REINHOLD ENVIRONMENTAL Ltd.

2012 NOx-Combustion Round Table & Expo Presentation

February 13-14, 2012, in Columbus, OH / Hosted by AEP

Training Class 5: Misconceptions of Catalyst Performance

Johnson Matthey Catalysts

REINHOLD ENVIRONMENTAL LTD.

2012 NOx-Combustion Round Table
Columbus, OH
February 13, 2012

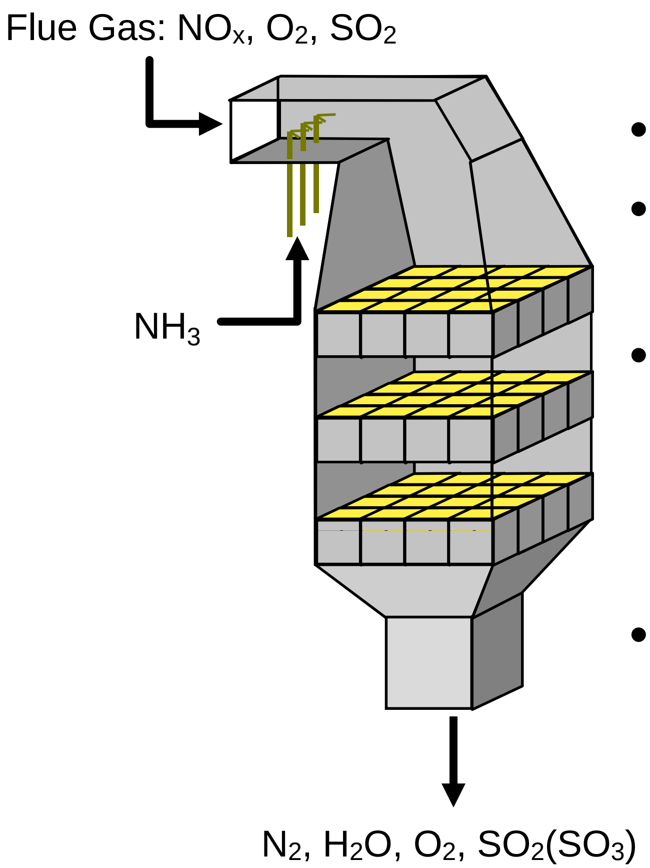
Ken Jeffers

ENVIRONMENTAL CATALYSTS AND TECHNOLOGIES

Topical Agenda

- The SCR Reactor – How it works
- Potential – Theoretical & Measured
- Garbage in, garbage out – SCR inlet quality affects the outlet quality
- Catalyst Lifetime
- Application of Performance Correction Curves

How the SCR Reactor Works – Quick Review of the Basics



- SCR = <u>S</u>elective <u>C</u>atalytic <u>R</u>eduction
- Purpose is to reduce NO_x (NO & NO_2) from combustion exhaust
- Ammonia (NH_3) is injected into flue gas as reducing agent. Flue gas passes through catalyst layers installed in a reactor
- NH_3 reacts with NO_x on the catalyst surface to form nitrogen and water vapor

$$4NO + 4NH_3 + O_2 \xrightarrow{\text{Catalyst}} 4N_2 + 6H_2O$$

$$2NO_2 + 4NH_3 + O_2 \xrightarrow{\text{Catalyst}} 3N_2 + 6H_2O$$

Each Layer does not do Equal work
Day 1 Performance

Example: 3 initial layers,
NO_x reduction = 90%
NH_3 slip </= 2 ppmvd
Fresh Catalyst

NO_x in = 300 ppmvd
NH_3 in = 272 ppmvd

Layer 1: α = 0.91
deNOx ~85%

NO_x out = 45 ppmvd
NH_3 out = 17 ppmvd

Layer 2: α = 0.38
deNOx ~37%

NO_x out = 28.2 ppmvd
NH_3 out = 0.2 ppmvd

Layer 3: α = 0.01
deNOx ~1%

NO_x out = 28.0 ppmvd
NH_3 Slip = 0.0 ppmvd

Each Layer does not do Equal work
End of Life Performance

Example: 3 initial layers,
NO_x reduction = 90%
NH_3 slip </= 2 ppmvd
Aged Catalyst

NO_x in = 300 ppmvd
NH_3 in = 272 ppmvd

Layer 1: α = 0.91
deNOx ~65%

NO_x out = 104 ppmvd
NH_3 out = 76 ppmvd

Layer 2: α = 0.73
deNOx ~58%

NO_x out = 44 ppmvd
NH_3 out = 16 ppmvd

Layer 3: α = 0.36
deNOx ~32%

NO_x out = 30.0 ppmvd
NH_3 Slip = 2.0 ppmvd

Potential: measure of catalyst's ability to reduce NO_x

NO_x reduction in a layer depends on:

- Potential in the layer – activity, total surface area
- NH_3 to NO_x ratio entering the layer

Laboratory testing to determine Catalyst Potential (Activity):

$$k = -AV \ln(1 - \eta)$$

$$P = \frac{k}{AV} \qquad AV = \frac{V_{fg}}{\text{Tot } SA_{cat}}$$

$$P = -\ln(1 - \eta)$$

Mis-Application of Equations

So . . . for 90% NO_x reduction:

$$P = -\ln(1 - 0.90) = -\ln(0.1)$$

$$P = 2.3$$

X

$k = -AV \ln(1 - \eta)$ valid for laboratory measurements with molar ratio (NH_3:NO_x) = 1.0
This equation not to be used for determining theoretical potential requirements

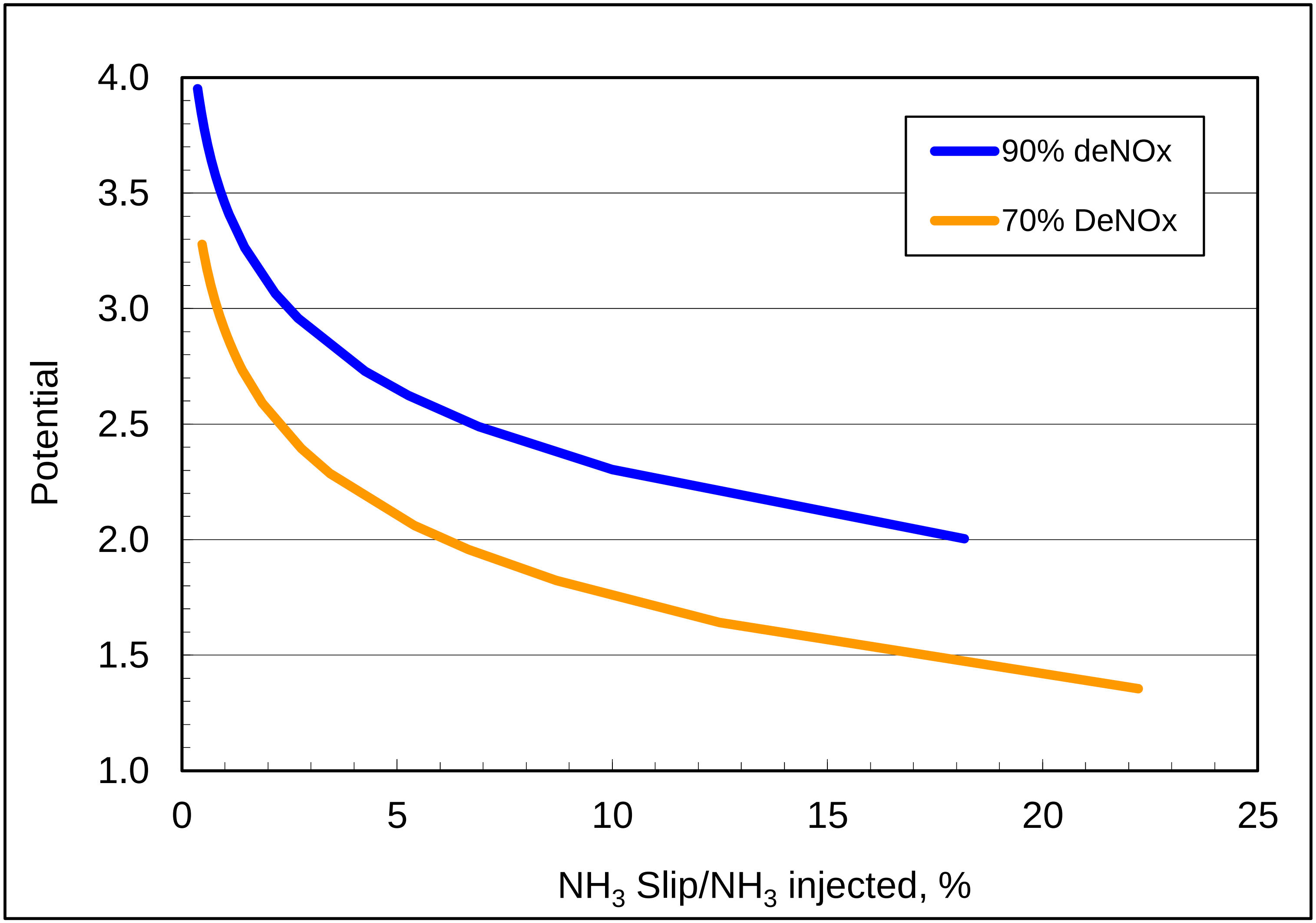
Potential – Theoretical Minimum Requirement

- Theoretical Potential – minimum requirement to achieve a desired NO_x reduction / NH_3 slip performance
- Theoretical $P_{min} = f(NO_{x\ in}, NO_{x\ out}, NH_3\ slip)$

NO_x in	NO_x out	deNOx	NH_3 Slip	P_{min}
10	1	90%	2	2.00
100	10	90%	2	3.07
200	20	90%	2	3.41
400	40	90%	2	3.75

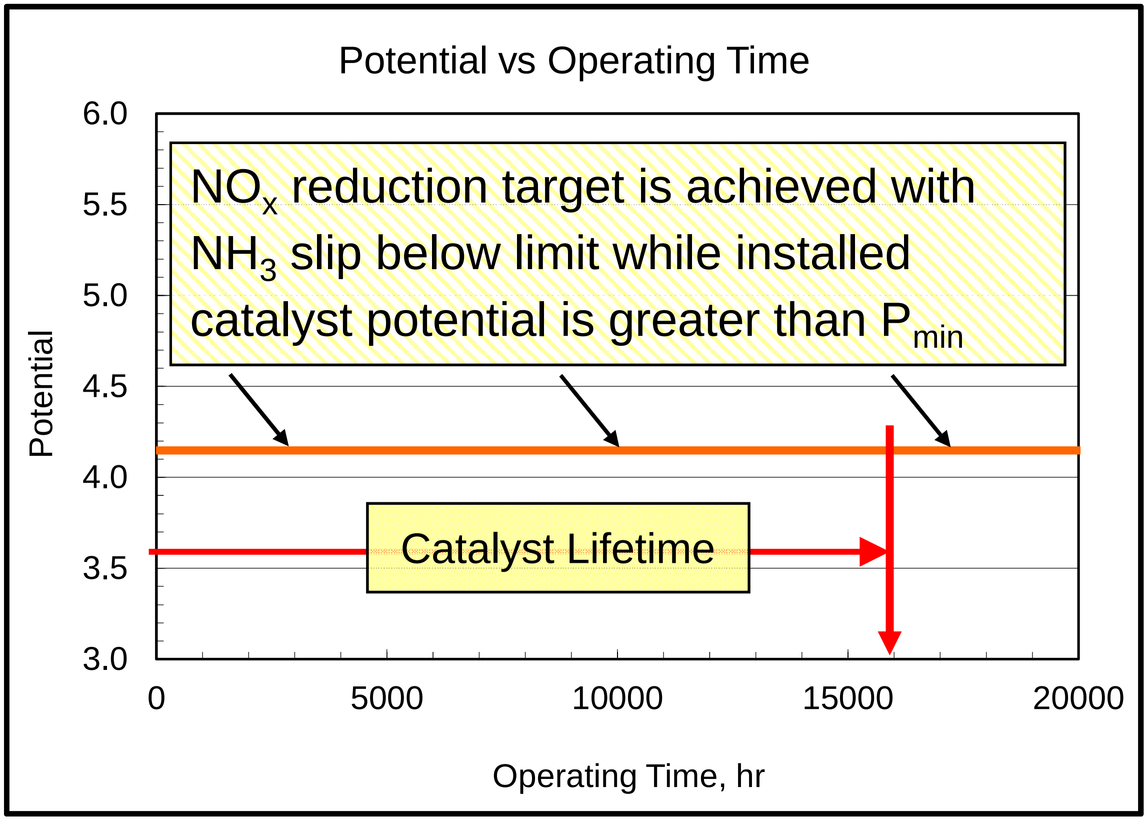
As slipped NH_3 becomes a smaller fraction of injected NH_3, more catalyst potential is required.

Potential Required for NH_3 slip ~ 2 ppmvd



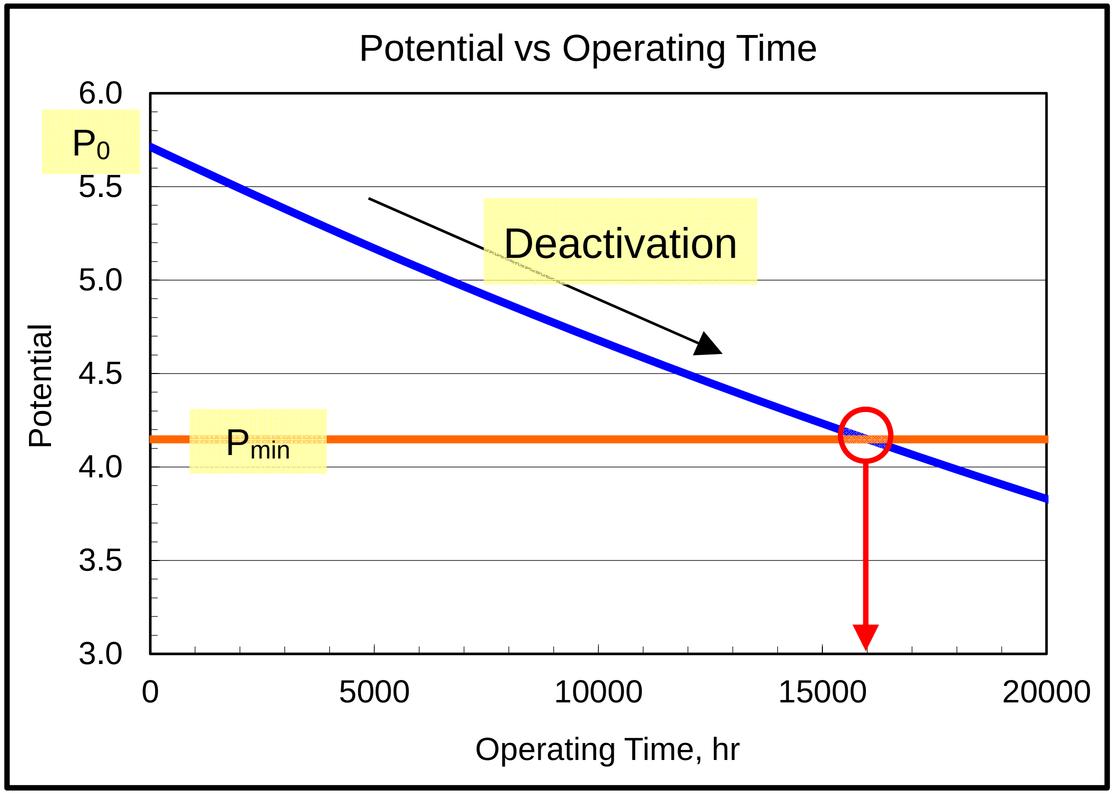
Practical Example – Minimum Potential

- $NO_{x\ in}$ = 300 ppmvd
- $NO_{x\ out}$ = 30 ppmvd
- 90% NO_x reduction
- NH_3 slip ≤ 2 ppmvd
- P_{min} = 4.15 (includes 15% margin)
- Catalyst lifetime = 16000 hr



Initial Potential, P_0

- Operating Life: 16000 hr
- P_{min} = 4.15
- Relative potential at 16000 hours: P/P_0 = 0.73
- Initial potential installed: P_0 = 5.7

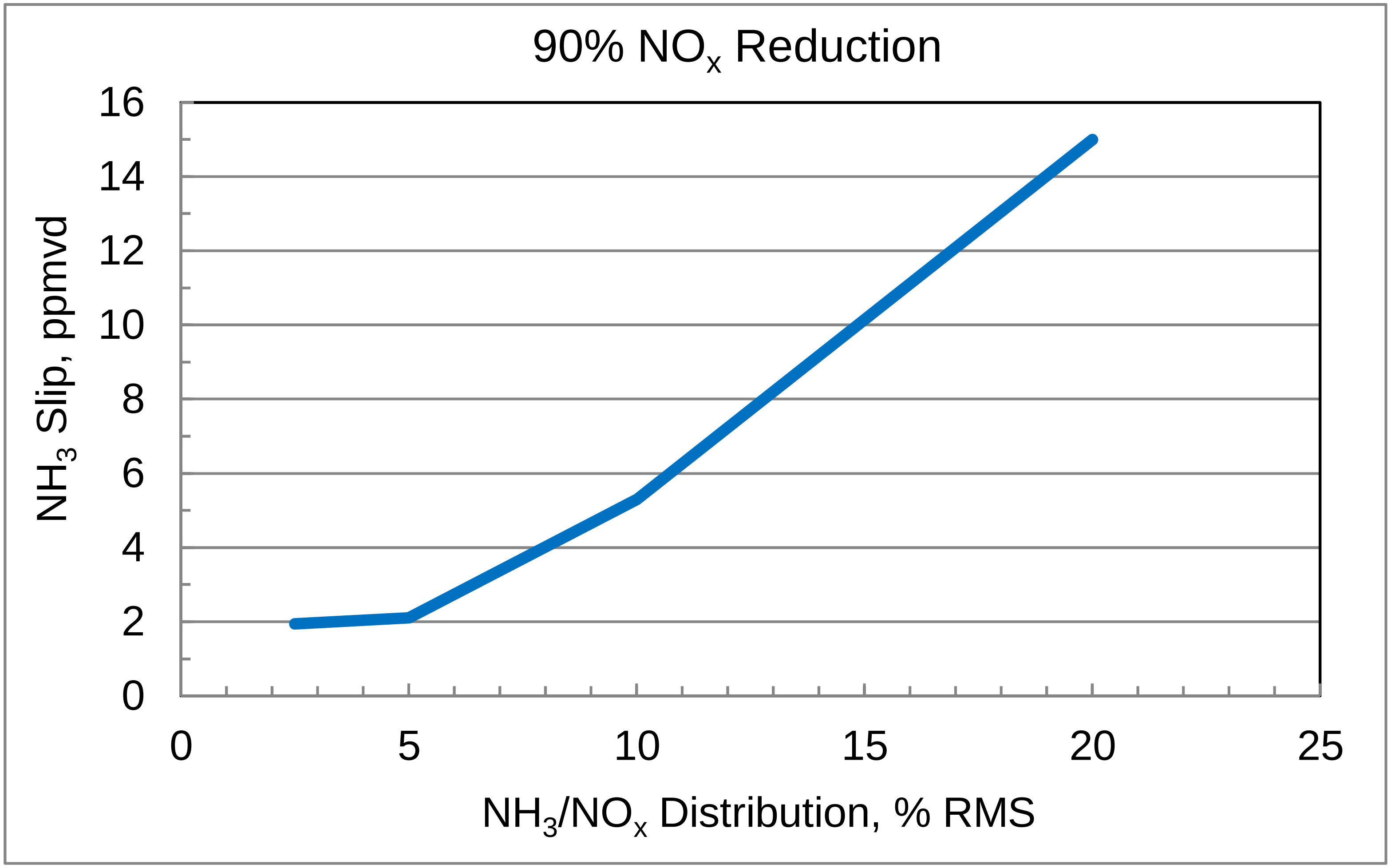


Beyond Installed Potential . . .
Thorough NH_3-NO_x Mixing is Required

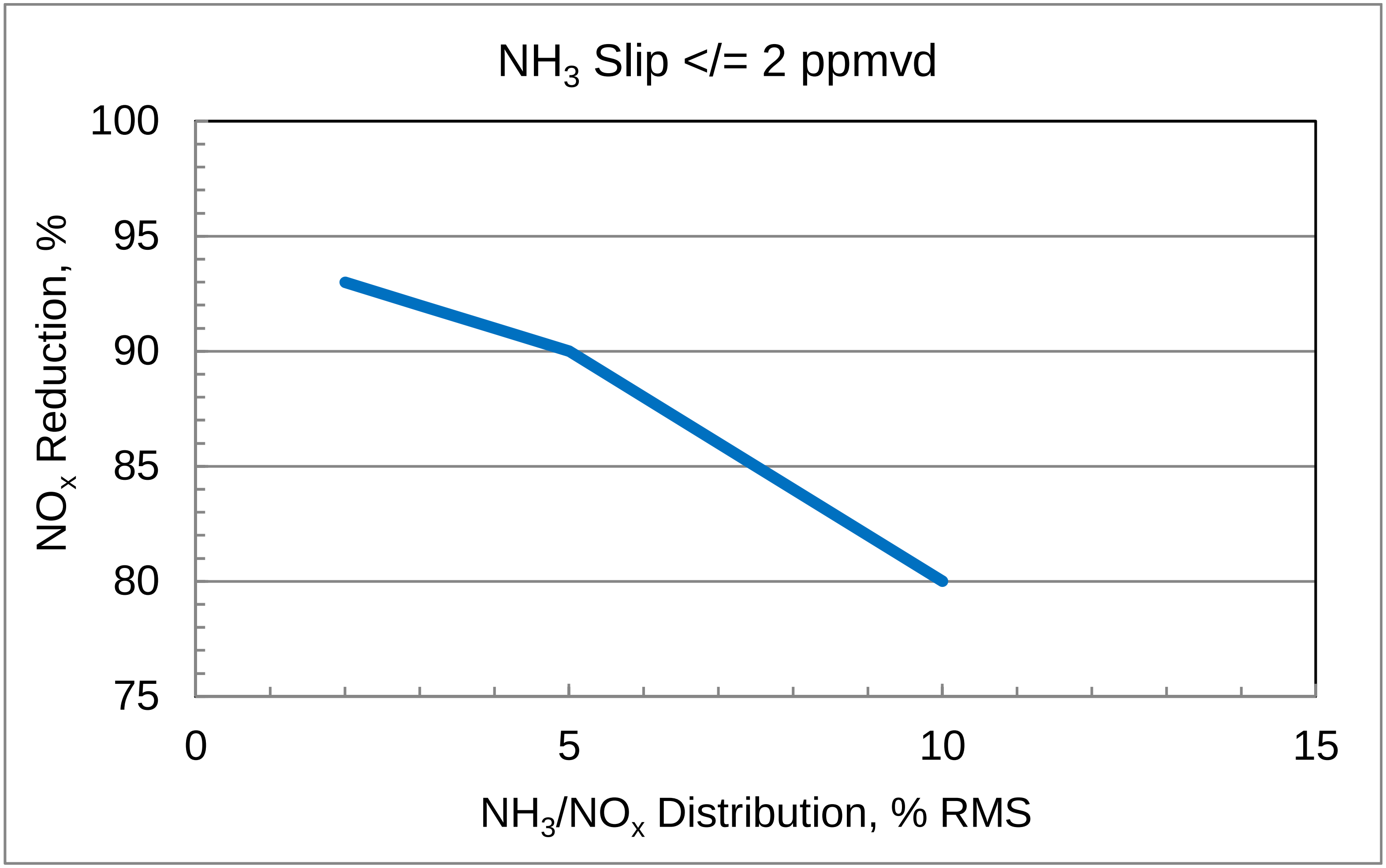
- Target: 90% NO_x Reduction, NH_3 Slip </= 2 ppmvd
- NH_3 slip depends on Mixing Quality at SCR inlet:

NH_3-NO_x inlet	NO_x out Dist	NH_3 Slip Avg	NH_3 Slip Max
2.5% RMS	23% RMS	<2 ppmvd	5 ppmvd
5% RMS	38% RMS	~2 ppmvd	10 ppmvd
10% RMS	68% RMS	5 ppmvd	>40 ppmvd

NH_3-NO_x Mixing
NH_3 Slip vs NH_3/NO_x Distribution



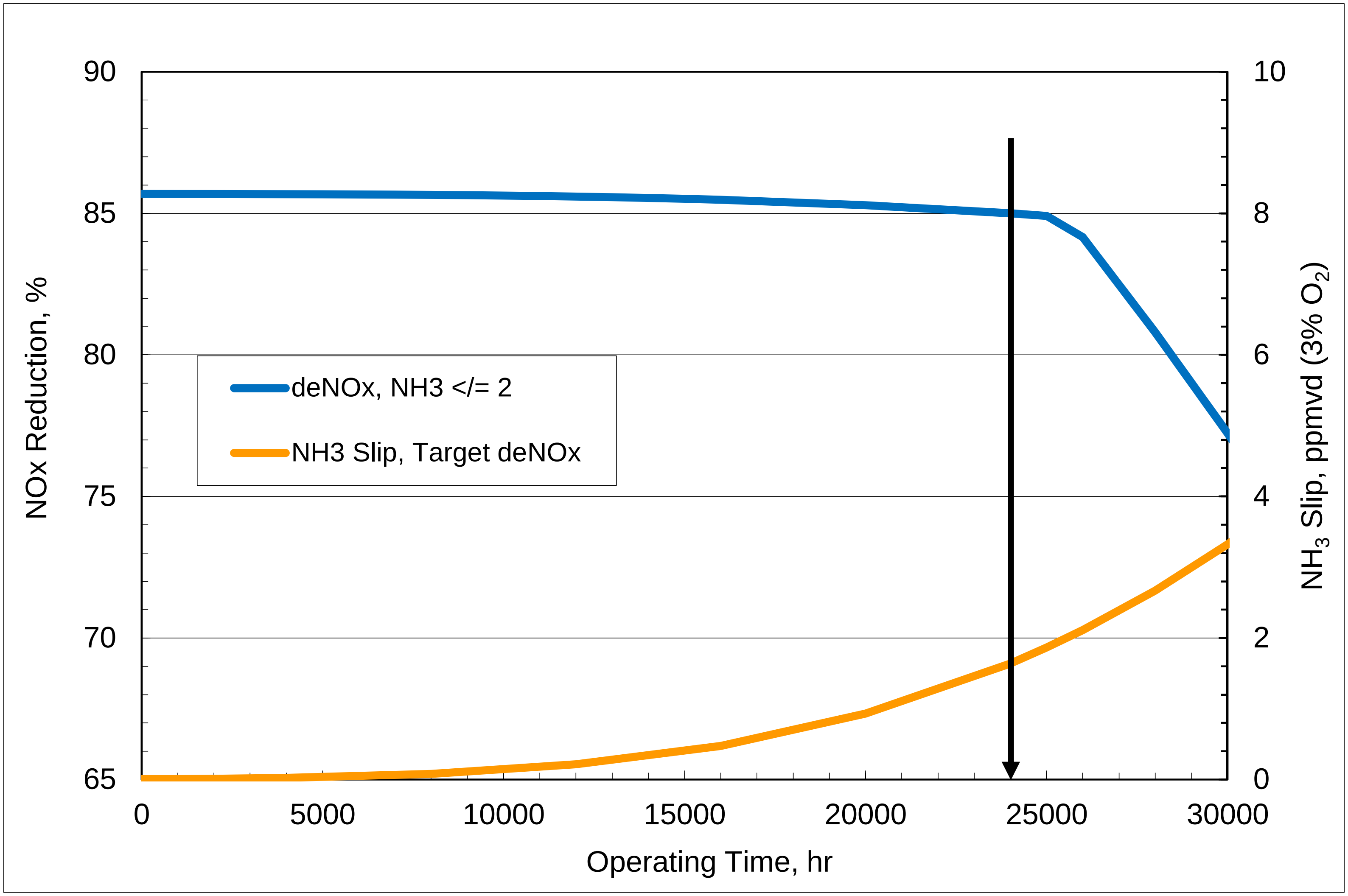
NH_3-NO_x Mixing
Best DeNOx vs NH_3/NO_x Distribution



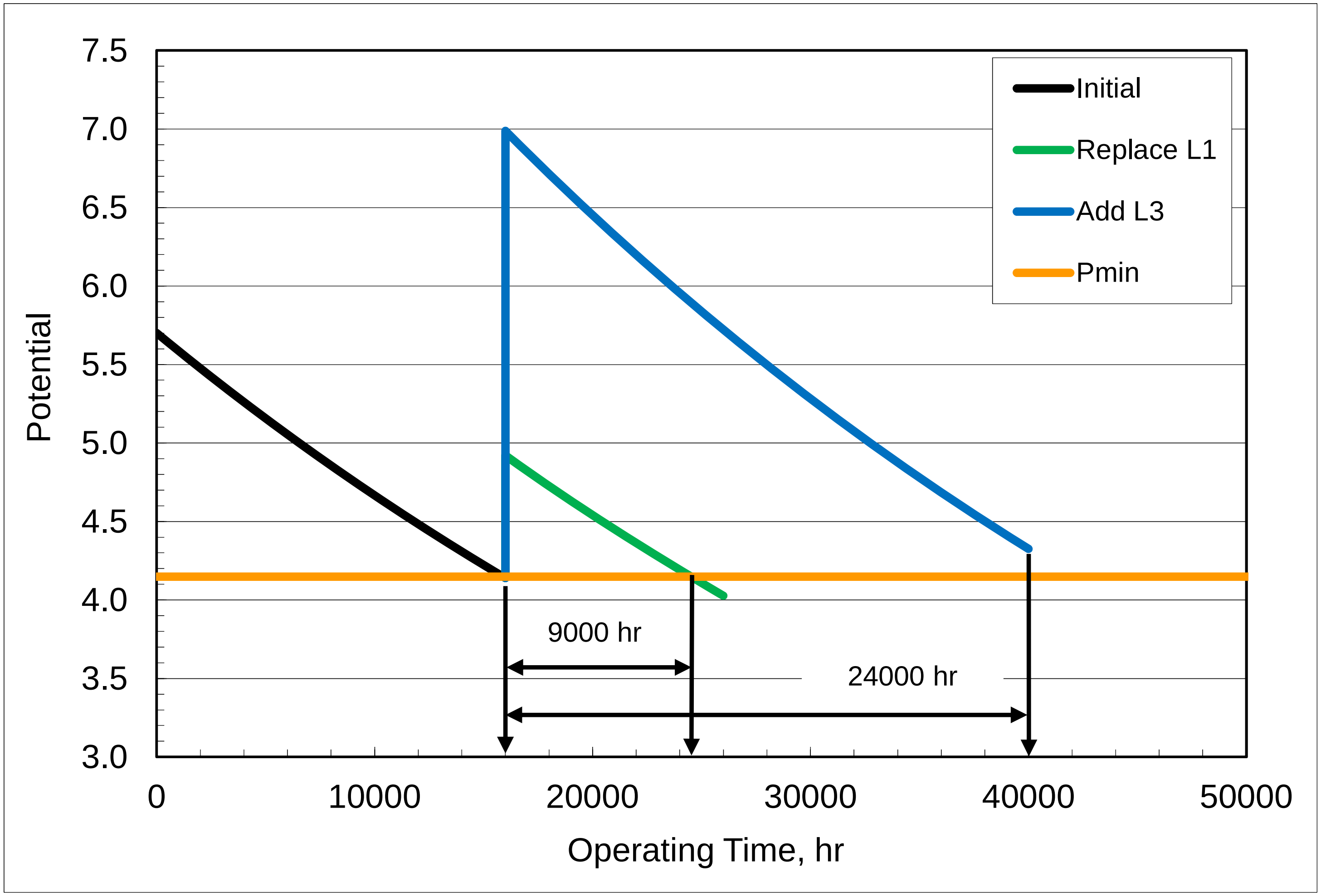
Catalyst Lifetime

- NO_x Performance Lifetime – duration the installed catalyst can achieve the desired NO_x reduction with NH_3 slip </ 2 ppmvd
- Beyond . . . Achieving desired NO_x reduction requires more NH_3 → higher NH_3 Slip

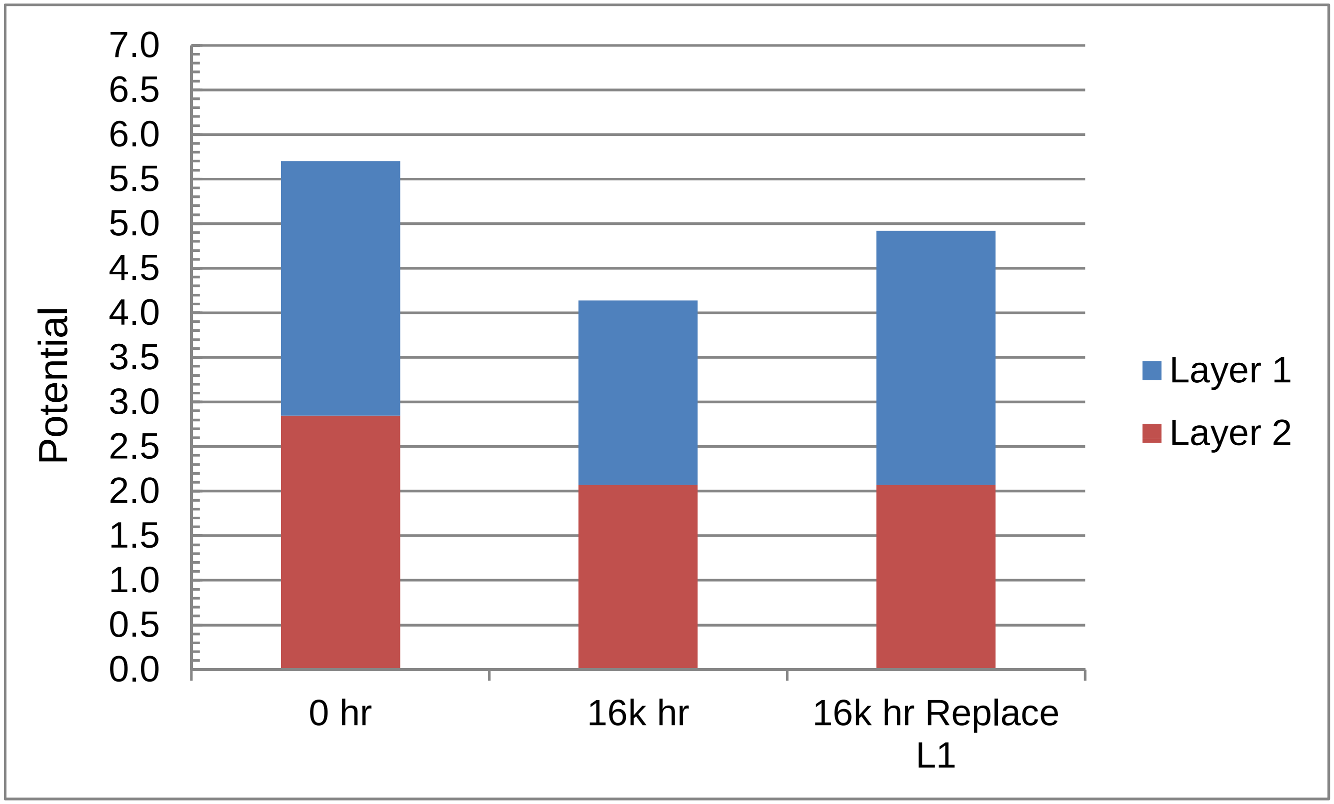
Catalyst Lifetime Example
Target: 85% deNOx, NH_3 slip = 2 at 24,000 hr



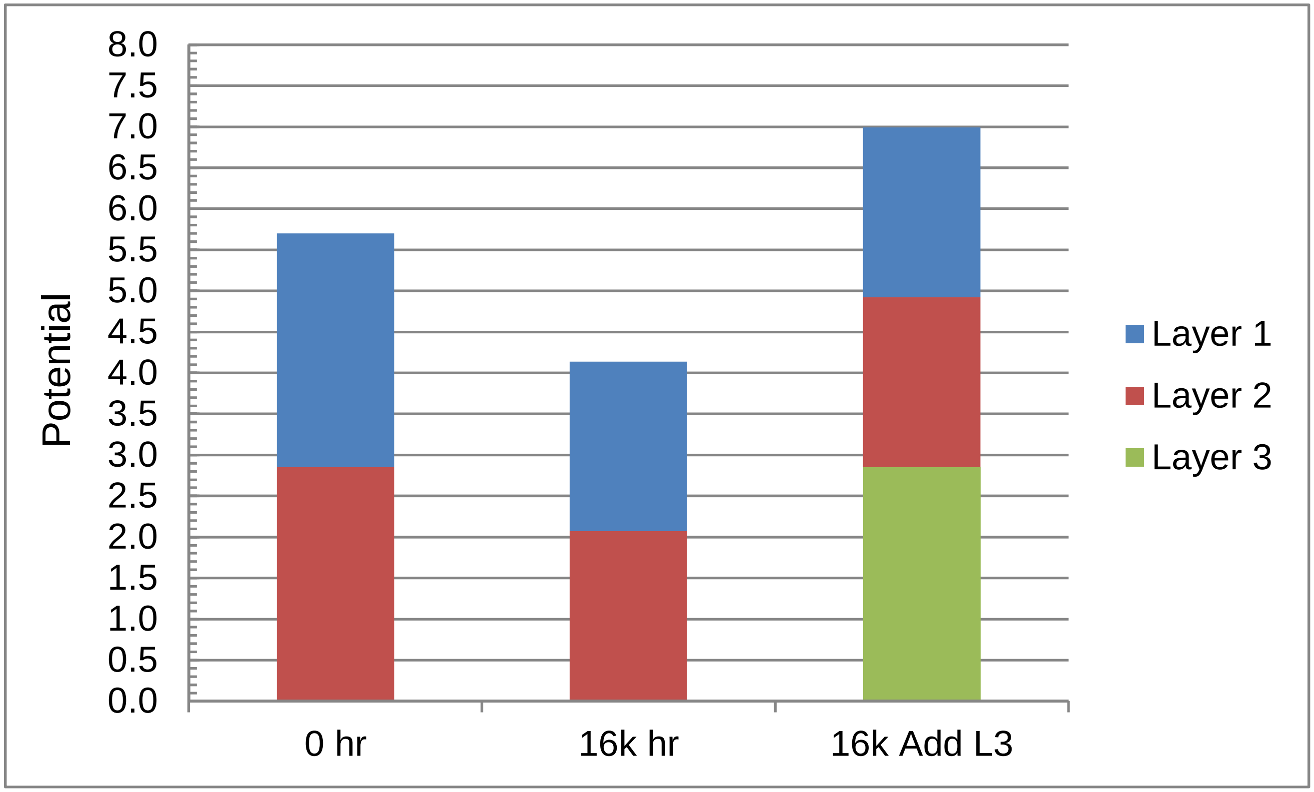
Catalyst Lifetime – Advantage of Spare Layers
2+1 Layer Example



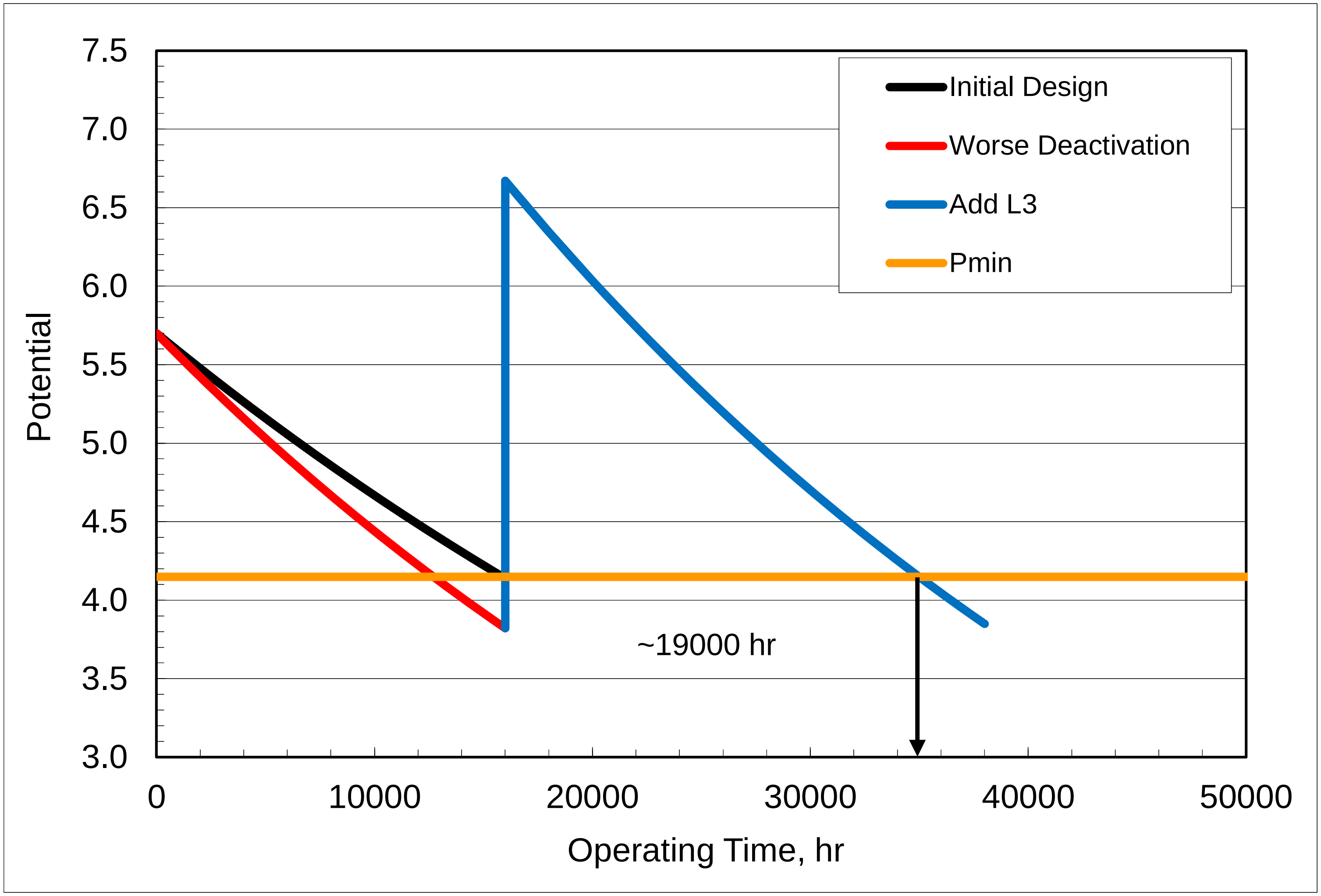
Adding Spare Layers vs Replacing Existing Layers



Adding Spare Layers vs Replacing Existing Layers



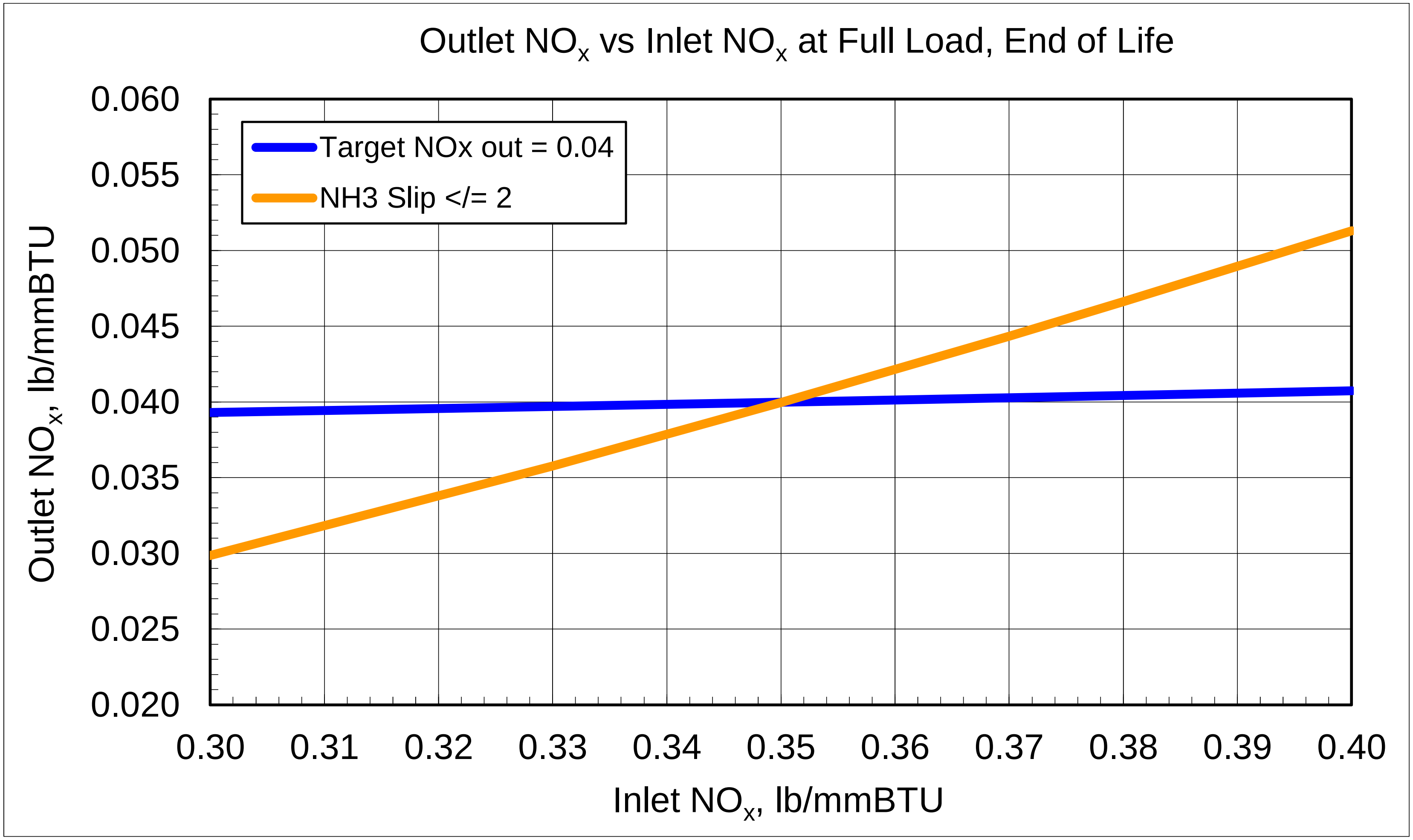
Catalyst Lifetime – Faster Than Expected Deactivation



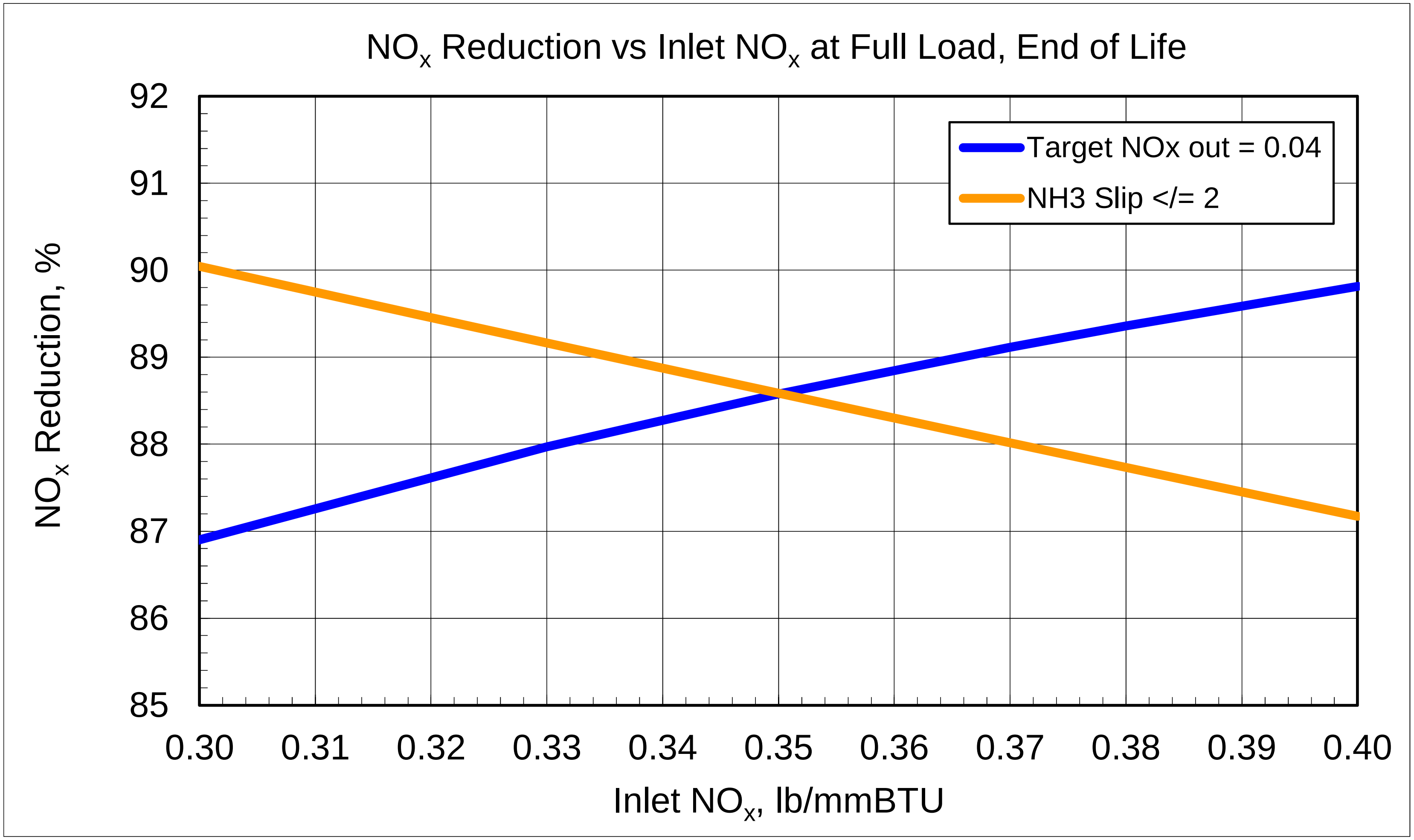
Performance Correction Curves

- Method to correct catalyst performance for off-design conditions
- With regard to temperature and flow rate, reasonably accurate for “small” deviations from design
  - Design Temperature +/- 50 °F
  - Design Flow +/- 10%
- More accurate if load-dependent
- Shape of curve depends on SCR operating scheme – controlling to $NO_{x,out}$

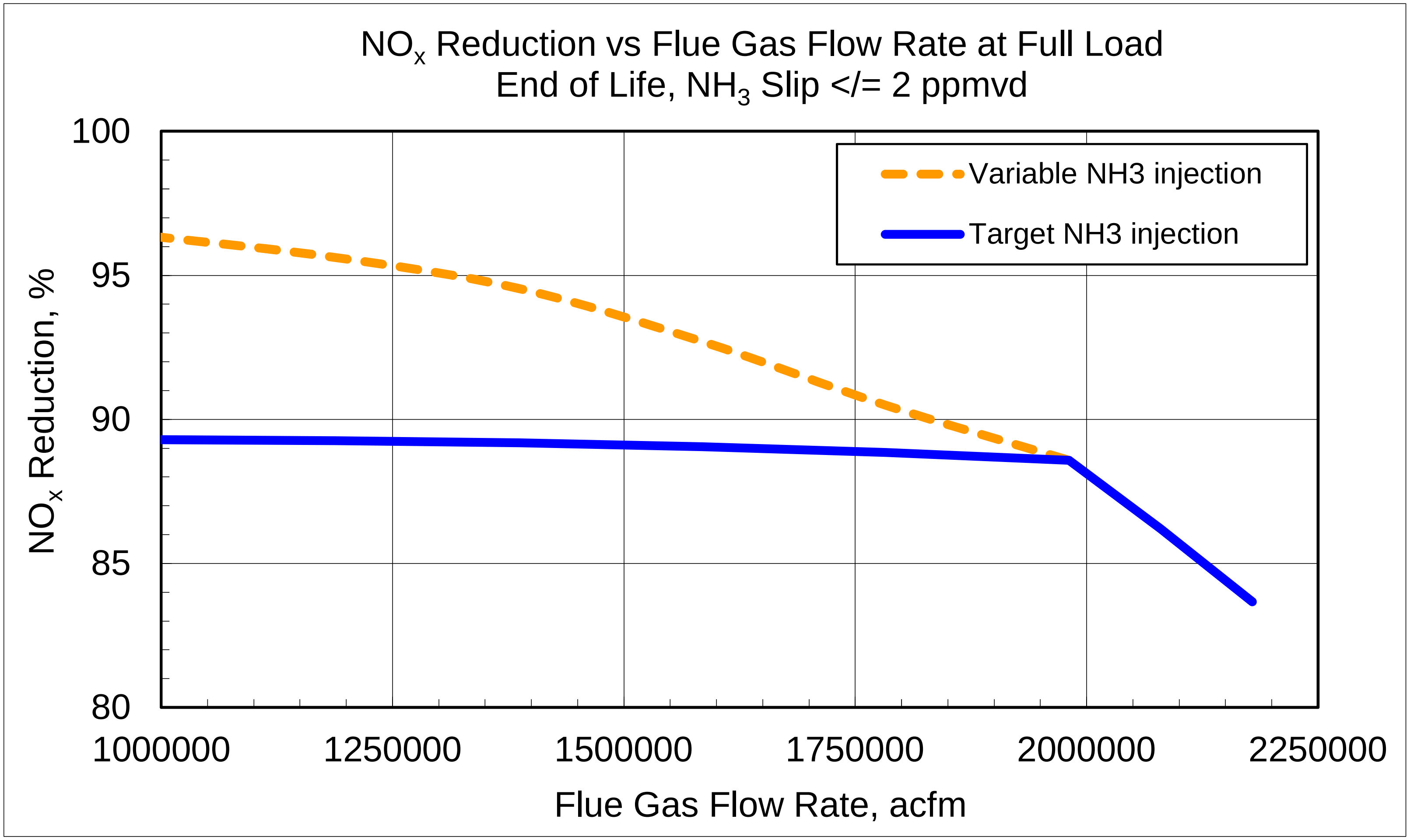
NO_x out vs NO_x in
Design NO_x out = 0.04 lb/mmBTU



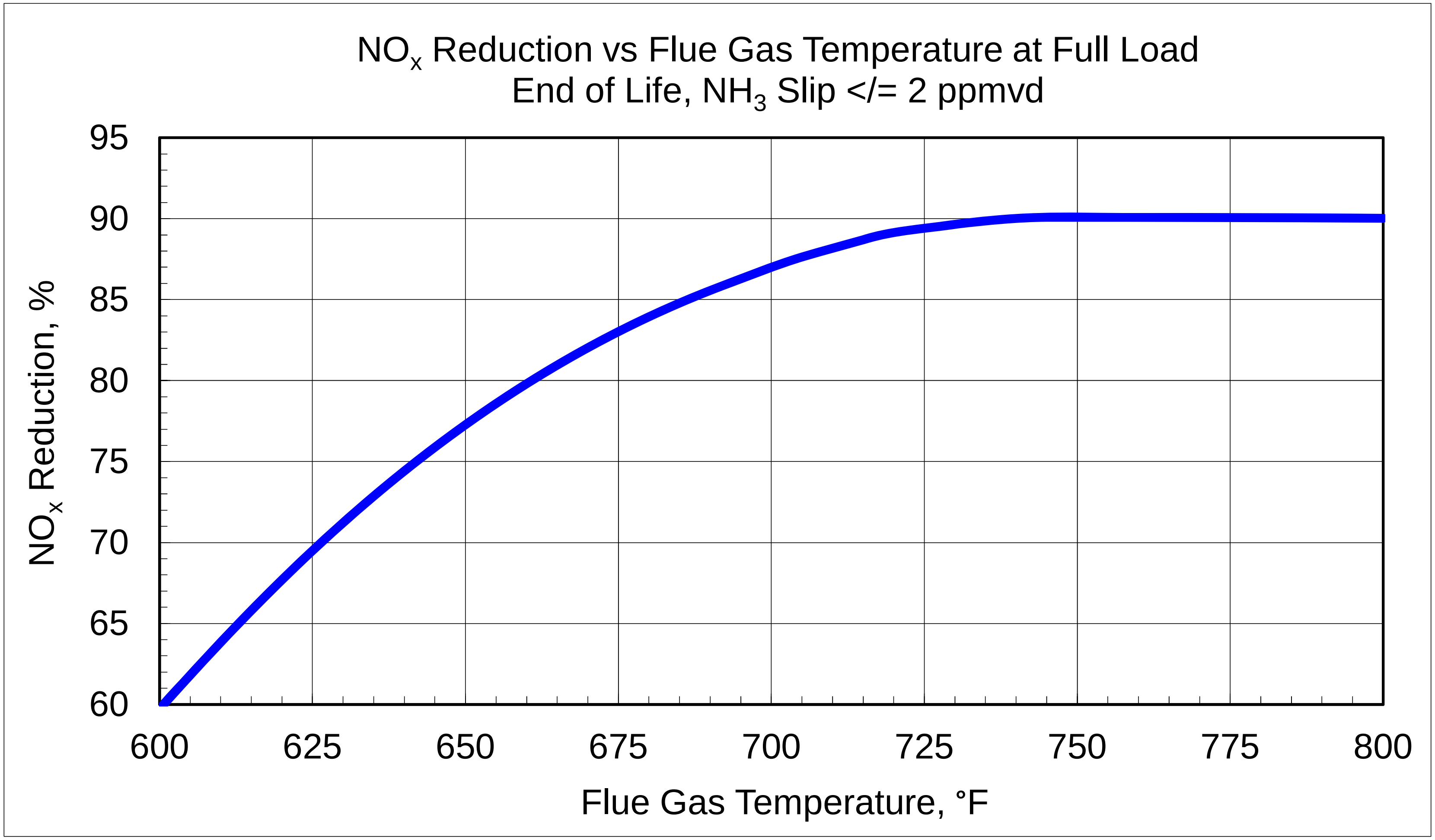
deNO$_x$ vs NO$_x$ in Design deNO$_x$ = 88.6%



deNO$_x$ vs Flue Gas Flow Rate
Design deNO$_x$ = 88.6% @ 1,981,000 acfm



deNO$_x$ vs Flue Gas Temperature
Design deNO$_x$ = 88.6% @ 715 °F



Summary

- Performance at each catalyst layer depends on inlet conditions and Potential
- 2 Concepts of Potential
  - Installed or Measured Potential
  - Theoretical minimum required Potential
- High NO_x reduction with low NH_3 slip requires good NH_3-NO_x mixing
- Add Spare Layers for increased Lifetime
- Correction Curves:
  - Accurate for “small” deviations from design operating conditions (Temperature, flow), more accurate if load-dependent
  - Shape may depend on control scheme

Thank You!

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