Knockout – draining ?
- Check the ammonia scrubber system – looks good?   Change out media?
- Check the NOx analyzer – is the NO_2 converter working?

RATA Tips & Points of Failure

- Check the PLC & DAS for accuracy
- Check heated lines
  - Do they have a downward slope throughout the line?
  - No cold spots?
  - Are they warm to the touch?
- The Test Van is CORRECT (the EPA Reference Method). PGVP gases with a good Zero gas.

RATA Tips & Points of Failure

- Stack Platform – Take a look inside: CEMS probe look good? Is it there?

- Stack Platform – Are platforms / railings safe and sound? Loosen bolts on sample ports (be nice to your tester)

- Stack Platform – Do all of the connections and valves look good?

RATA Tips & Points of Failure

- Balance the NOx and the Ammonia slip – so that you pass both at the same time.
- Check for SCR seal leaks and stack stratification. Good idea to install multi-point probes in the stack.
- It is good to run with the highest allowed NOx emissions
  - It will make the RATA equation easier to pass, and
  - you will have the lowest ammonia emissions.

RATA Tips & Points of Failure

- Do a Linearity or Cylinder Gas Audit before RATA day
- Perform Site CEMS calibration early – complete well before the RATA test. Do a manual calibration as well. Swap bottles with tester for accuracy.
- An extra check that everything is good will make compliance easier


Questions ?