Wet-Burn-Wet Abatement Evaluation on 300mm Silicon Nitride Deposition

SESHA Conference 2017

Agenda Outline

- Introduction and Objectives
- Test Setup and Timeline
- Chamber Cleaning Test Results
- Deposition Process Test Results
- Discussion
- Questions

Introduction and Objectives

Silicon Nitride Deposition

- Silicon Nitride is typically used in semiconductors as a dielectric, oxidation mask or a passivation layer

$$3\ SiH_4 + 4\ NH_3 \rightarrow Si_3N_4 + 12\ H_2$$

- Process flows also include a carrier gas and possibly N2O

- As required, removal of deposits from tool reaction chamber walls requires a chamber cleaning step often through flows of NF3 and carrier gases

Burn-Wet Operation Summary

SiN – Dep Process Abatement

Gases Put Into Burner

Process Step

SiH4

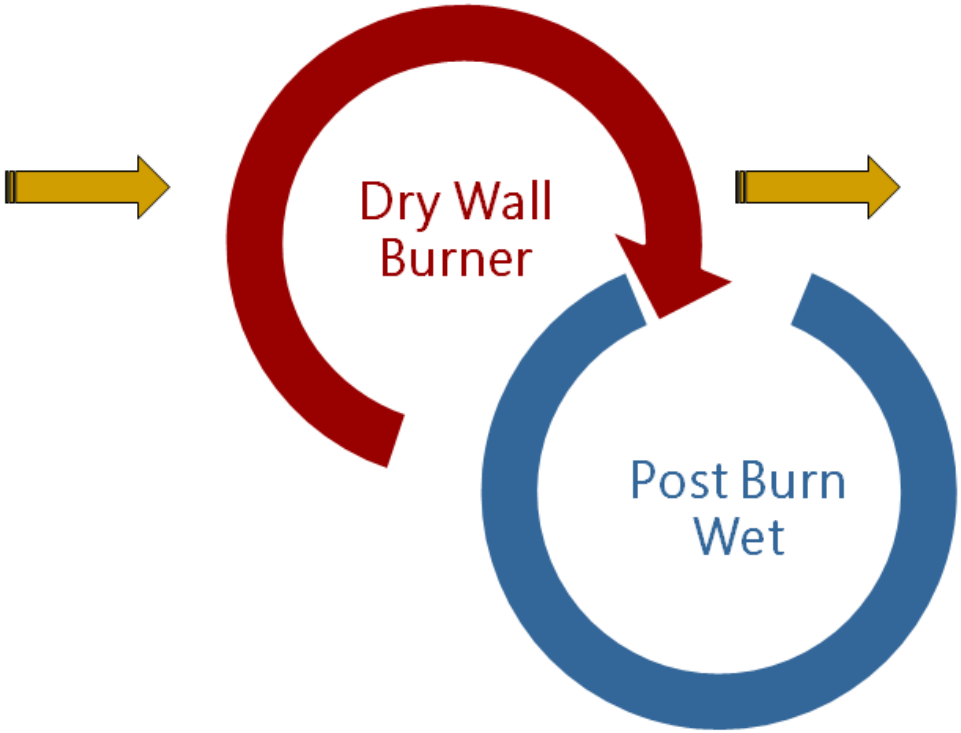
NH3

Clean Step

C2F6/NF3

HF/F2

SiF4



Burner Output

Si-Deposits

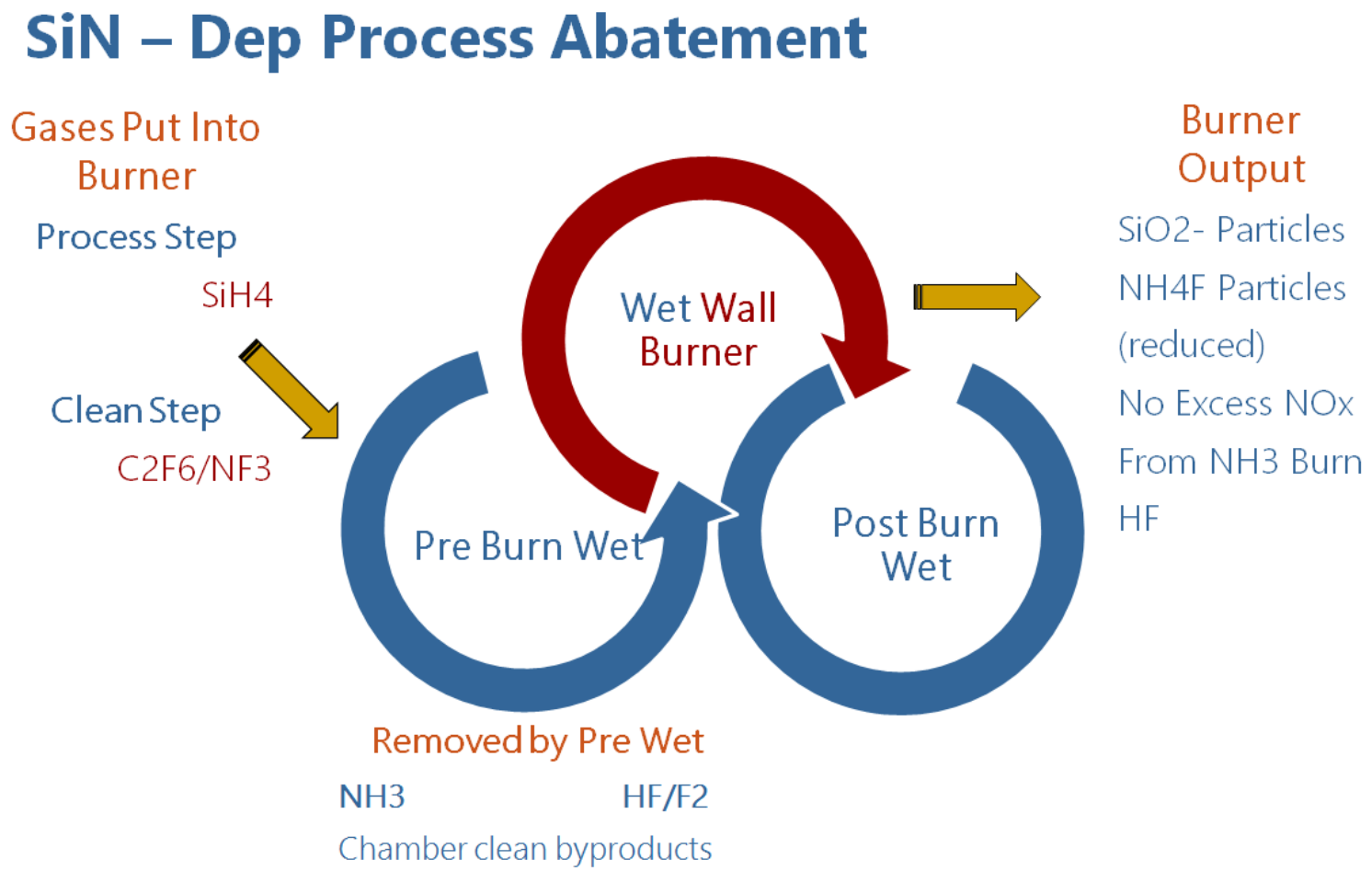
Si-particles

NH4F Sub-μ particles

High NOx

HF

Wet-Burn-Wet Operation Summary



Project Scope

- Evaluate an Airgard Encompass wet-burn-wet abatement unit for performance against currently installed TPU-4 burn-wet abatement unit
  - Remove ammonia prior to house exhaust system
  - Concerns regarding excess ammonium fluoride particulates
  - Concerns regarding excess NOx generated due to ammonia

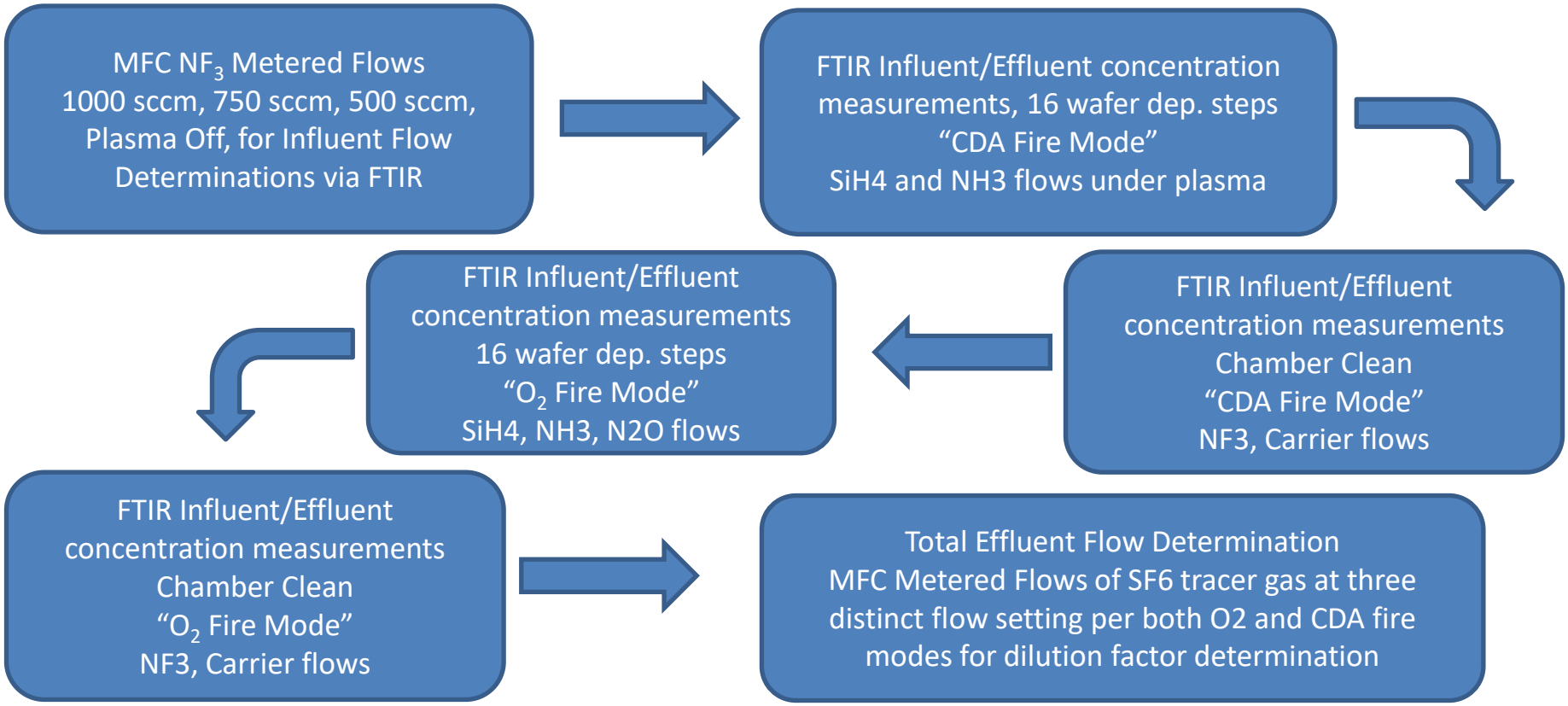
- Further concerns regarding Greenhouse Gas Destruction
  - NF3 DRE
  - N2O DRE and effects on NOx
  - Performance with CDA and O_2
- Reliability and maintenance of unit

Test Setup and Timeline

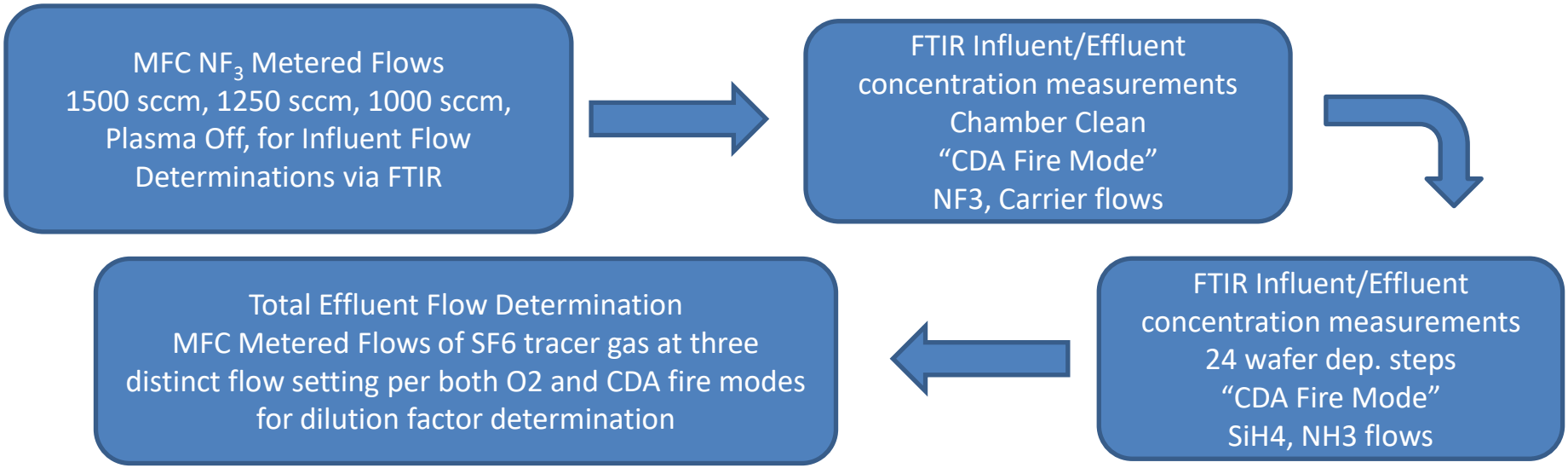
Testing Method

- Extractive Fourier Transform Infrared (FTIR) Spectroscopy
- Procedures were consistent with EPA Protocol for Measuring Destruction or Removal Efficiency of Fluorinated Greenhouse Gas Abatement Equipment in Electronics Manufacturing (March 2010)
- Data was gathered using Method 2, “Total Volume Measurements”, which measures DREs under actual process conditions where byproducts are formed and analytical determined influent/effluent exhaust flows were performed via process NF_3 or SF_6 tracer gas injection

Timeline for Encompass Testing (Day 1)



Timeline for TPU Testing (Day 2)



Average Influent/Effluent Flows and DFs

Encompass Avg. Influent Flow	43.0 slm
TPU Avg. Influent Flow	44.5 slm
Encompass Avg. Effluent Flow, O_2 Fire	145 slm
Encompass Avg. Effluent Flow, CDA Fire	410 slm
TPU Avg. Effluent Flow, CDA Fire	419 slm
Encompass O_2 Fire DF	**3.4**
Encompass CDA Fire DF	**9.5**
TPU CDA Fire DF	**9.4**

Chamber Clean Step Results

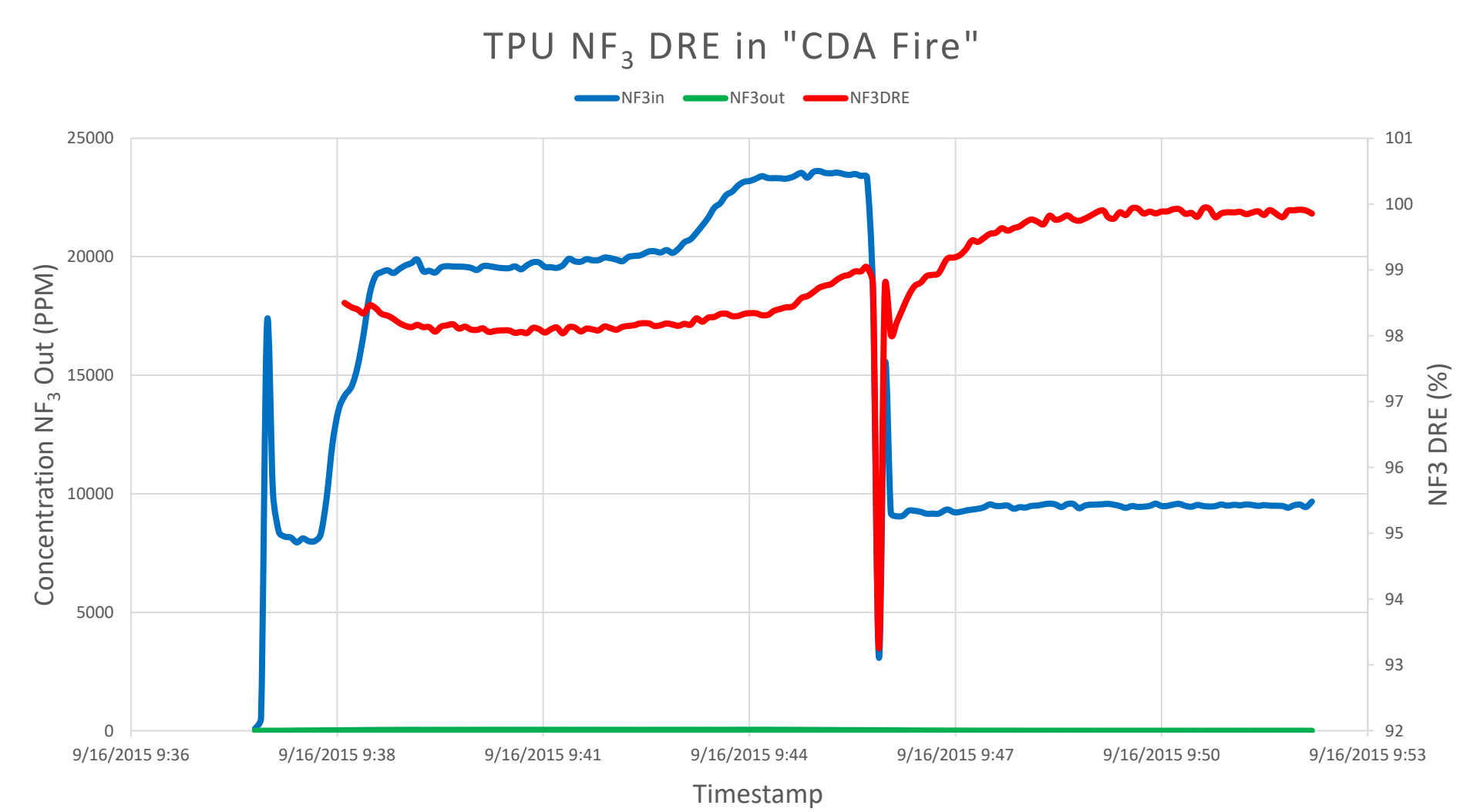
Chamber Clean Testing Objectives

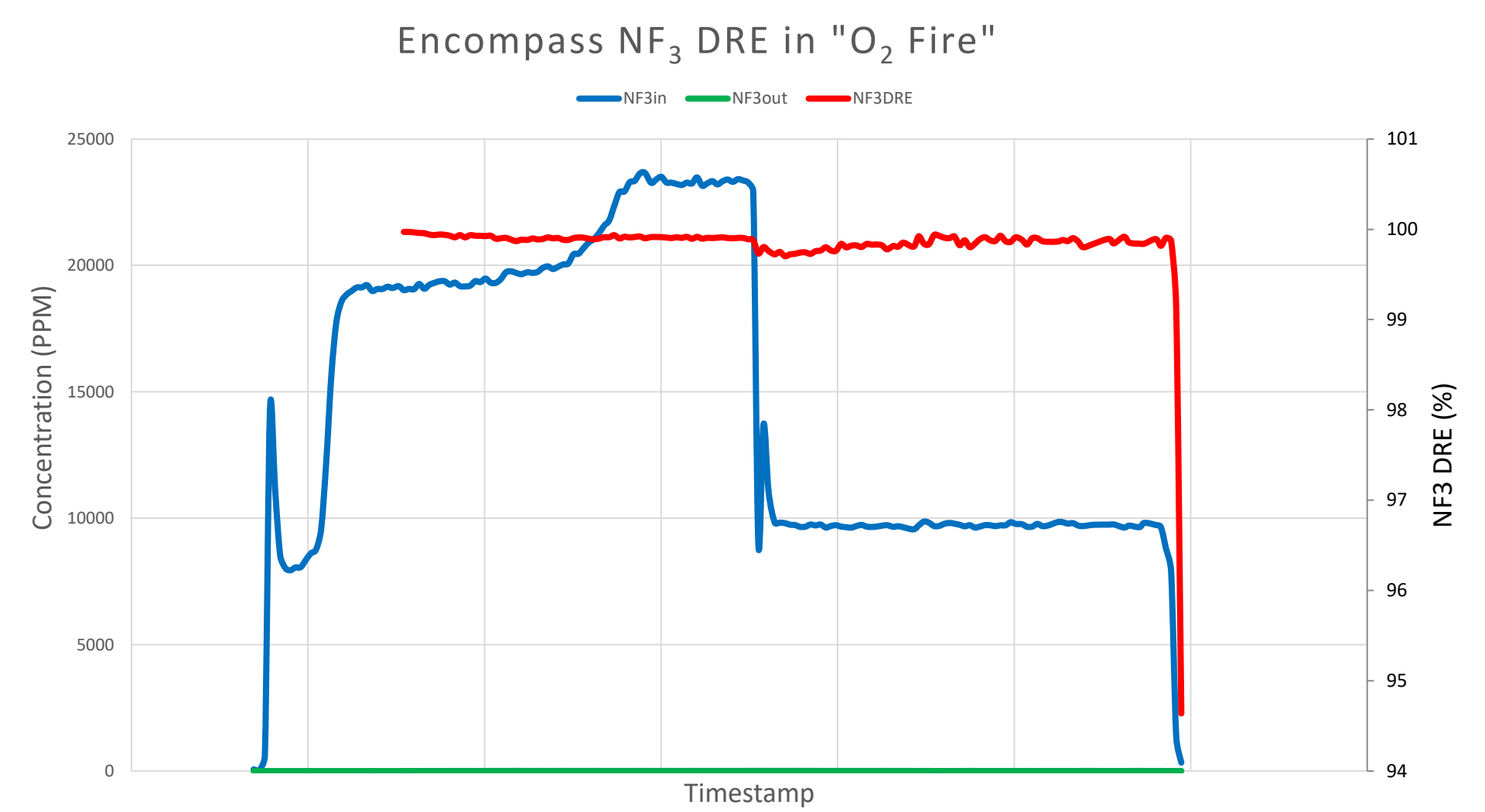
- What is the effective DRE for NF3?
- Is there appreciable destruction of NF3 in “CDA fire” mode?

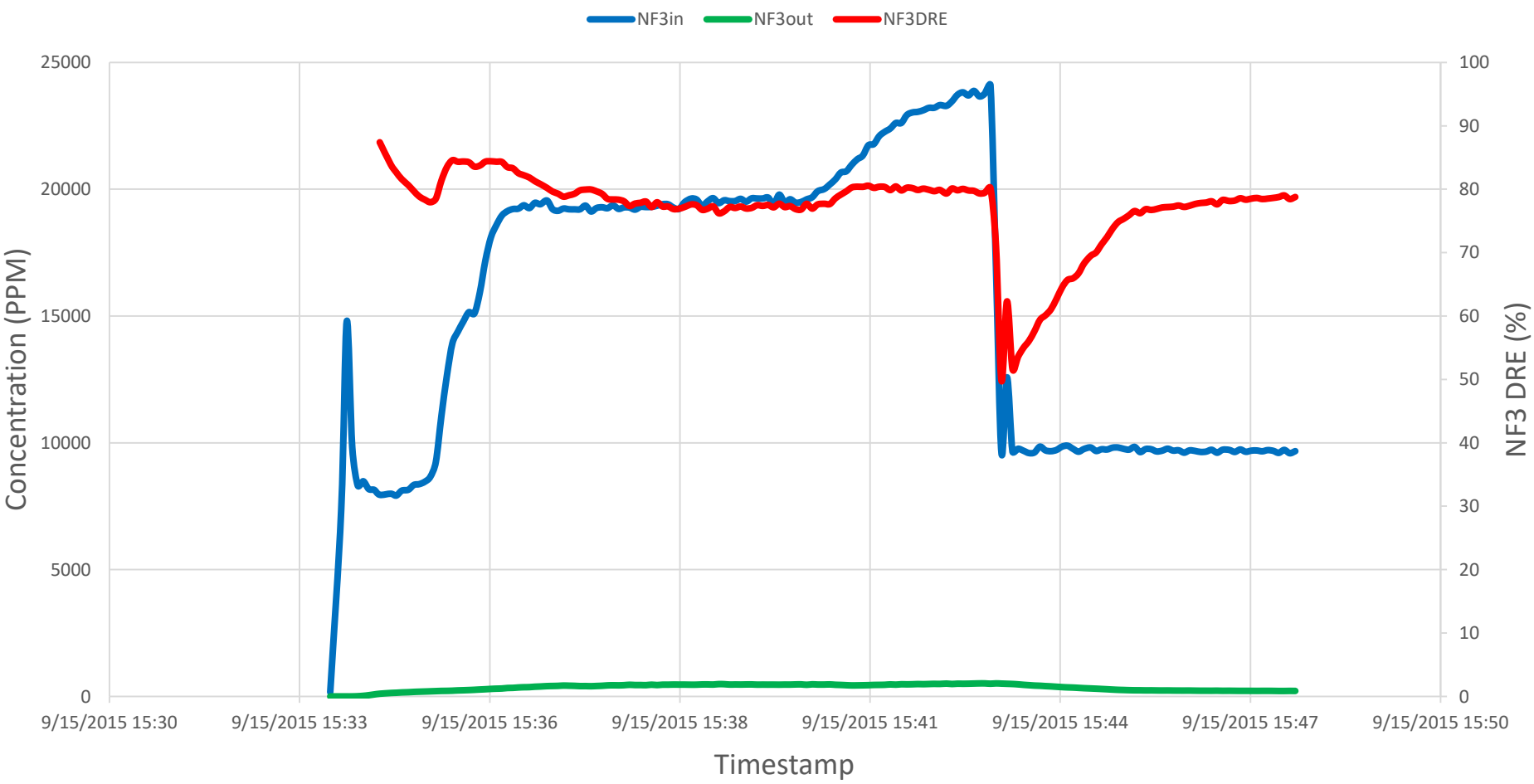
  Certain fabs do not have available O2 supplies plumbed throughout the support level

  To claim abatement, MRR requires fabs to test their abatement units

- Are there differences in levels of NOx generated between the abatement units?


TPU NF3 DRE in "CDA Fire"
NF3in
NF3out
NF3DRE
Concentration NF3 Out (PPM)
NF3 DRE (%)
25000
20000
15000
10000
5000
0
101
100
99
98
97
96
95
94
93
92
9/16/2015 9:36
9/16/2015 9:38
9/16/2015 9:41
9/16/2015 9:44
9/16/2015 9:47
9/16/2015 9:50
9/16/2015 9:53
Timestamp


Encompass NF3 DRE in "O2 Fire"
NF3in
NF3out
NF3DRE
25000
20000
15000
10000
5000
0
Concentration (PPM)
101
100
99
98
97
96
95
94
NF3 DRE (%)
Timestamp


Encompass NF3 DRE in "CDA Fire"
NF3in
NF3out
NF3DRE
Concentration (PPM)
NF3 DRE (%)
25000
20000
15000
10000
5000
0
100
90
80
70
60
50
40
30
20
10
0
9/15/2015 15:30
9/15/2015 15:33
9/15/2015 15:36
9/15/2015 15:38
9/15/2015 15:41
9/15/2015 15:44
9/15/2015 15:47
9/15/2015 15:50
Timestamp

NF3 DRE Results

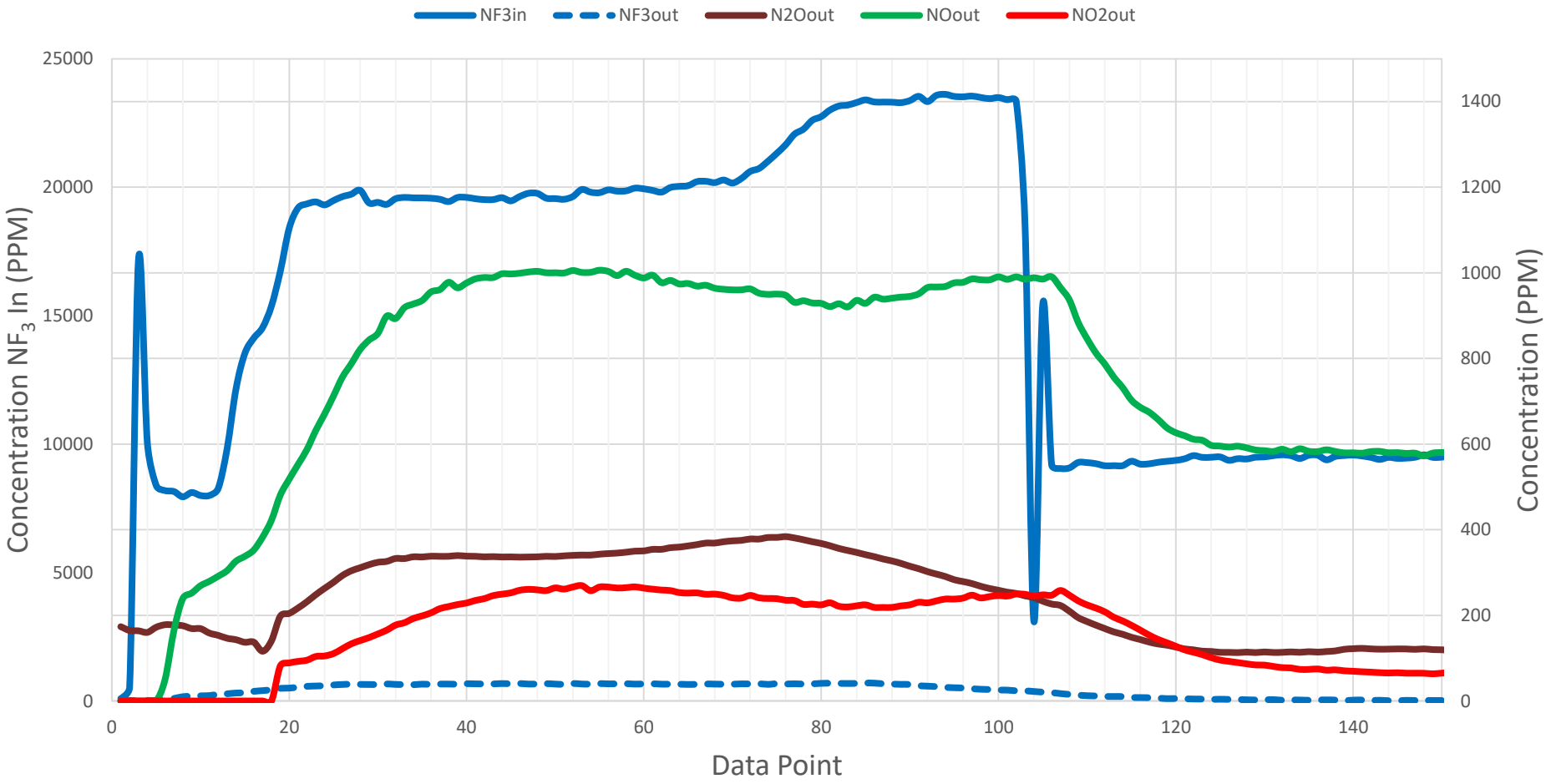
- Both Encompass operating in “O2 fire” mode and TPU in “CDA fire” mode achieved average DREs of about 99%.

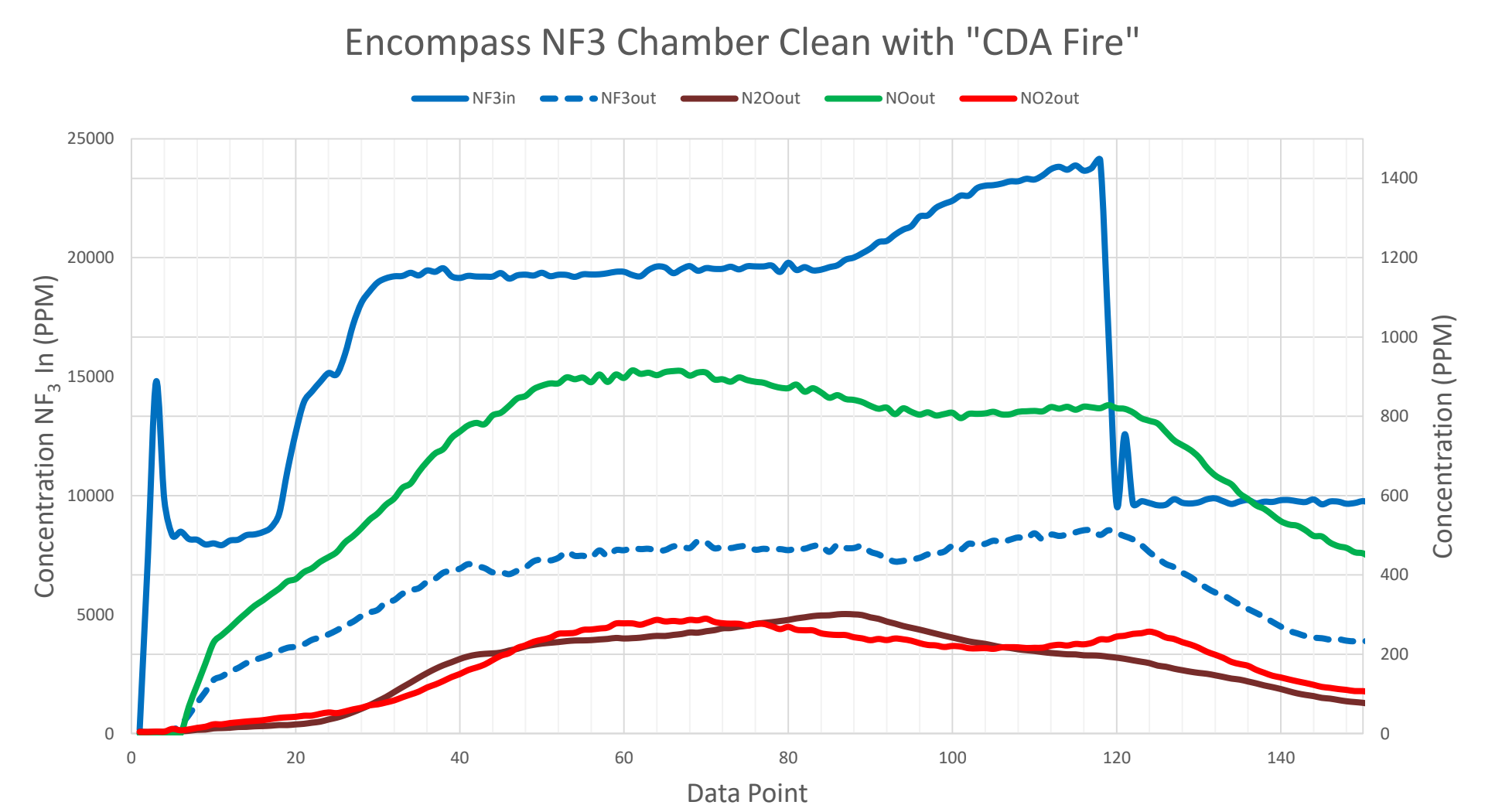
  Extensive maintenance of the TPU was performed one day prior to testing including the combustor liner

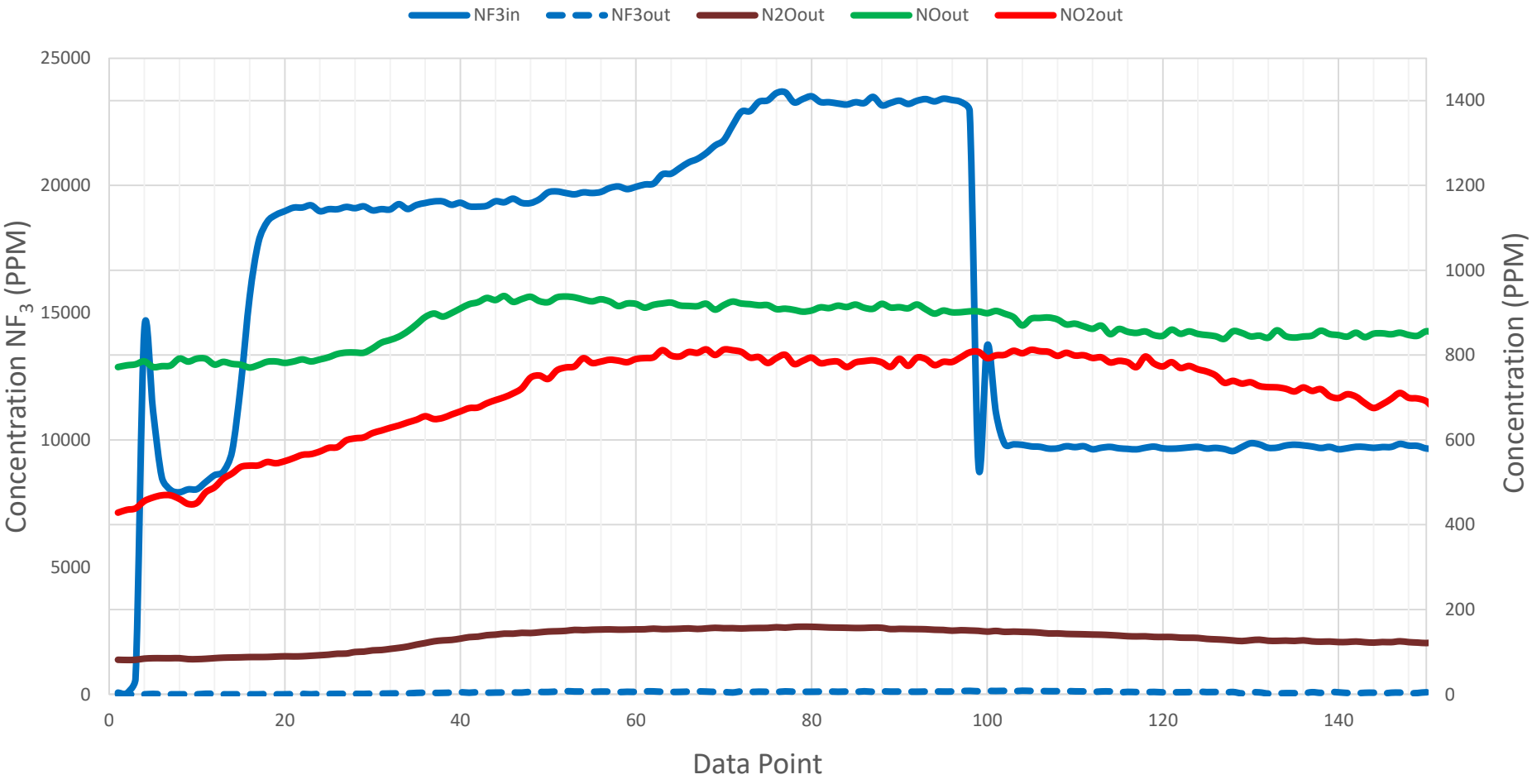
  Previous testing by TI on other TPUs at another TI facility indicates that DRE is greatly affected by combustor liner plugging

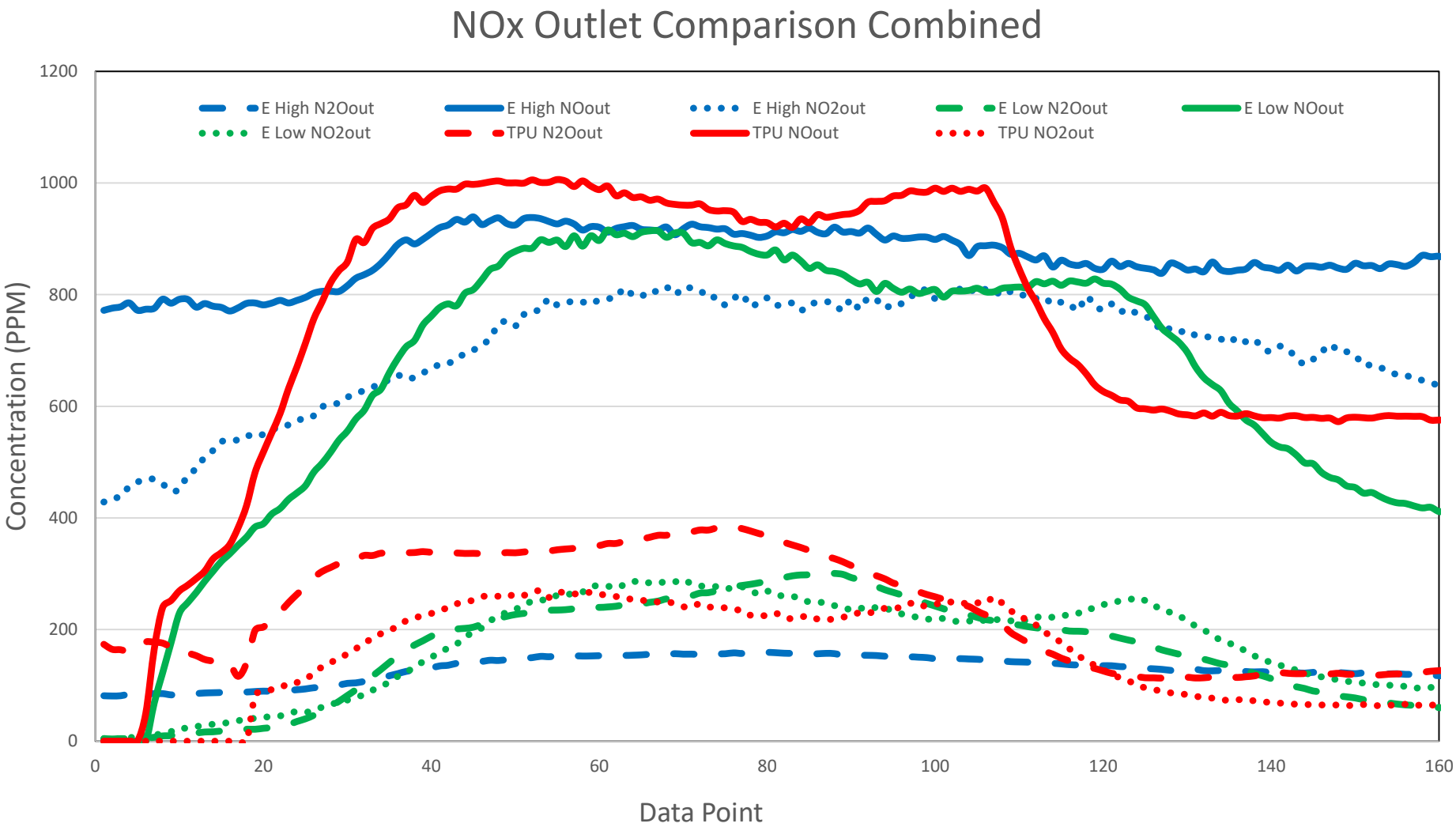
- The average DRE for the Encompass in “CDA fire” mode was ~80%

- EPA Subpart I default DRE for NF3 is 88% from Table I-16


TPU Chamber Clean with "O2 Fire"
NF3in
NF3out
N2Oout
NOout
NO2out
Concentration NF3 In (PPM)
Concentration (PPM)
Data Point
25000
20000
15000
10000
5000
0
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140


Encompass NF3 Chamber Clean with "CDA Fire"
NF3in
NF3out
N2Oout
NOout
NO2out
Concentration NF_3 In (PPM)
Concentration (PPM)
Data Point
25000
20000
15000
10000
5000
0
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140


Encompass NF_3 Chamber Clean with "O_2 Fire"
NF3in
NF3out
N2Oout
NOout
NO2out
Concentration NF_3 (PPM)
Concentration (PPM)
Data Point
25000
20000
15000
10000
5000
0
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140


NOx Outlet Comparison Combined
E High N2Oout
E High NOout
E High NO2out
E Low N2Oout
E Low NOout
E Low NO2out
TPU N2Oout
TPU NOout
TPU NO2out
Concentration (PPM)
0
200
400
600
800
1000
1200
0
20
40
60
80
100
120
140
160
Data Point

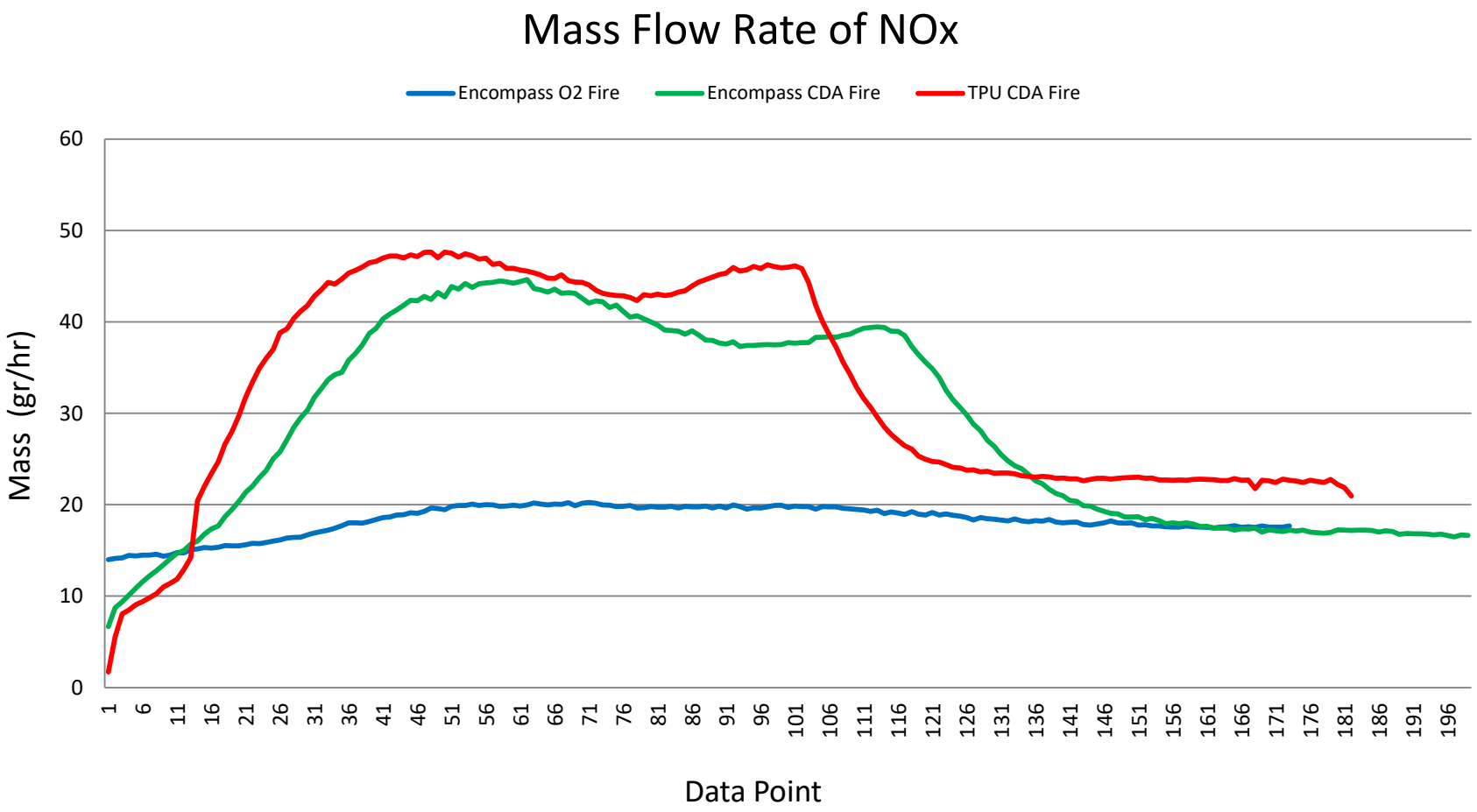
Chamber Clean NO_x Results

- The Encompass abatement unit running in “CDA fire” mode was very comparable to the TPU also in “CDA fire” mode

	Avg. NO (ppmv)	Avg. NO_2 (ppmv)	Avg. N_2O (ppmv)
Encompass @ CDA Fire	645	169	152
TPU (CDA Fire)	787	163	236

  - The two also have similar dilution factors

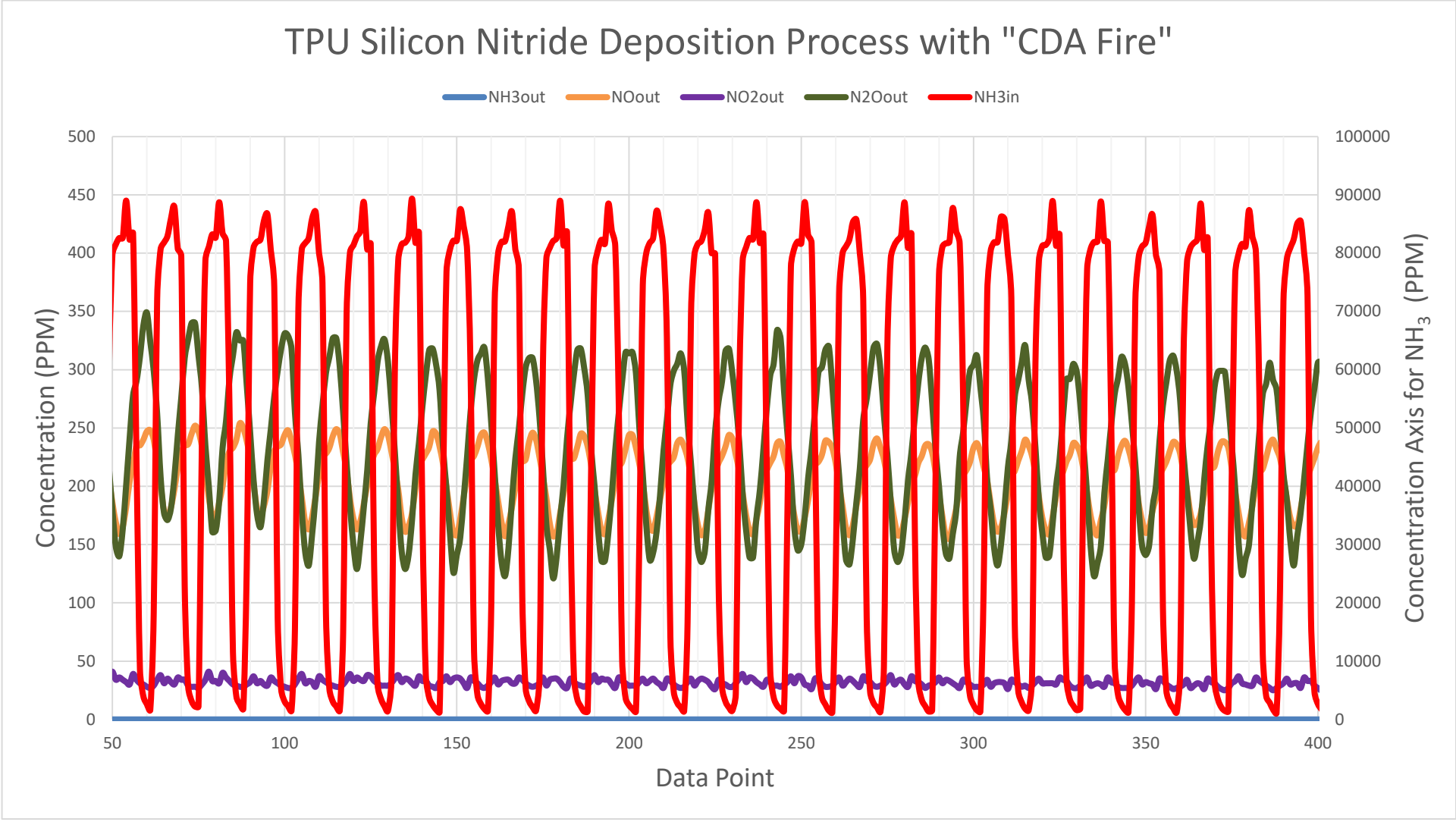
- The NOx concentration was markedly higher for the Encompass unit running in “O2 fire” mode
  - This is expected as higher temperatures will favor NO2 production
  - Interestingly, due to the lower total flow rate, the mass flow of NOx is actually less than the CDA fire modes

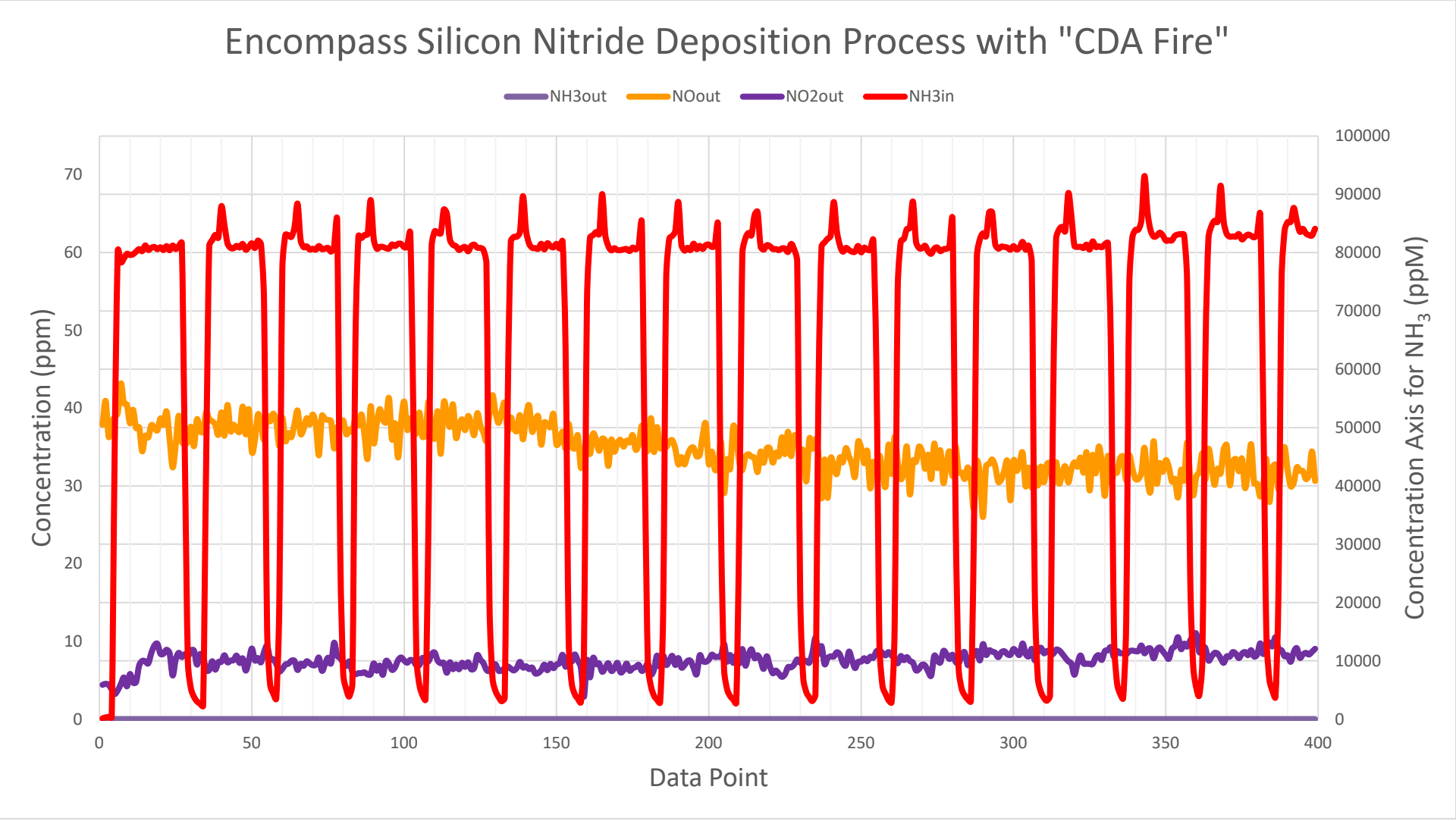

Mass Flow Rate of NOx
Encompass O2 Fire
Encompass CDA Fire
TPU CDA Fire
Mass (gr/hr)
0
10
20
30
40
50
60
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
141
146
151
156
161
166
171
176
181
186
191
196
Data Point

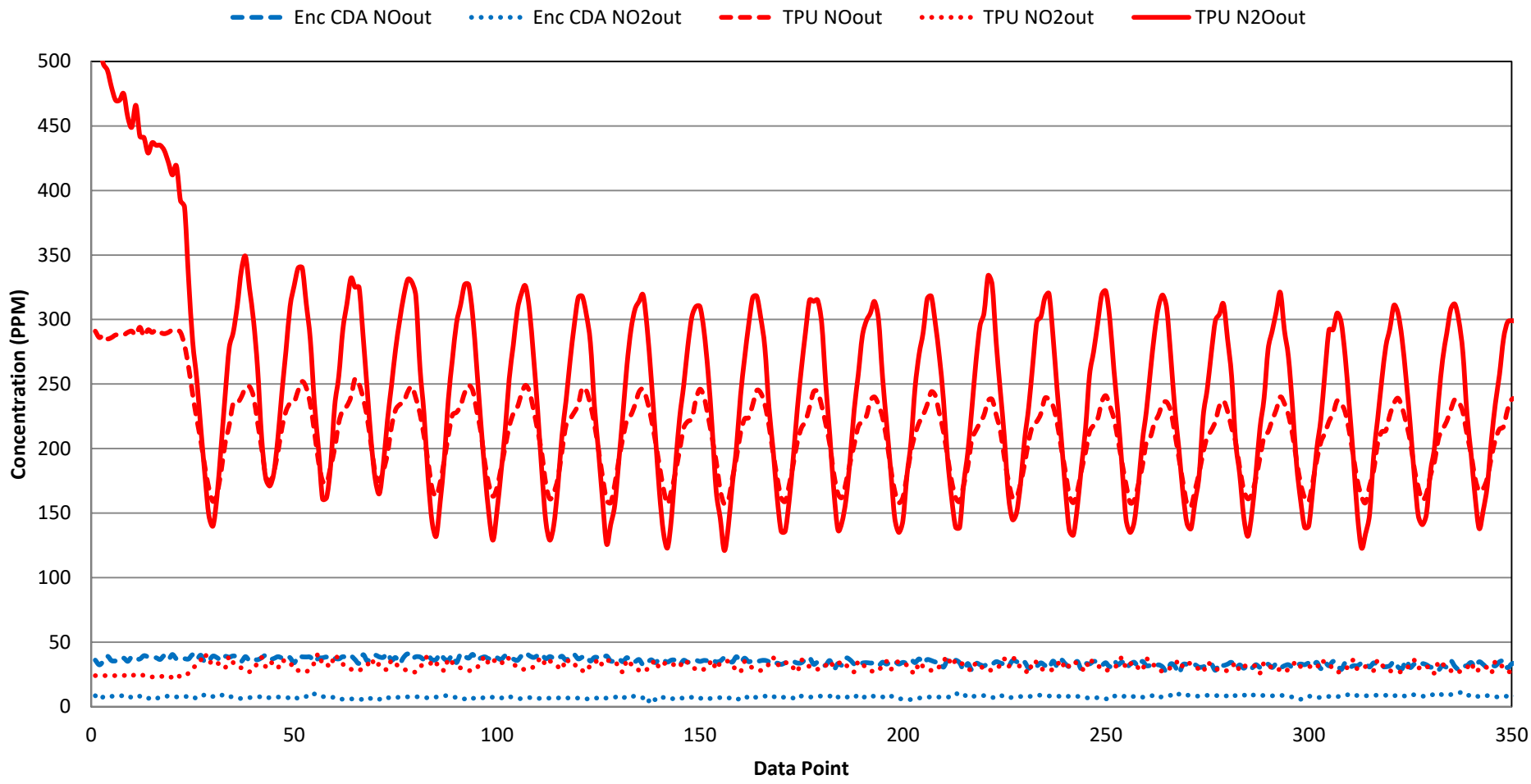
Process Step Results

Process Step Testing Objectives

- What is the NH3 Removal Efficiency?
- Does the Encompass wet-burn-wet first stage remove the NH3 effectively and what are the differences in NOx production?


TPU Silicon Nitride Deposition Process with "CDA Fire"
NH3out
NOout
NO2out
N2Oout
NH3in
Concentration (PPM)
Concentration Axis for NH3 (PPM)
Data Point
500
450
400
350
300
250
200
150
100
50
0
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
50
100
150
200
250
300
350
400


Encompass Silicon Nitride Deposition Process with "CDA Fire"
NH3out
NOout
NO2out
NH3in
Concentration (ppm)
Concentration Axis for NH3 (ppM)
Data Point
0
10
20
30
40
50
60
70
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
0
50
100
150
200
250
300
350
400


Encompass CDA Versus TPU CDA NOx Out (Process Emissions)
Enc CDA NOout
Enc CDA NO2out
TPU NOout
TPU NO2out
TPU N2Oout
Concentration (PPM)
500
450
400
350
300
250
200
150
100
50
0
0
50
100
150
200
250
300
350
Data Point

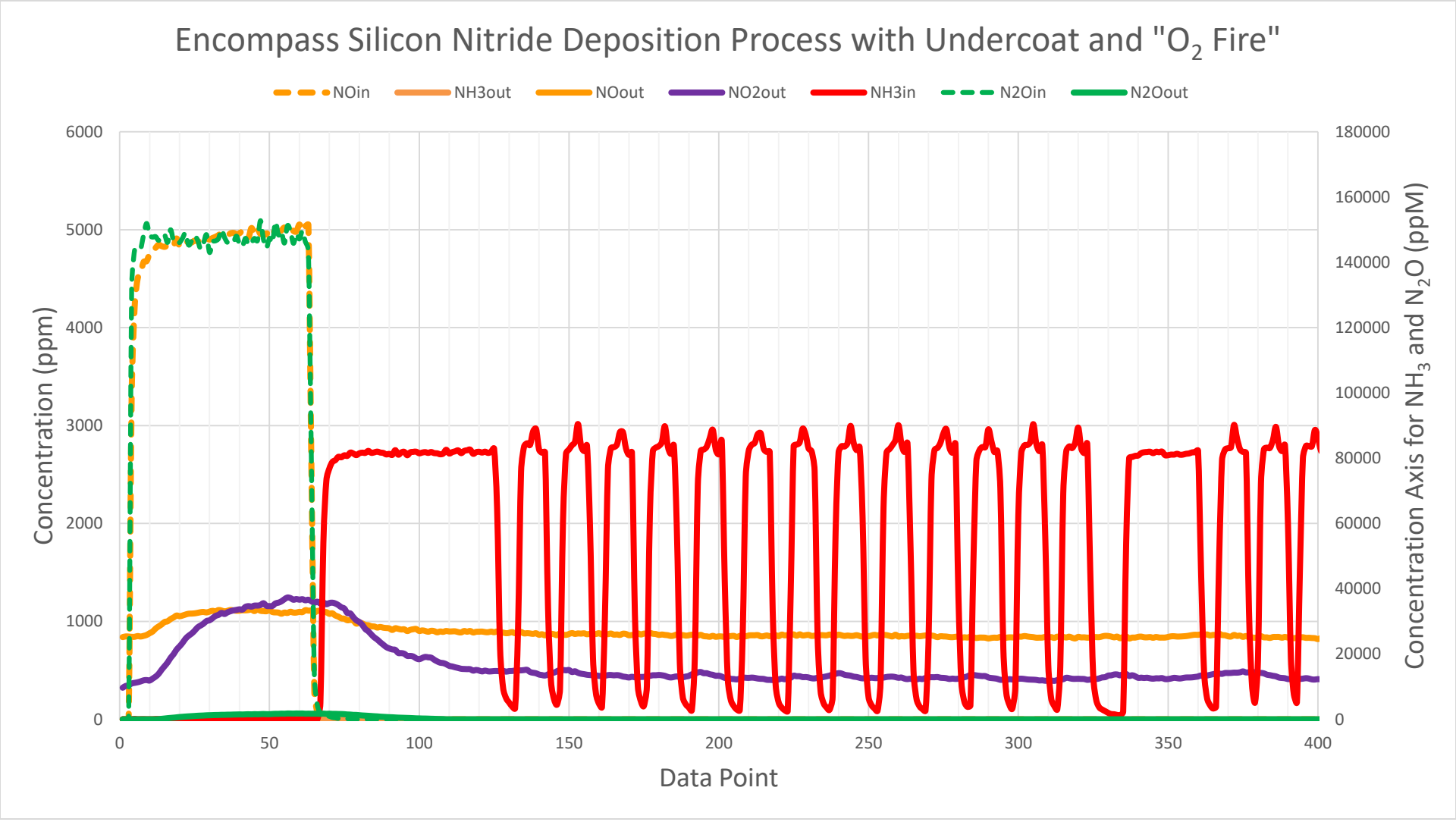
Process Step NO_x Results

- Again, the Encompass abatement unit running in “CDA fire” mode was very comparable to the TPU also in “CDA fire” mode. The inlet concentrations of NH3 were pretty much identical.

	Avg. NO (ppmv)	Avg. NO_2 (ppmv)	Avg. N_2O (ppmv)
Encompass @ CDA Fire	34	8	< 10
TPU (CDA Fire)	212	31	251

- Appears that the first stage wet scrubber which allows removal of excess NH3 prior to the burn chamber, makes a significant difference in NOx and N2O production. It is believed that excess NH can react with NO to produce N2O.

$$NH + NO \leftrightarrow N2O + H$$


Encompass Silicon Nitride Deposition Process with Undercoat and "O2 Fire"
NOin
NH3out
NOout
NO2out
NH3in
N2Oin
N2Oout
Concentration (ppm)
Concentration Axis for NH3 and N2O (ppM)
Data Point
0
1000
2000
3000
4000
5000
6000
0
20000
40000
60000
80000
100000
120000
140000
160000
180000
0
50
100
150
200
250
300
350
400

Process Step NO_x Results (cont.)

- The Encompass running in “O2 fire” mode data seems to back up the efficacy of the first stage wet-scrubber as the N2O levels drop below detect after the pre-coat step.

- The N2O destruction efficiency of the Encompass in “O2 fire” mode also averaged ~99% although we do see increases in NOx production in the effluent as expected.

- It is also evident that the N2O/NOx levels did not fluctuate with NH3 input as seen in the TPU.

Miscellaneous Discussion

Utility and Maintenance

- Utilities forecasted for the Encompass were comparable to that of the existing Edwards TPU

- Final cost analysis showed an increase of about 20% from forecasted costs, mainly due to water usage. However the costs of operation of the Encompass unit was still comparable to the TPU.

- The Encompass unit, once the testing was done, ran for ~13 months without maintenance needed. Repairs were needed after the unit developed a water leak. This ability to run without maintenance reduces the cost of operation of the Encompass significantly versus the TPU. Estimates show overall a difference of ~60% savings.

- Although particulates were not quantified, it was noticed that the Encompass effluent seemed to have a higher concentration of aerosol particulates than the TPU. It is theorized that the particulates may have been trapped by the ceramic liner used by the TPU. This is partially evident in the Encompass' ability to run continuously without need for maintenance.

NOx and DRE Discussion

- It is important to take into account that NOx production is a complex issue and that the burners in both the Encompass and TPU unit were not tuned to minimize NOx prior to testing.

- In developing the Mandatory Reporting Rule Subpart I, EPA concluded that maintenance performed on an abatement unit could affect the DRE for greenhouse gases. Lowering the frequency of maintenance can give greater confidence that a unit is achieving the require DREs. Also, internal testing at TI has shown that TPU DRE degrades over time as chamber liner plugs up during normal processing.

- Also, as buildup in the combustion chamber is minimal (due to the Encompass Wetted Wall technology), maintenance is not expected to have any effect on DRE.

Future Evaluation Considerations

- Next step could potentially be to measure DREs again to track possible degradation over time of NF3

- Results from the wet-burn-wet technology seems promising in removing unwanted chemistries from reaching the combustion chamber. TI plans to evaluate a unit for tungsten oxide deposition