Southwest Research Institute®

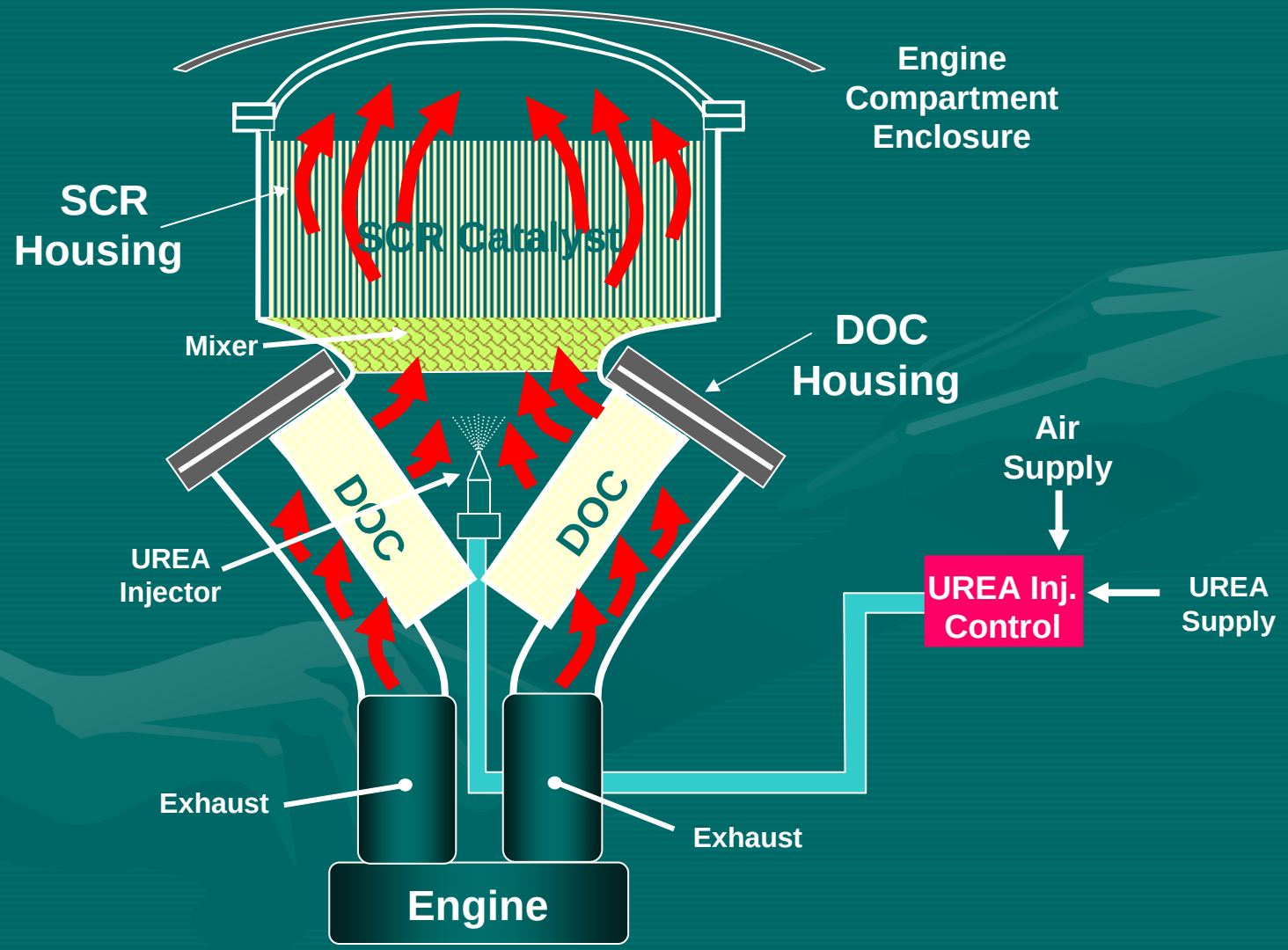
SwRI Locomotive Aftertreatment Informational Meeting

Locomotive Aftertreatment Concepts

Magdi Khair
Southwest Research Institute
San Antonio, Texas
December 2006

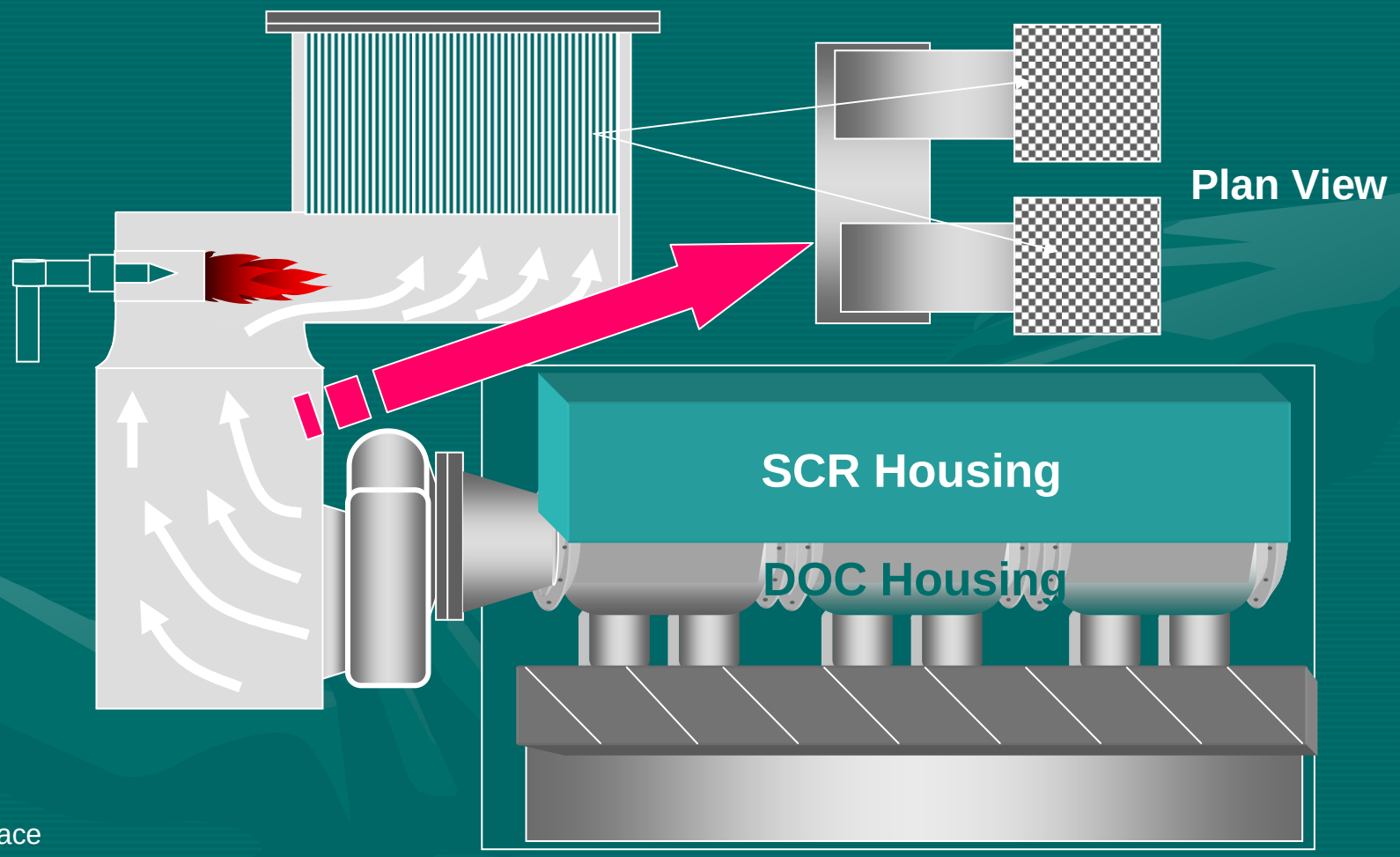
Concept 1

Pre-Turbo SCR NO_x Reduction System



Concept 2

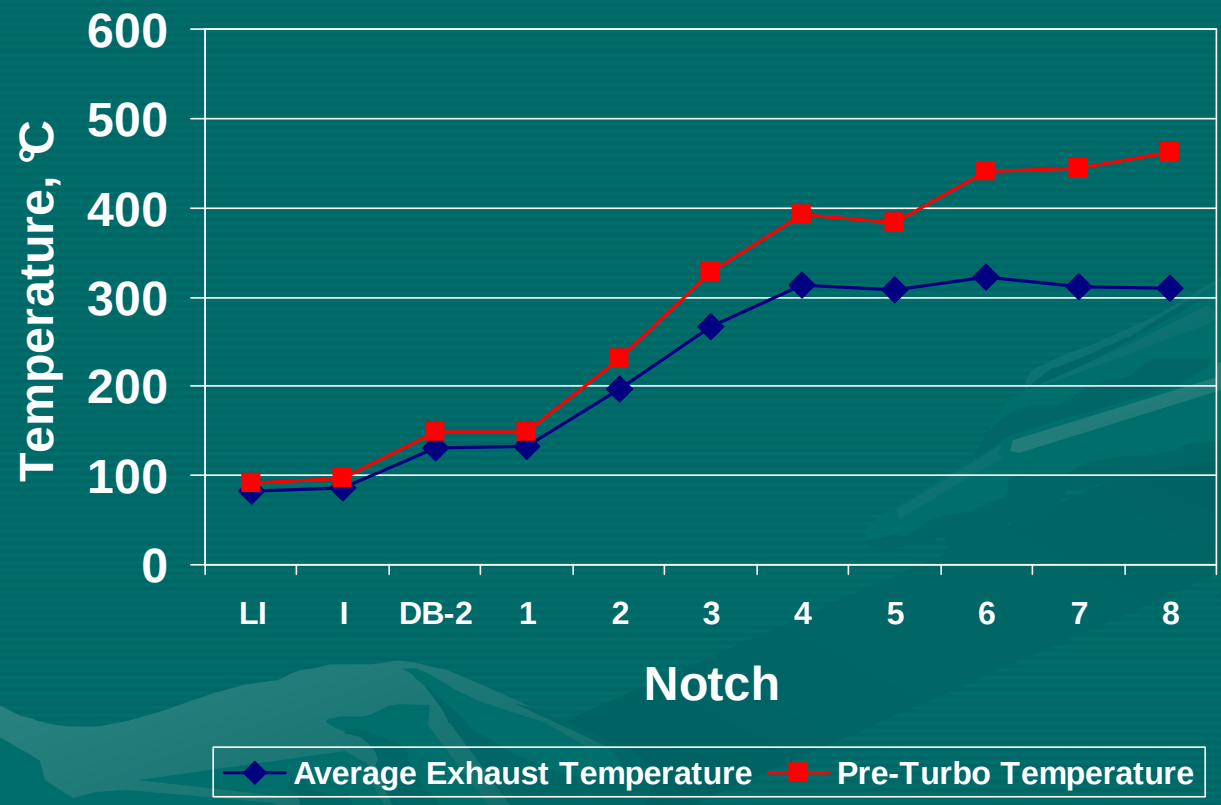
Post-SCR Actively Regenerated Wallflow DPF



- Space
- Weight
- Back Pressure

Projections 1 & 2

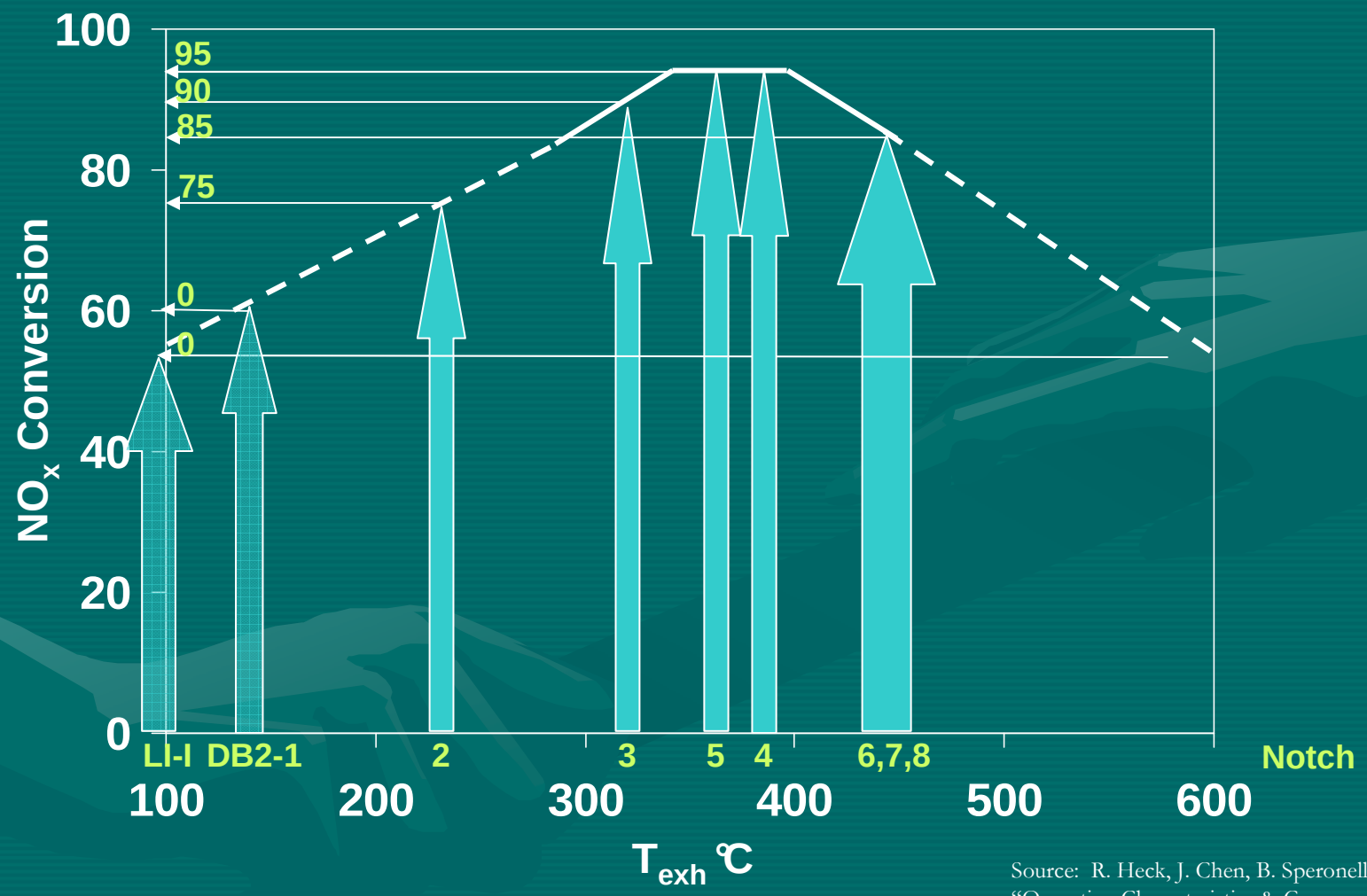
Pre- & Post-Turbo $T_{exh.}$- EMD



LI = Low Idle
I = Idle
DB-2 = Dynamic Brake

Loco: UP8353
Model: EMD SD70Ace
MY/EPA: 2005-Tier 2
HP: 4300

Catalytic Formulation VT- EMD



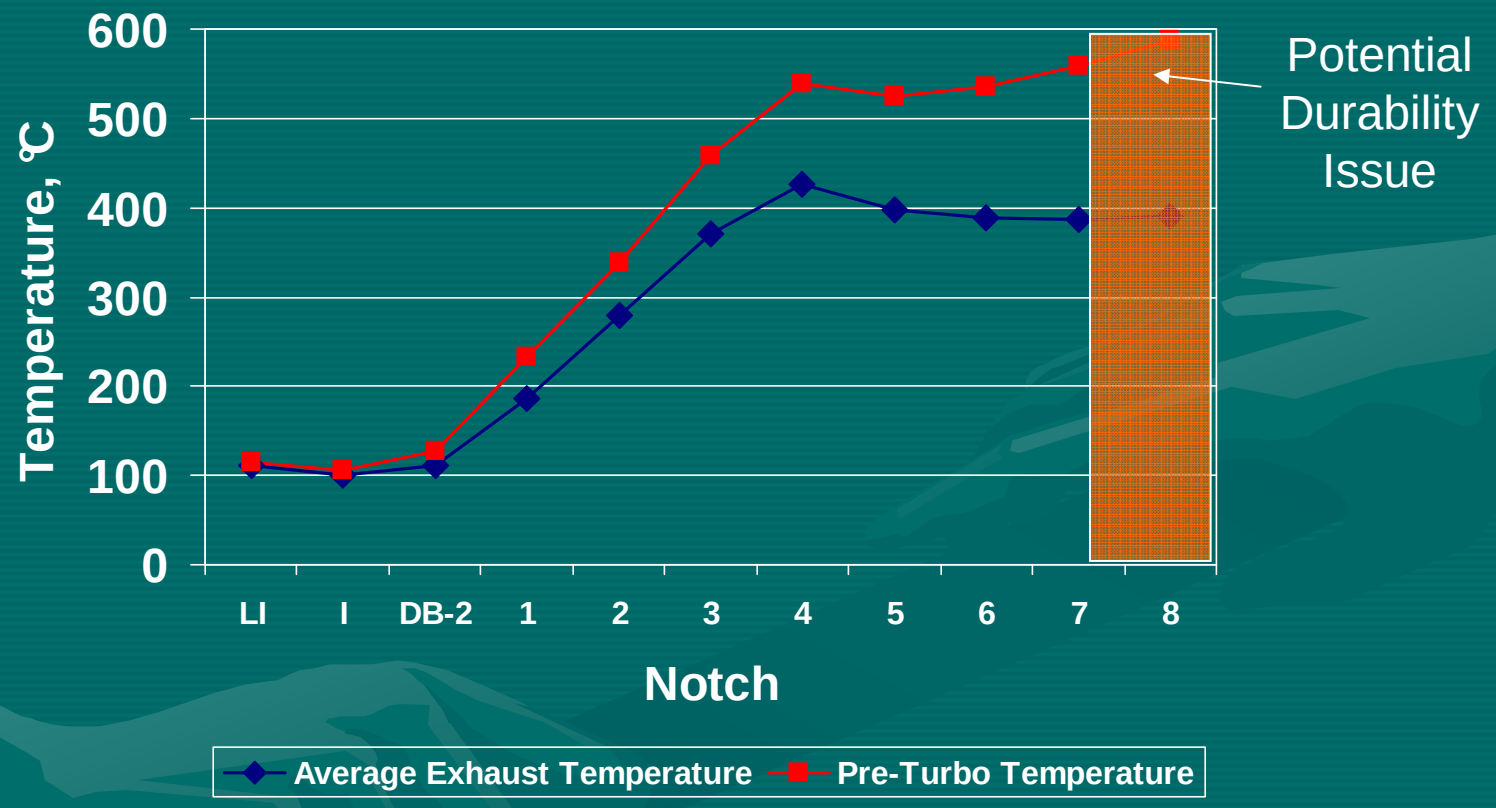
Source: R. Heck, J. Chen, B. Speronello, 1994, "Operating Characteristics & Commercial Operating Experience with High Temperature SCR NO_x Catalyst", Environmental Progress

Projected NO_x and PM For Concept 1 & 2 VT Formulation/Wallflow DPF - EMD

Notch Position	Pre-Turbo T_{exh} °C	Corr. NO_x g/kW-h	Projected NO_x Conv., %	Projected NO_x , g/kW-h	E.O. PM g/kW-h	Projected PM Red., %	Projected PM g/kW-h
LI	91	46.0	0	46.0	0.80	80	0.16
I	96	32.6	0	32.6	1.86	80	0.37
DB-2	149	12.3	0	12.3	0.25	80	0.05
1	149	12.6	0	12.6	0.19	90	0.02
2	231	9.0	75	2.25	0.29	90	0.03
3	237	6.8	90	0.68	0.32	90	0.03
4	393	5.7	95	0.29	0.26	90	0.03
5	384	5.1	95	0.26	0.22	90	0.03
6	441	5.3	85	0.80	0.24	90	0.03
7	445	5.3	85	0.80	0.24	90	0.02
8	462	5.9	85	0.89	0.21	90	0.02

1) SCR Installed Pre-Turbo
2) DPF is Actively-Regenerated
3) A Pre-SCR DOC is Used

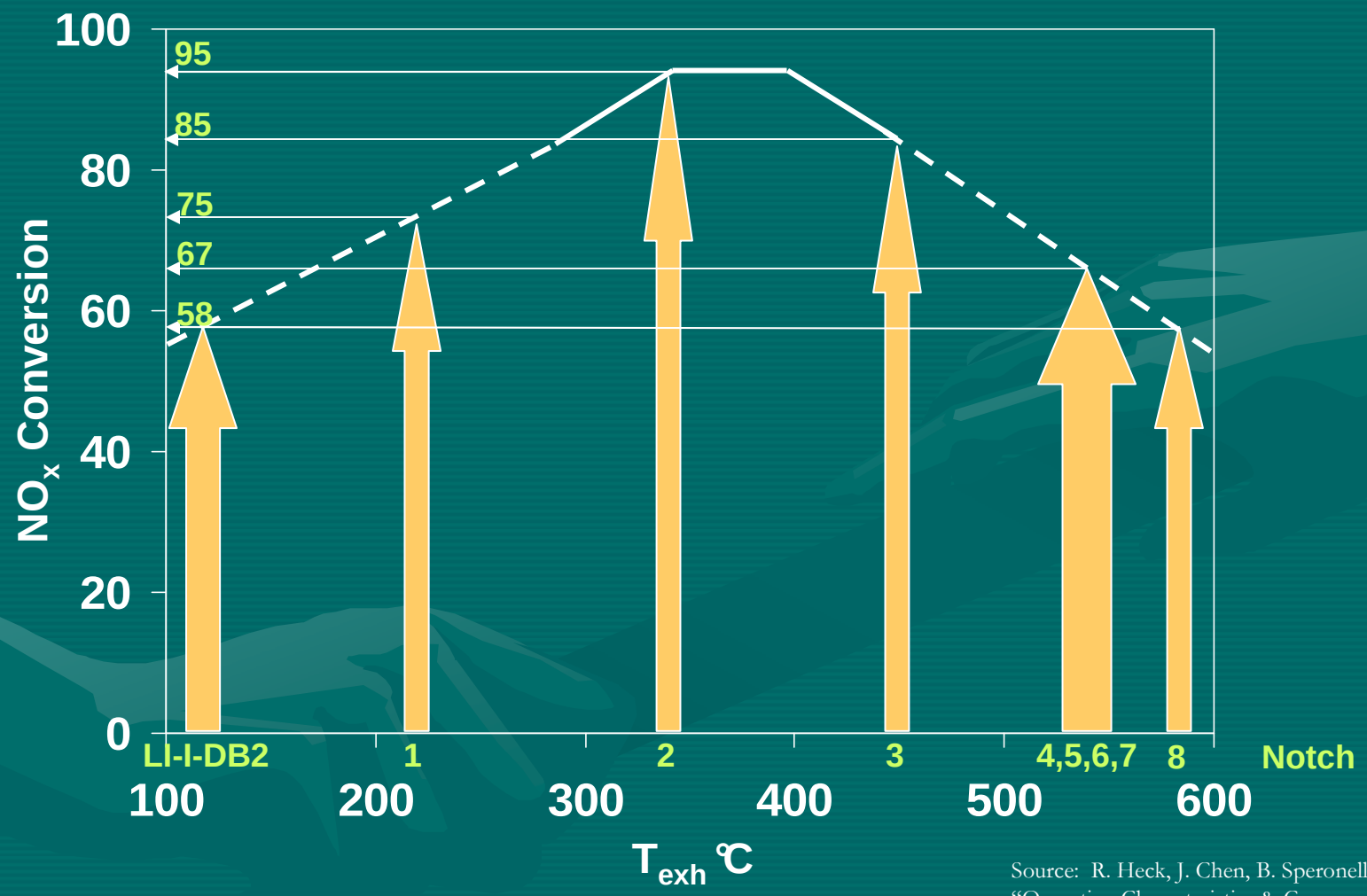
Pre- & Post-Turbo $T_{exh.}$- GE



LI = Low Idle
I = Idle
DB-2 = Dynamic Brake

Loco: BNSF7736
Model: GE ES44DC
MY/EPA: 2005-Tier 2
HP: 4400

Catalytic Formulation VT- GE



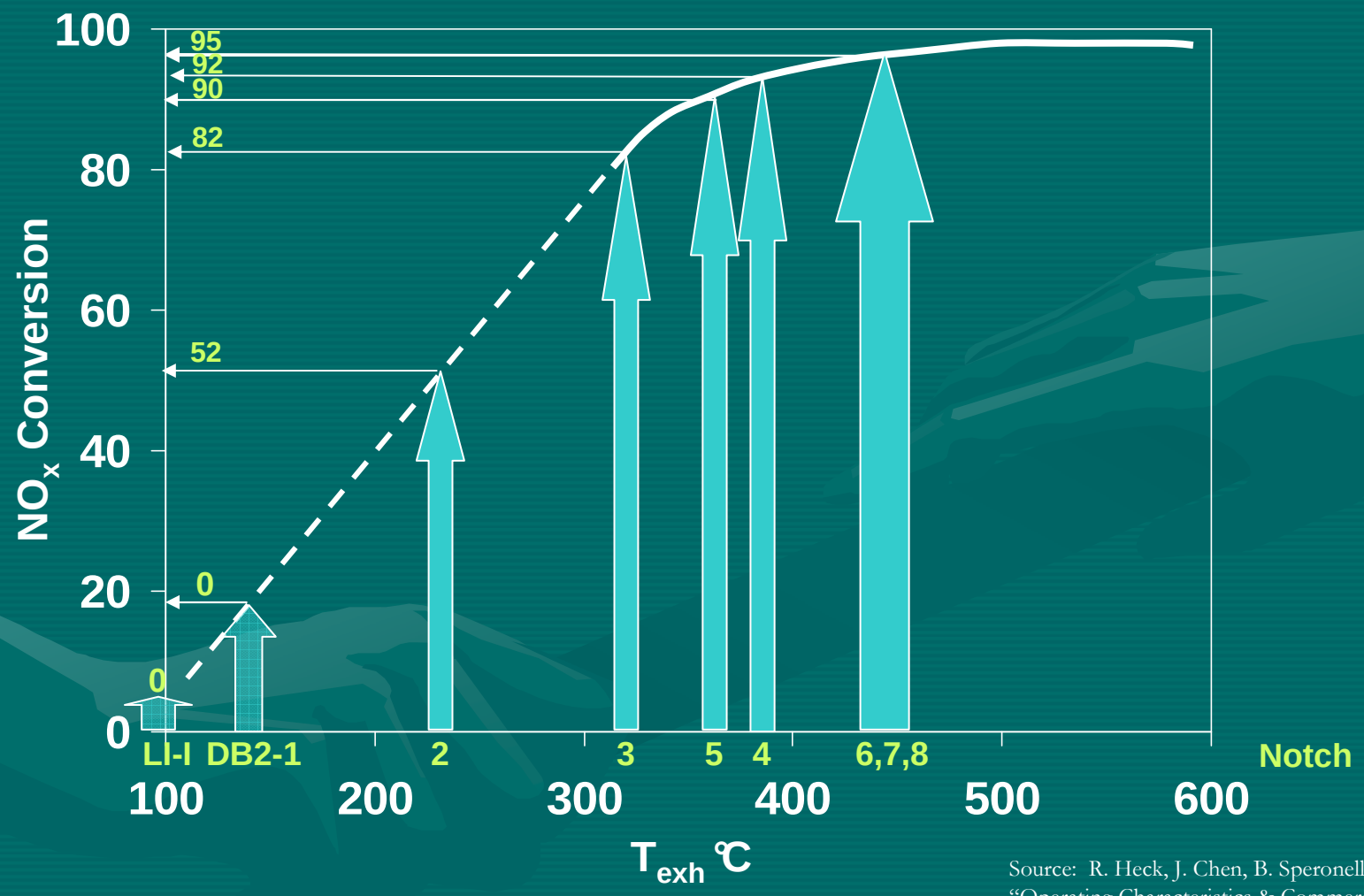
Source: R. Heck, J. Chen, B. Speronello, 1994, "Operating Characteristics & Commercial Operating Experience with High Temperature SCR NO_x Catalyst", Environmental Progress

Projected NO_x and PM For Concept 1 & 2 VT Formulation/Wallflow DPF - GE

Notch Position	Pre-Turbo T_{exh} °C	Corr. NO_x g/kW-h	Projected NO_x Conv., %	Projected NO_x , g/kW-h	E.O. PM g/kW-h	Projected PM Red., %	Projected PM g/kW-h
LI	114	49.1	0	49.10	0.89	80	0.18
I	106	26.0	0	26.00	0.61	80	0.12
DB-2	127	31.5	0	31.50	2.01	80	0.4
1	233	5.7	75	1.43	0.35	90	0.04
2	338	6.2	95	0.31	0.33	90	0.03
3	459	6.0	85	0.90	0.34	90	0.03
4	540	5.8	67	1.91	0.29	90	0.03
5	525	5.6	67	1.85	0.24	90	0.03
6	536	5.9	67	1.95	0.18	90	0.02
7	559	5.7	67	1.88	0.18	90	0.02
8	588	5.6	58	2.35	0.18	90	0.02

1) SCR Installed Pre-Turbo
2) DPF is Actively-Regenerated
3) A Pre-SCR DOC is Used

Catalytic Formulation Z- EMD



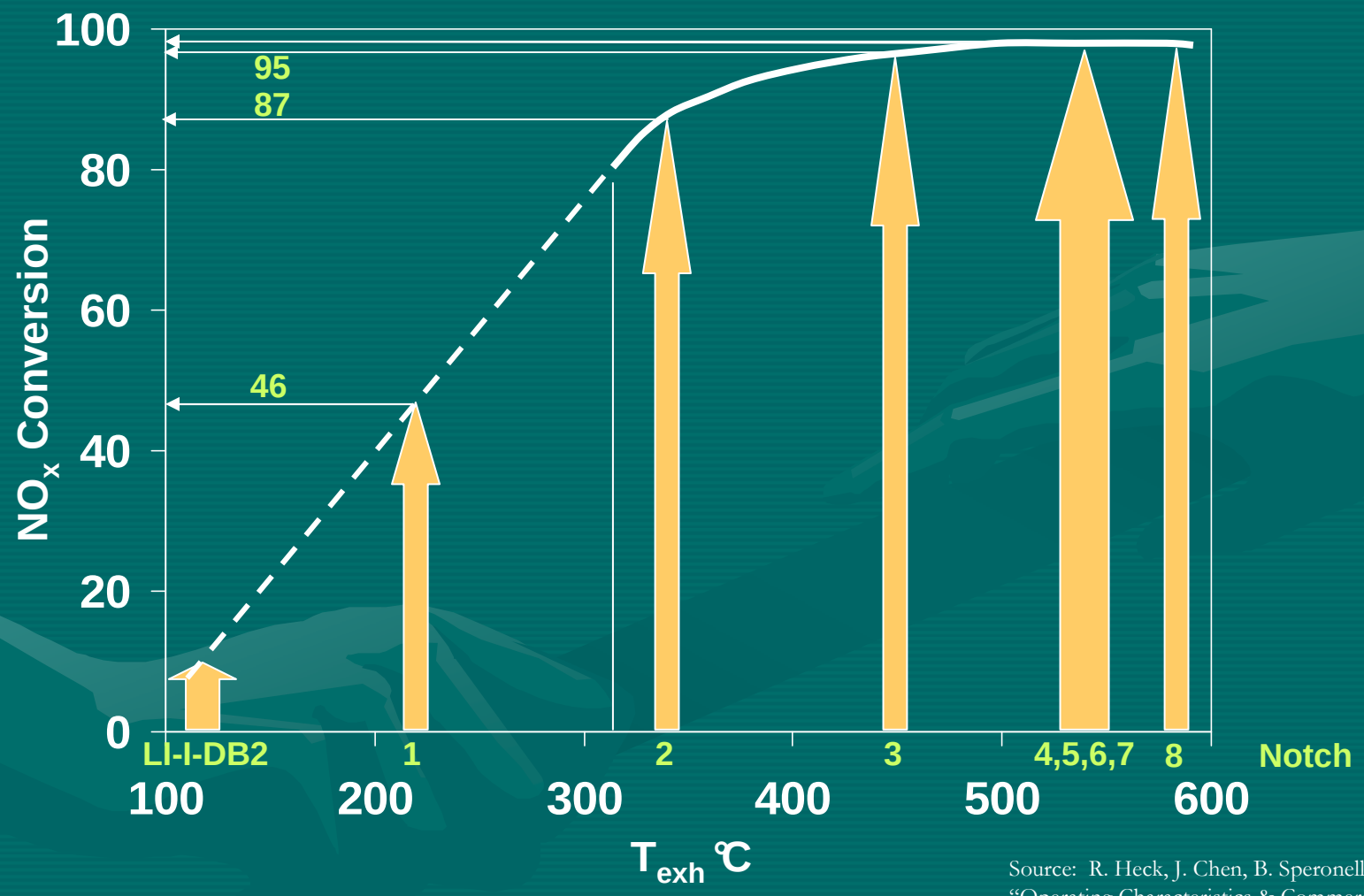
Source: R. Heck, J. Chen, B. Speronello, 1994, "Operating Characteristics & Commercial Operating Experience with High Temperature SCR NO_x Catalyst", Environmental Progress

Projected NO_x and PM For Concept 1 & 2
Z Formulation/Wallflow DPF - EMD

Notch Position	Pre-Turbo T_{exh} °C	Corr. NO_x g/kW-h	Projected NO_x Conv., %	Projected NO_x , g/kW-h	E.O. PM g/kW-h	Projected PM Red., %	Projected PM g/kW-h
LI	91	46.0	0	46.0	0.80	80	0.16
I	96	32.6	0	32.6	1.86	80	0.37
DB-2	149	12.3	0	12.3	0.25	80	0.05
1	149	12.6	0	12.6	0.19	90	0.02
2	231	9.0	52	4.33	0.29	90	0.03
3	237	6.8	82	0.54	0.32	90	0.03
4	393	5.7	90	0.57	0.26	90	0.03
5	384	5.1	92	0.41	0.22	90	0.03
6	441	5.3	95	0.27	0.24	90	0.03
7	445	5.3	95	0.27	0.24	90	0.02
8	462	5.9	95	0.30	0.21	90	0.02

1) SCR Installed Pre-Turbo
2) DPF is Actively-Regenerated
3) A Pre-SCR DOC is Used

Catalytic Formulation Z- GE



Source: R. Heck, J. Chen, B. Speronello, 1994, "Operating Characteristics & Commercial Operating Experience with High Temperature SCR NO_x Catalyst", Environmental Progress

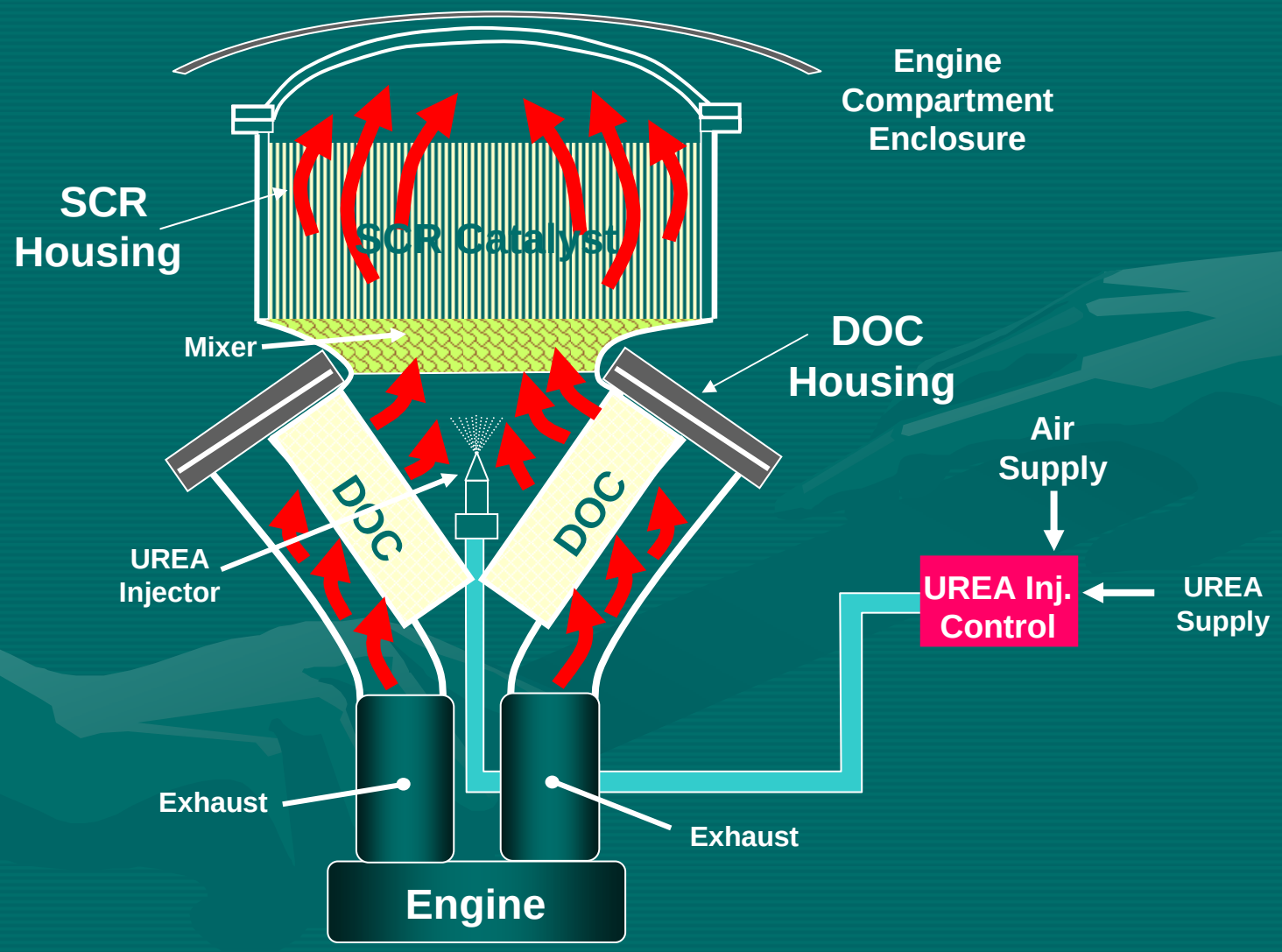
Projected NO_x and PM For Concept 1 & 2
Z Formulation/Wallflow DPF - GE

Notch Position	Pre-Turbo T_{exh} °C	Corr. NO_x g/kW-h	Projected NO_x Conv., %	Projected NO_x , g/kW-h	E.O. PM g/kW-h	Projected PM Red., %	Projected PM g/kW-h
LI	114	49.1	0	49.10	0.89	80	0.18
I	106	26.0	0	26.00	0.61	80	0.12
DB-2	127	31.5	0	31.50	2.01	80	0.4
1	233	5.7	46	3.08	0.35	90	0.04
2	338	6.2	87	0.81	0.33	90	0.03
3	459	6.0	95	0.30	0.34	90	0.03
4	540	5.8	95	0.29	0.29	90	0.03
5	525	5.6	95	0.28	0.24	90	0.03
6	536	5.9	95	0.30	0.18	90	0.02
7	559	5.7	95	0.29	0.18	90	0.02
8	588	5.6	95	0.28	0.18	90	0.02

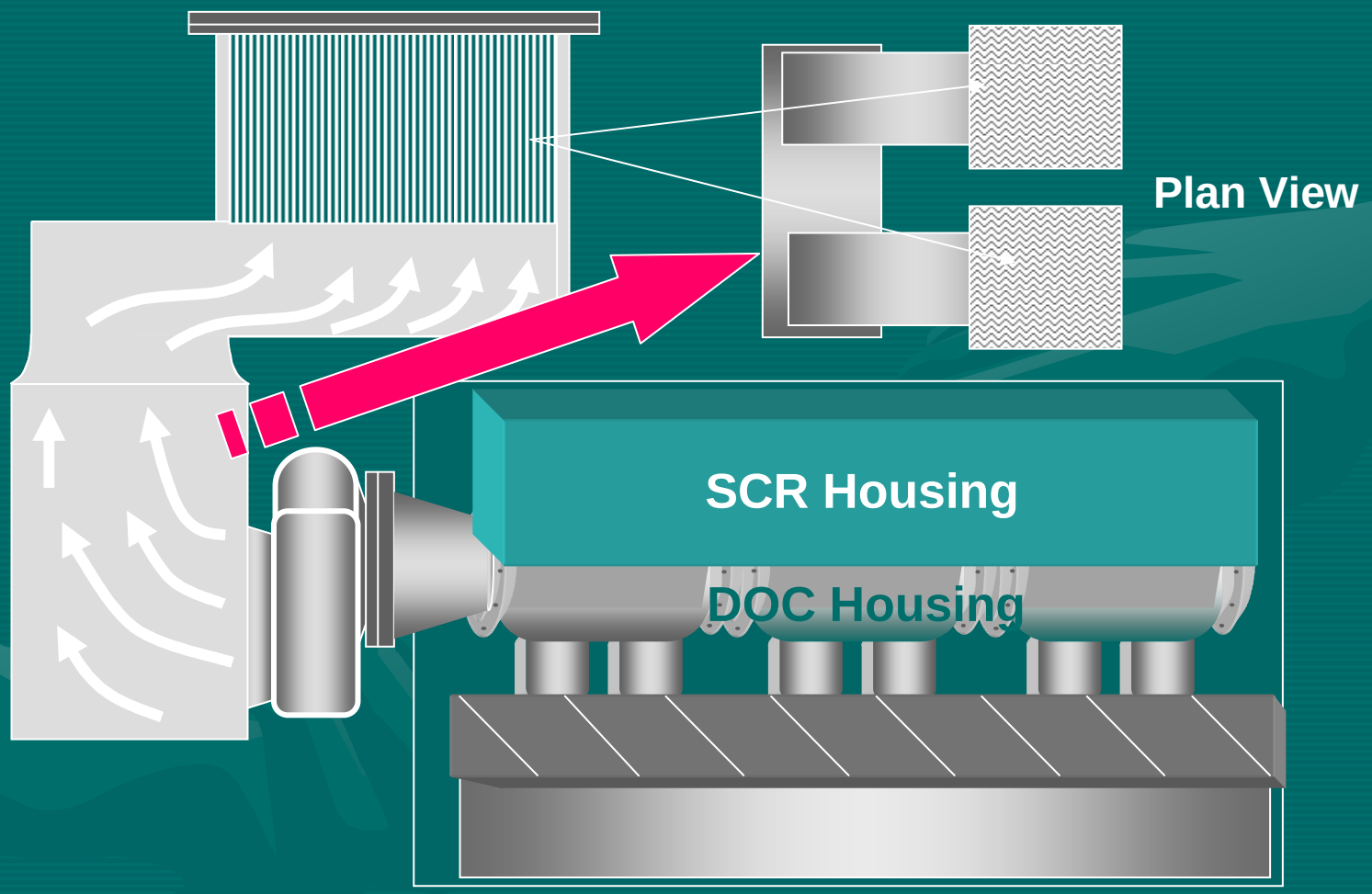
1) SCR Installed Pre-Turbo
2) DPF is Actively-Regenerated
3) A Pre-SCR DOC is Used

Concept 3

Pre-Turbo SCR NO_x Reduction System



Post-SCR Flowthrough DPF- EMD



Projections 3

Projected NO_x and PM For Concept 3
Z Formulation/Flowthrough DPF - EMD

Notch Position	Pre-Turbo T_{exh} °C	Corr. NO_x g/kW-h	Projected NO_x Conv., %	Projected NO_x , g/kW-h	E.O. PM g/kW-h	Projected PM Red., %	Projected PM g/kW-h
LI	91	46.0	0	46.0	0.80	50	0.40
I	96	32.6	0	32.6	1.86	50	0.93
DB-2	149	12.3	0	12.3	0.25	50	0.13
1	149	12.6	0	12.6	0.19	60	0.08
2	231	9.0	52	4.33	0.29	60	0.12
3	327	6.8	82	0.54	0.32	60	0.13
4	393	5.7	90	0.57	0.26	60	0.10
5	384	5.1	92	0.41	0.22	60	0.09
6	441	5.3	95	0.27	0.24	60	0.10
7	445	5.3	95	0.27	0.24	60	0.10
8	462	5.9	95	0.30	0.21	60	0.08

1) SCR Installed Pre-Turbo
2) DPF is Flowthrough
3) A Pre-SCR DOC is Used

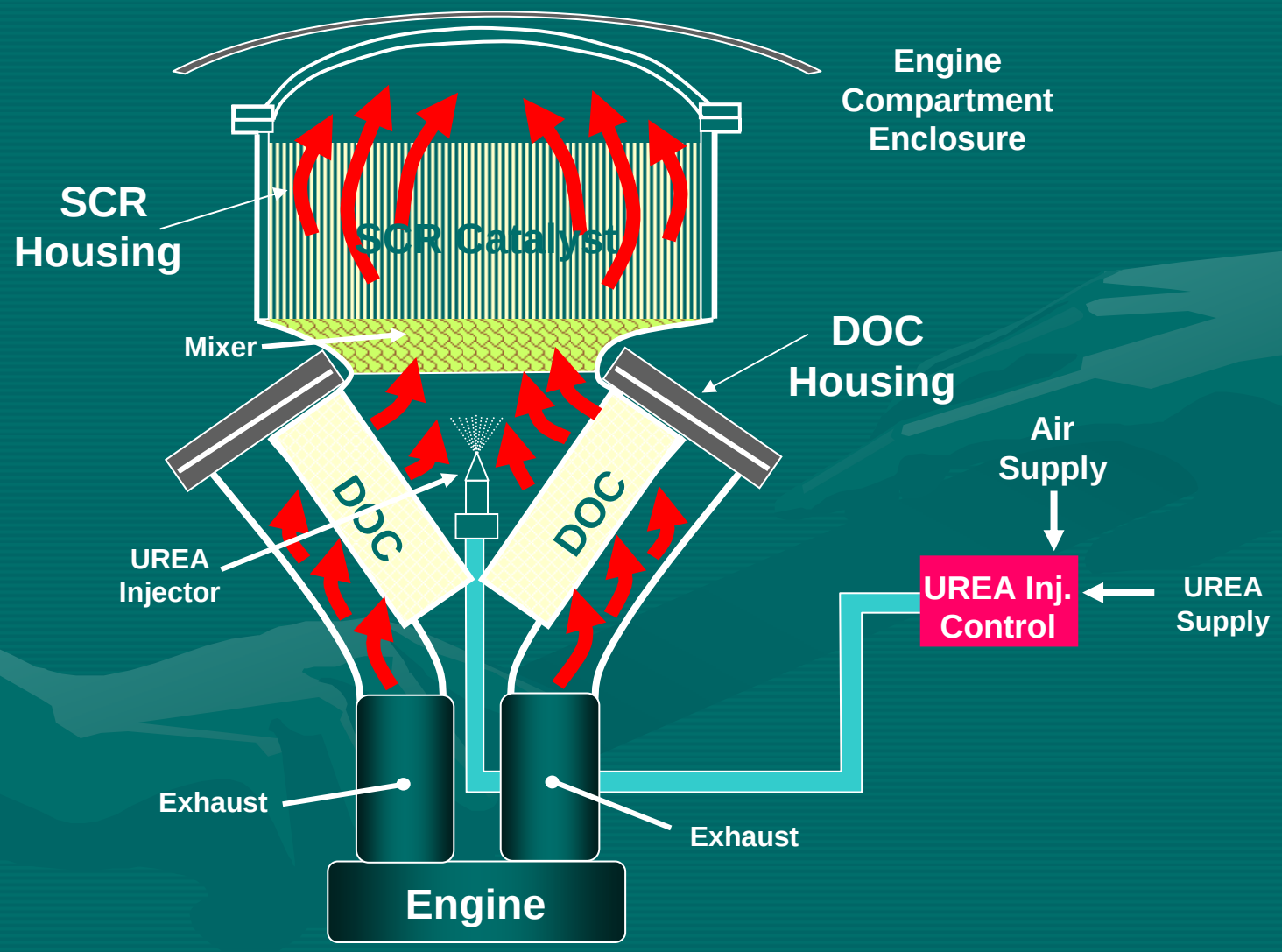
Projected NO_x and PM For Concept 3
Z Formulation/Flowthrough DPF - GE

Notch Position	Pre-Turbo T_{exh} °C	Corr. NO_x g/kW-h	Projected NO_x Conv., %	Projected NO_x , g/kW-h	E.O. PM g/kW-h	Projected PM Red., %	Projected PM g/kW-h
LI	114	49.1	0	49.10	0.89	50	0.45
I	106	26.0	0	26.00	0.61	50	0.31
DB-2	127	31.5	0	31.50	2.01	50	1.1
1	233	5.7	46	3.08	0.35	60	0.14
2	338	6.2	87	0.81	0.33	60	0.13
3	459	6.0	95	0.30	0.34	60	0.14
4	540	5.8	95	0.29	0.29	60	0.12
5	525	5.6	95	0.28	0.24	60	0.10
6	536	5.9	95	0.30	0.18	60	0.07
7	559	5.7	95	0.29	0.18	60	0.07
8	588	5.6	95	0.28	0.18	60	0.07

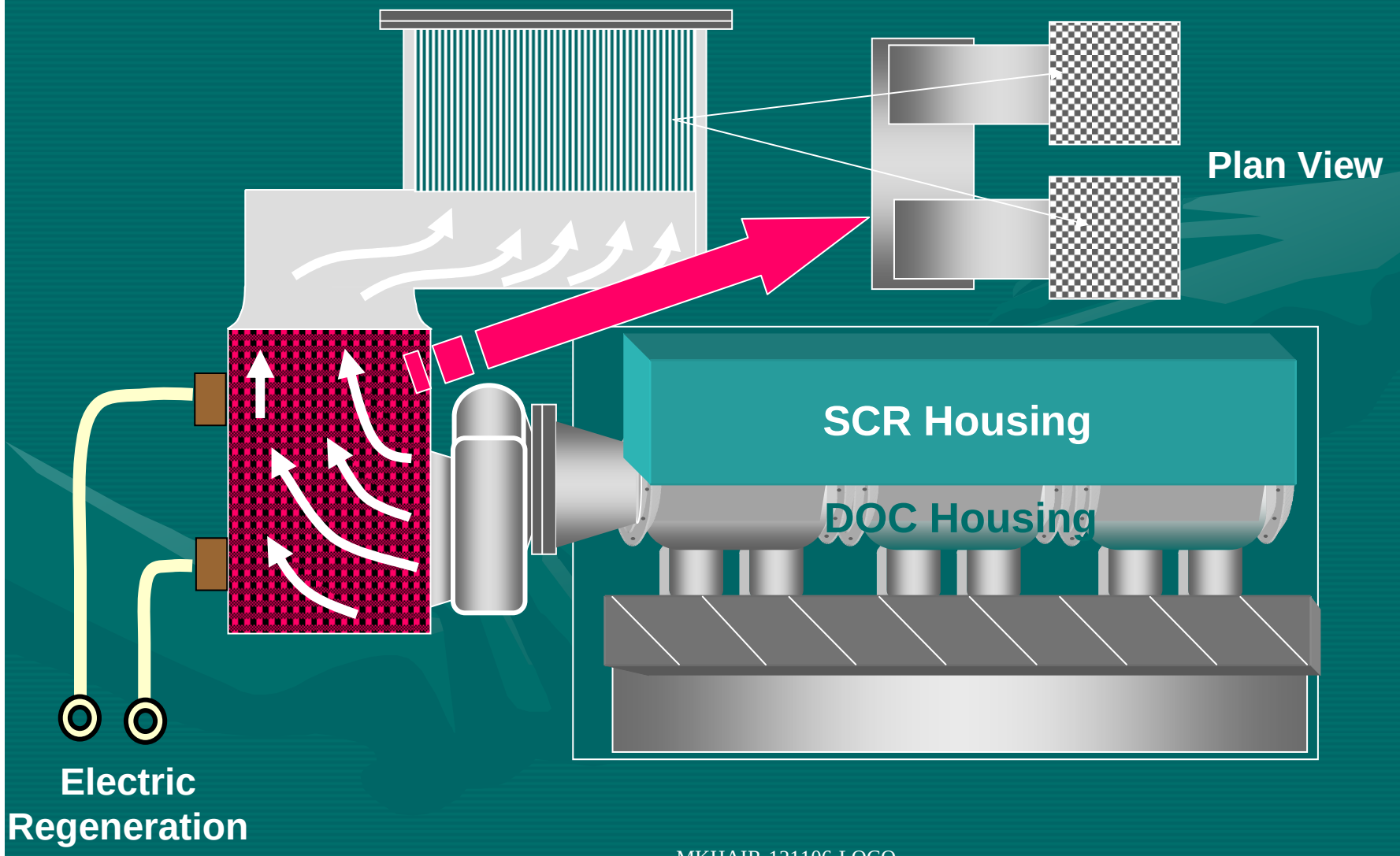
1) SCR Installed Pre-Turbo
2) DPF is Flowthrough
3) A Pre-SCR DOC is Used

Concept 4

Pre-Turbo SCR NO_x Reduction System



Post-SCR Wallflow DPF Electric Regeneration



Projections 4

Projected NO_x and PM For Concept 4 Z Formulation/Wallflow DPF - EMD

Notch Position	Pre-Turbo T_{exh} °C	Corr. NO_x g/kW-h	Projected NO_x Conv., %	Projected NO_x , g/kW-h	E.O. PM g/kW-h	Projected PM Red., %	Projected PM g/kW-h
LI	91	46.0	0	46.0	0.80	80	0.16
I	96	32.6	0	32.6	1.86	80	0.37
DB-2	149	12.3	0	12.3	0.25	80	0.05
1	149	12.6	0	12.6	0.19	90	0.02
2	231	9.0	52	4.33	0.29	90	0.03
3	327	6.8	82	0.54	0.32	90	0.03
4	393	5.7	90	0.57	0.26	90	0.03
5	384	5.1	92	0.41	0.22	90	0.03
6	441	5.3	95	0.27	0.24	90	0.03
7	445	5.3	95	0.27	0.24	90	0.02
8	462	5.9	95	0.30	0.21	90	0.02

1) SCR Installed Pre-Turbo
2) DPF is Actively-Regenerated
3) A Pre-SCR DOC is Used

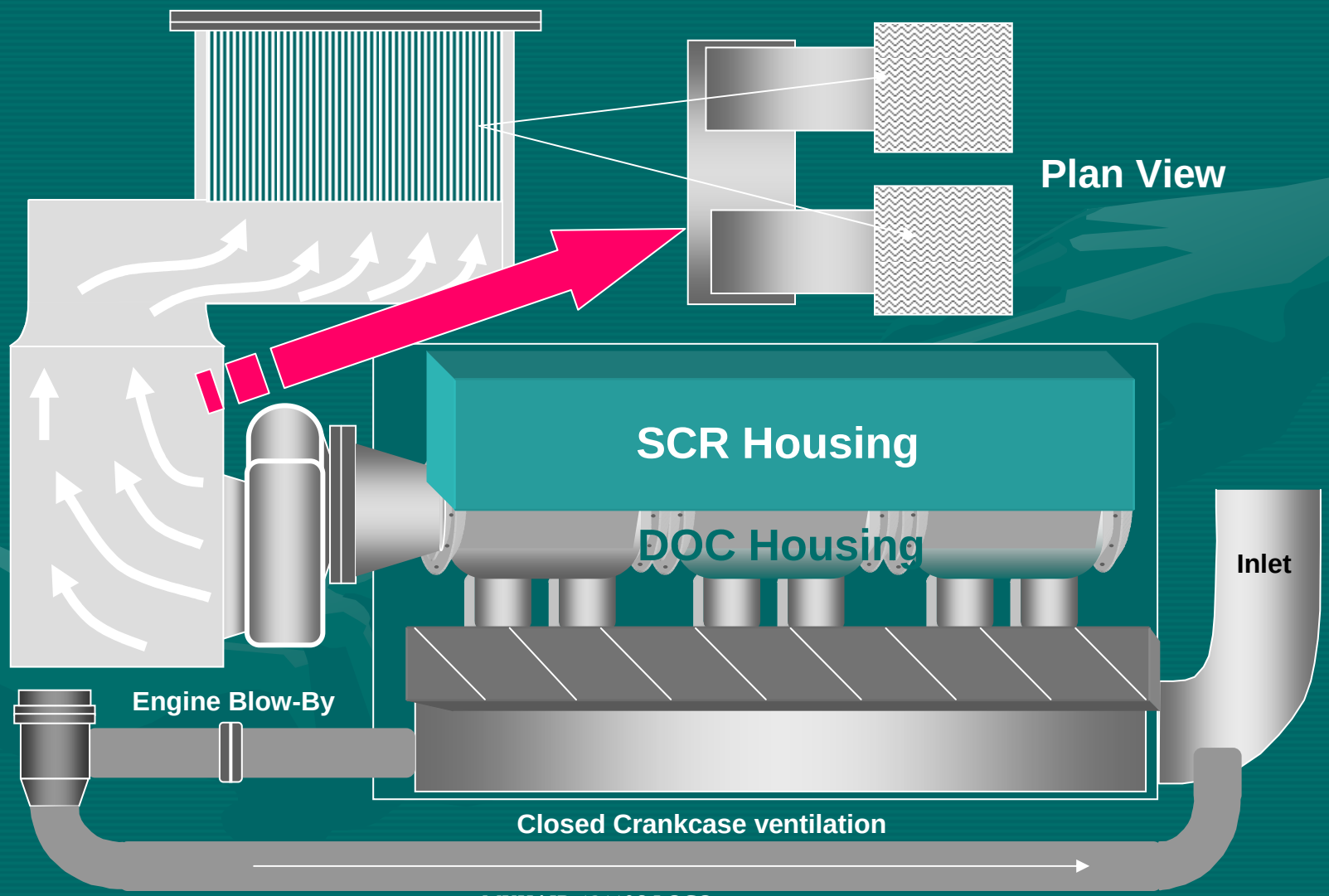
Projected NO_x and PM For Concept 4 Z Formulation/Wallflow DPF - GE

Notch Position	Pre-Turbo T_{exh} °C	Corr. NO_x g/kW-h	Projected NO_x Conv., %	Projected NO_x , g/kW-h	E.O. PM g/kW-h	Projected PM Red., %	Projected PM g/kW-h
LI	114	49.1	0	49.10	0.89	80	0.18
I	106	26.0	0	26.00	0.61	80	0.12
DB-2	127	31.5	0	31.50	2.01	80	0.4
1	233	5.7	46	3.08	0.35	90	0.04
2	338	6.2	87	0.81	0.33	90	0.03
3	459	6.0	95	0.30	0.34	90	0.03
4	540	5.8	95	0.29	0.29	90	0.03
5	525	5.6	95	0.28	0.24	90	0.03
6	536	5.9	95	0.30	0.18	90	0.02
7	559	5.7	95	0.29	0.18	90	0.02
8	588	5.6	95	0.28	0.18	90	0.02

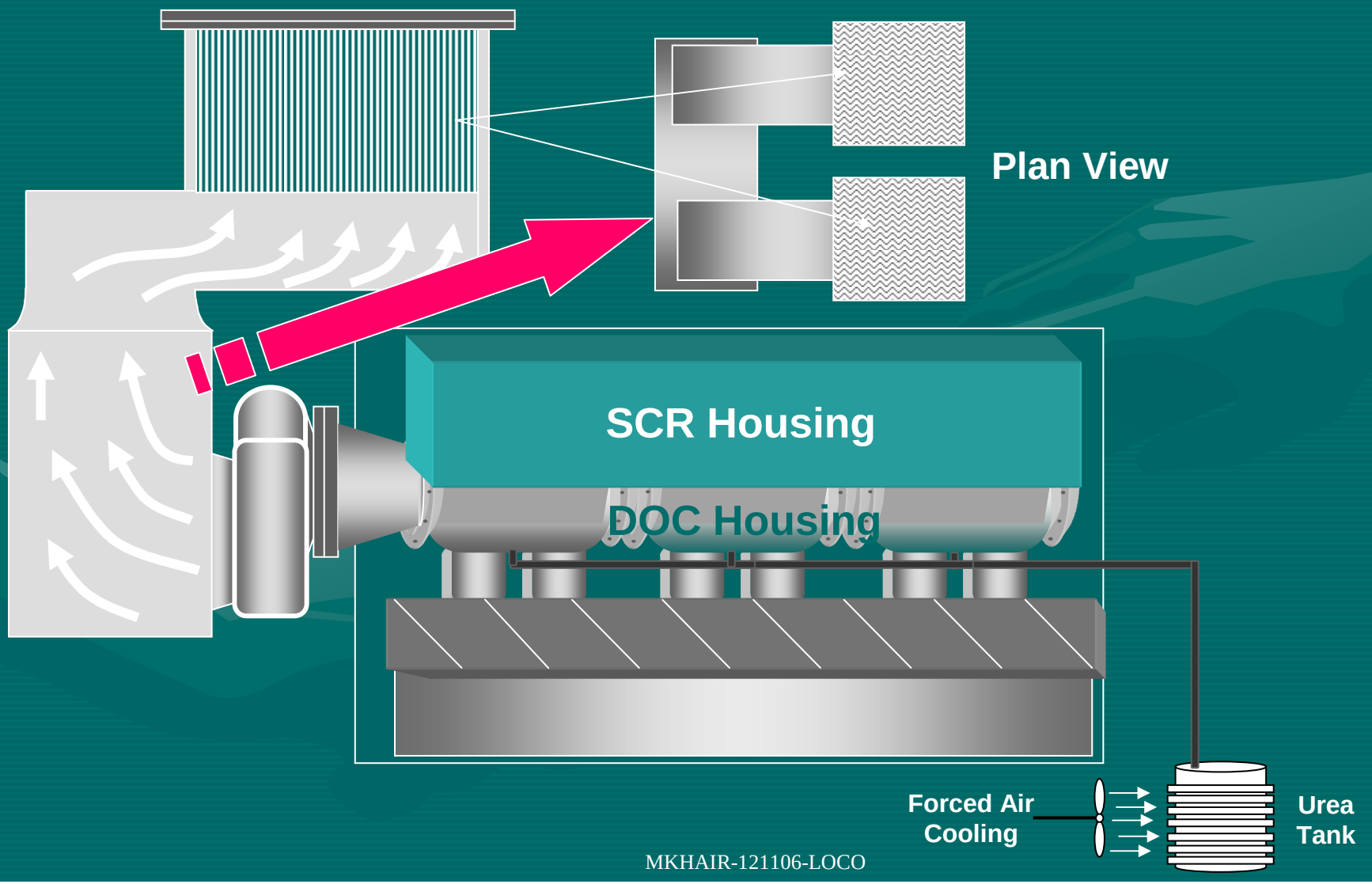
1) SCR Installed Pre-Turbo
2) DPF is Actively-Regenerated
3) A Pre-SCR DOC is Used

Other Concepts

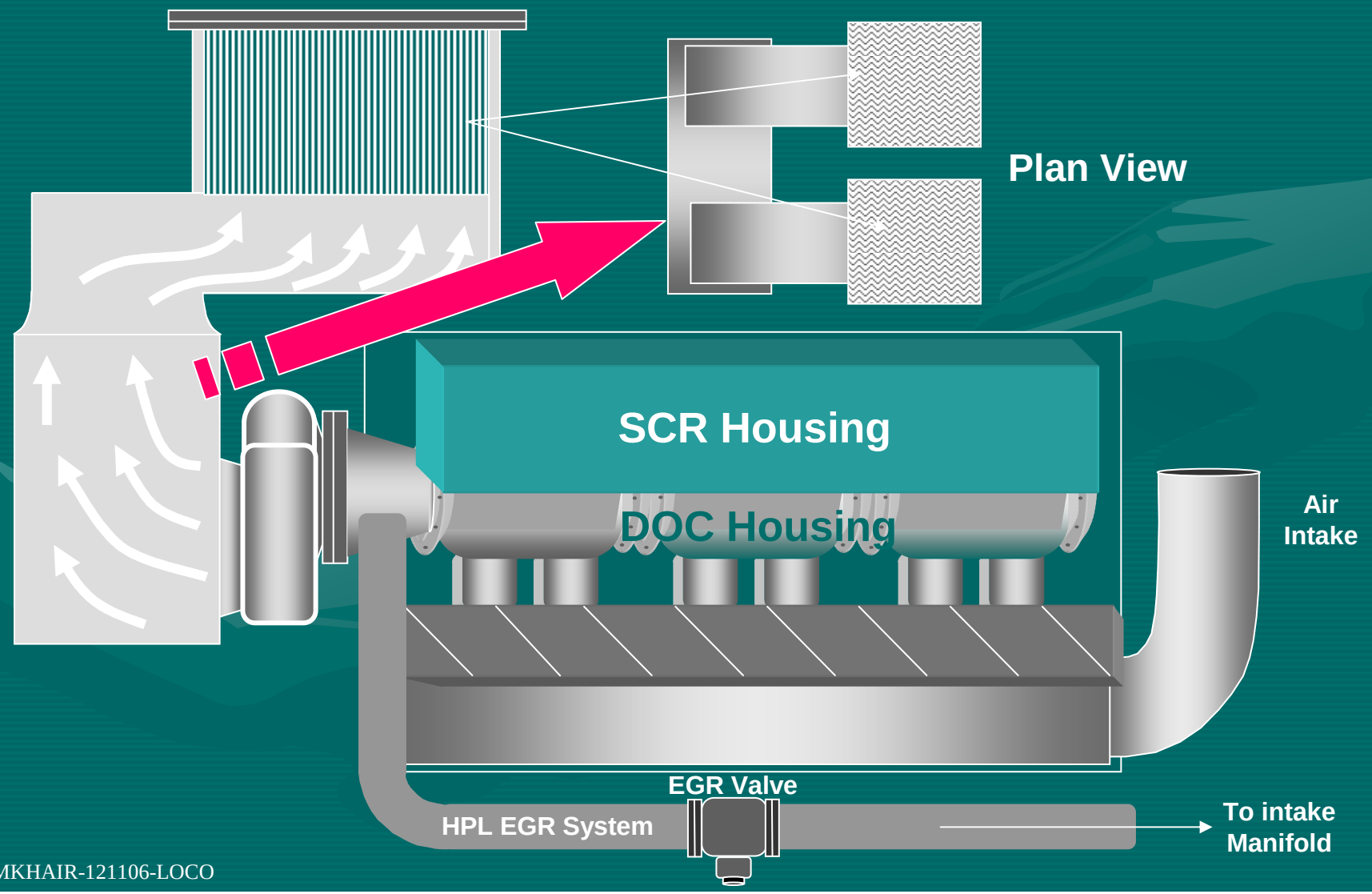
Engine Blow-By – Closed Crankcase Ventilation - EMD



Urea Tank Temperature Control



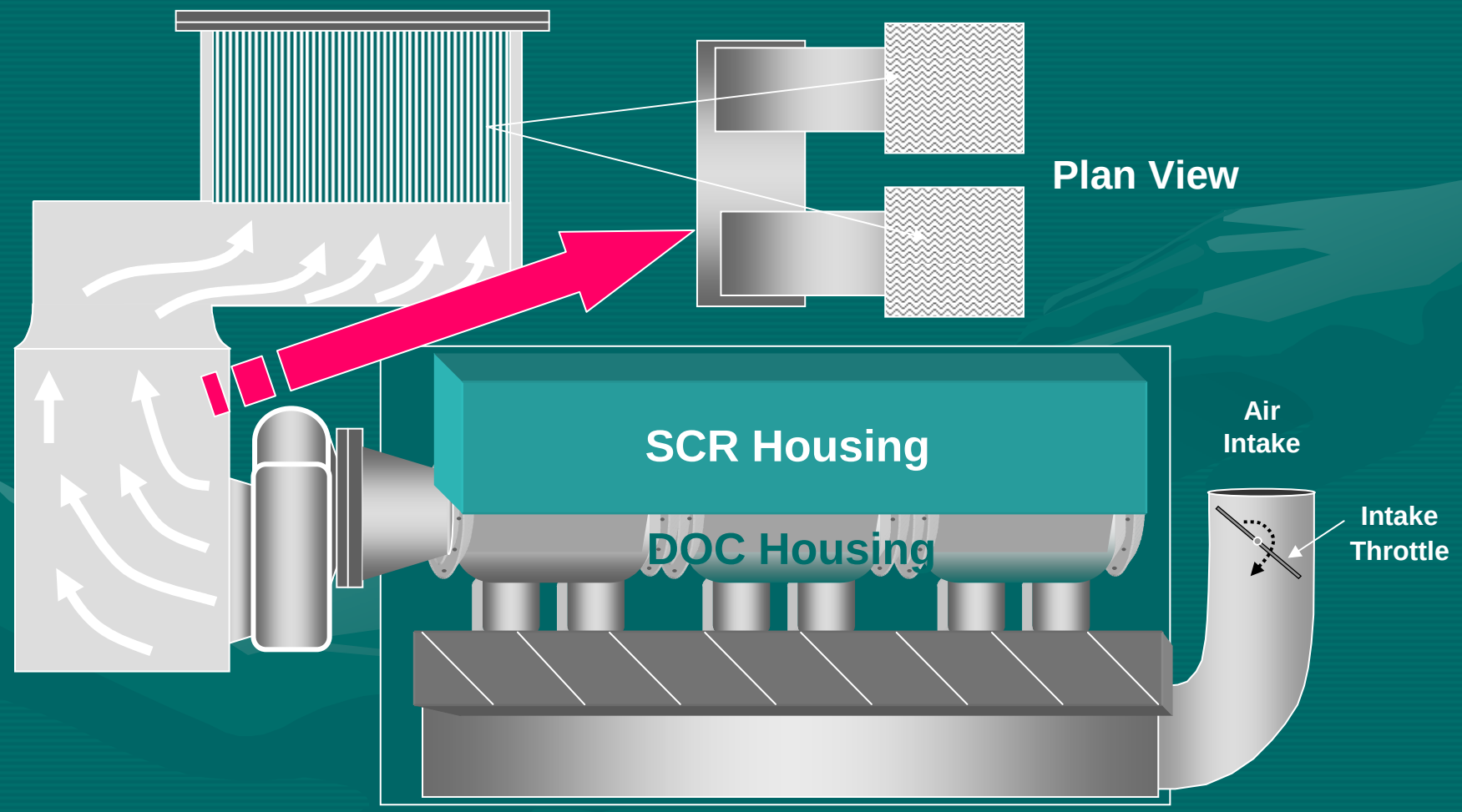
Exhaust Gas Recirculation



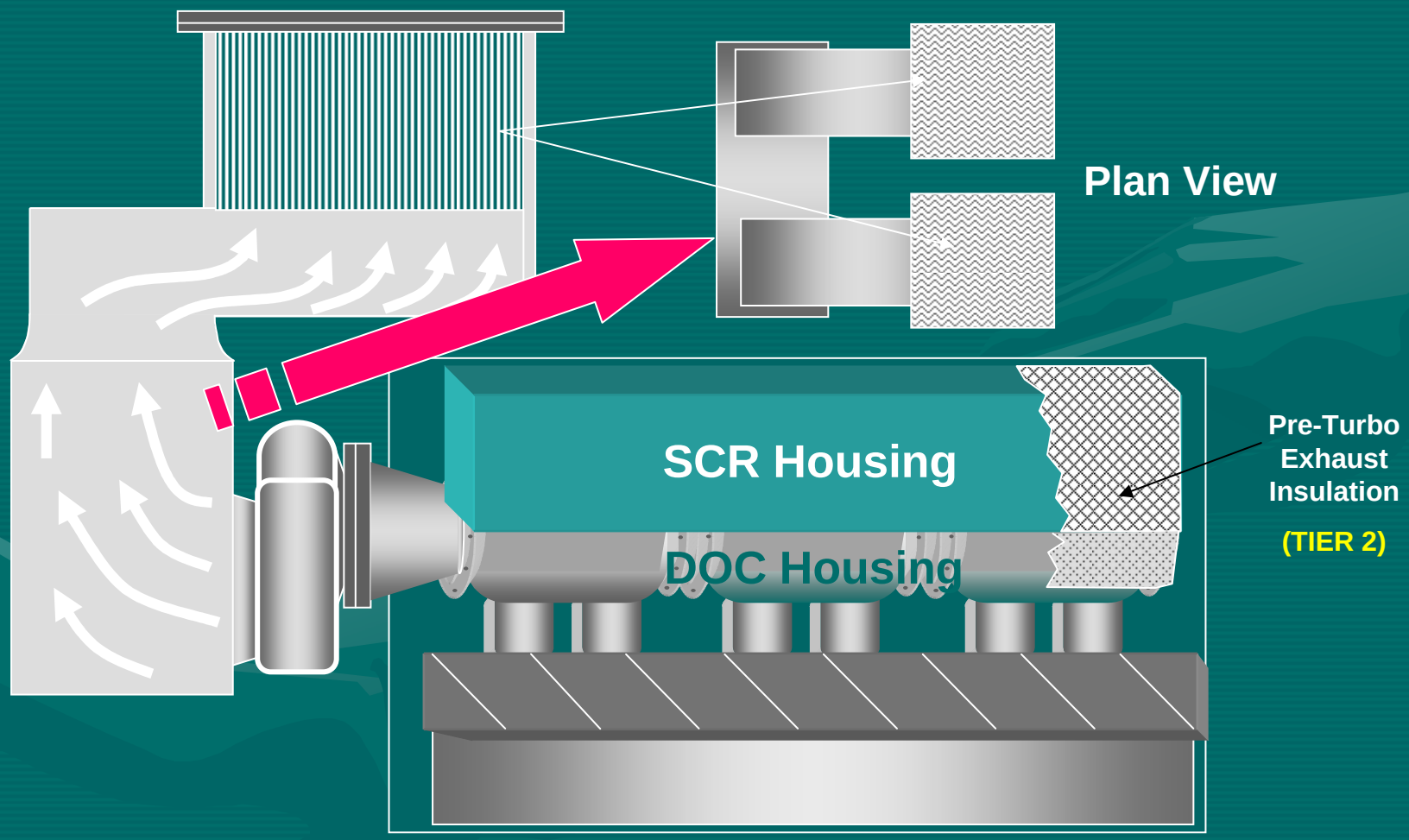
MKHAIR-121106-LOCO

Engine Intake Throttling For LI-I-DB-2

EMD

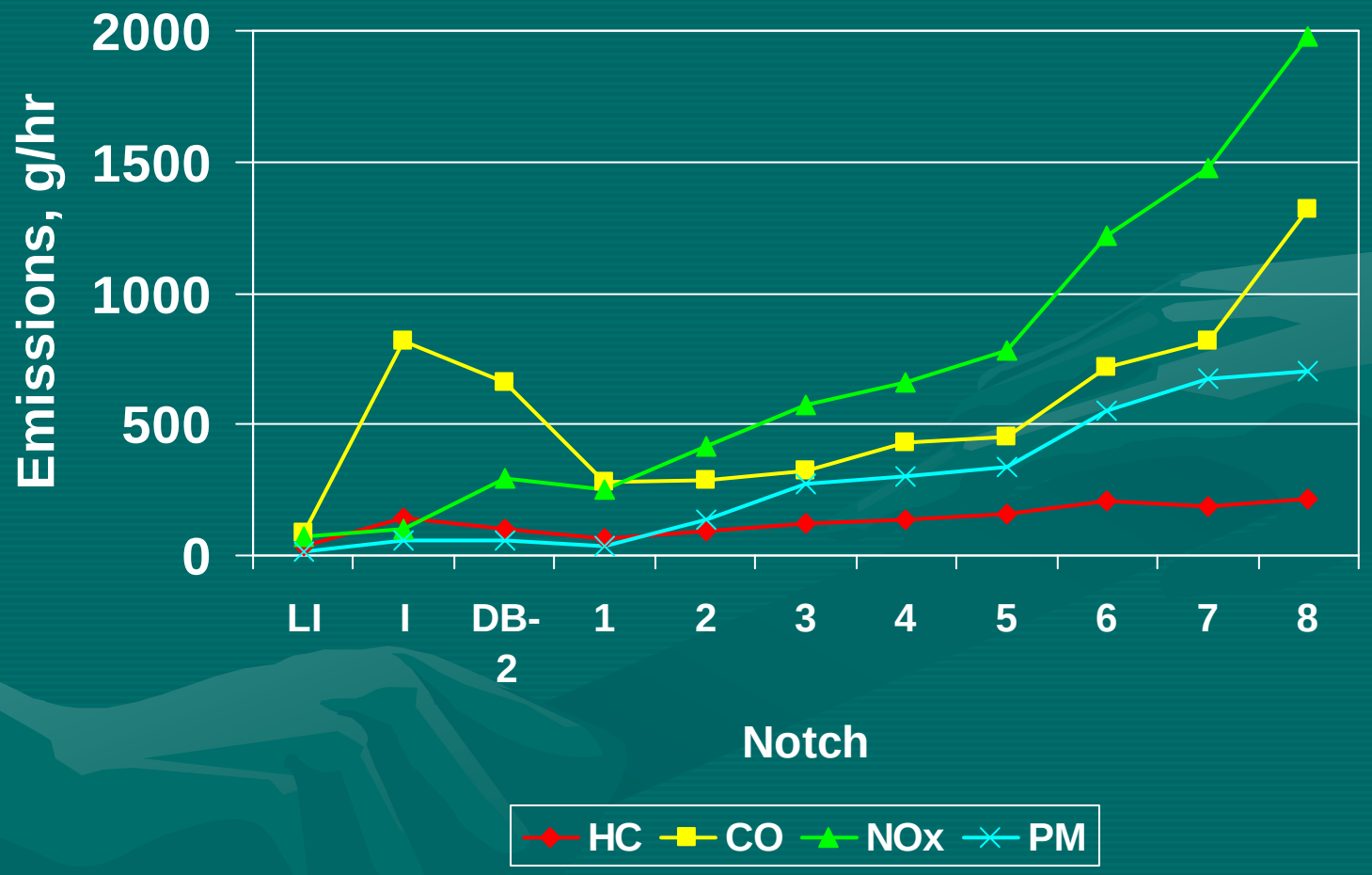


Exhaust Insulation - EMD



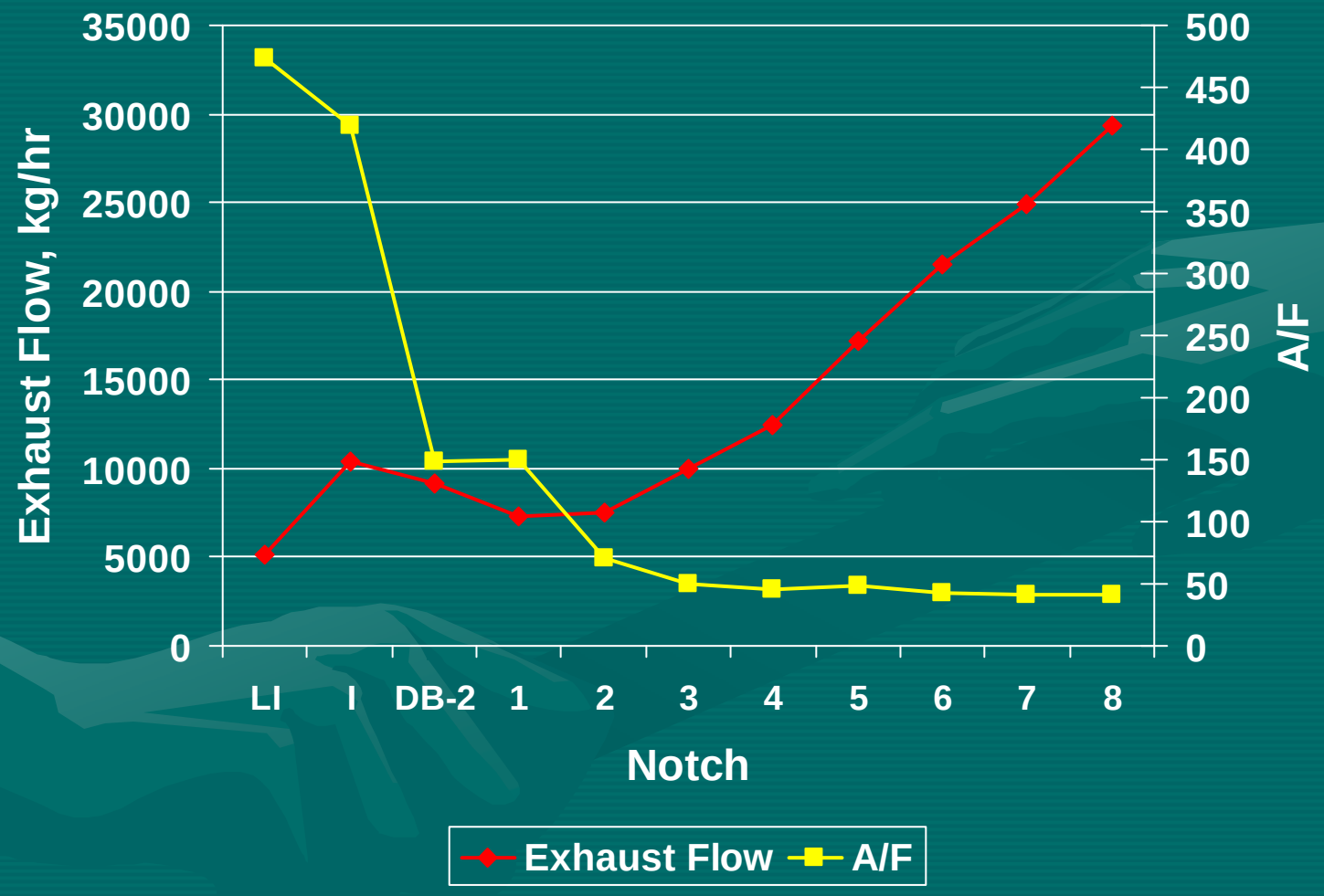
EMD Emissions

EMD Emissions



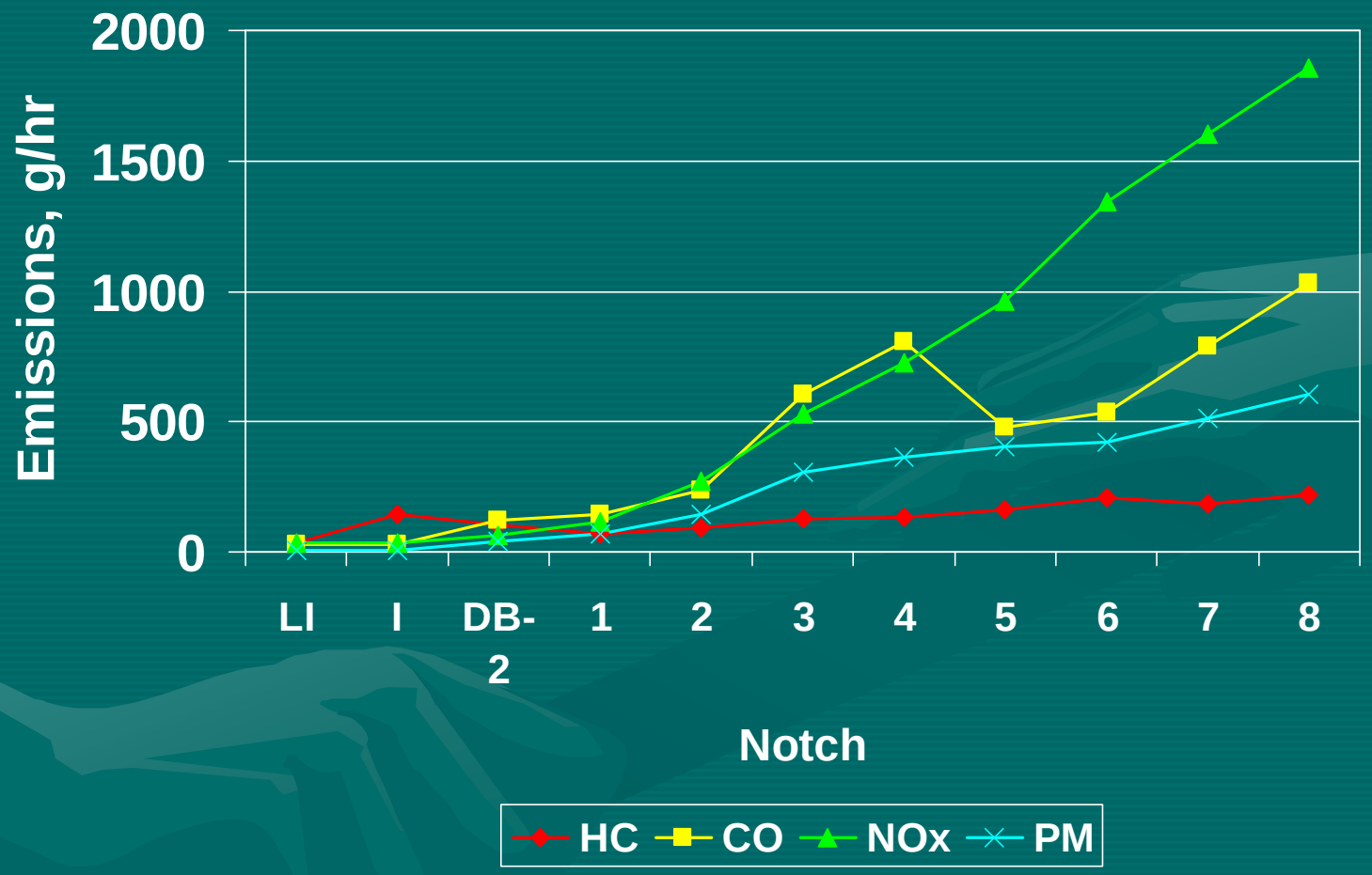
NO_x Scale if 1/10th actual valve

EMD A/F and Exhaust Flow



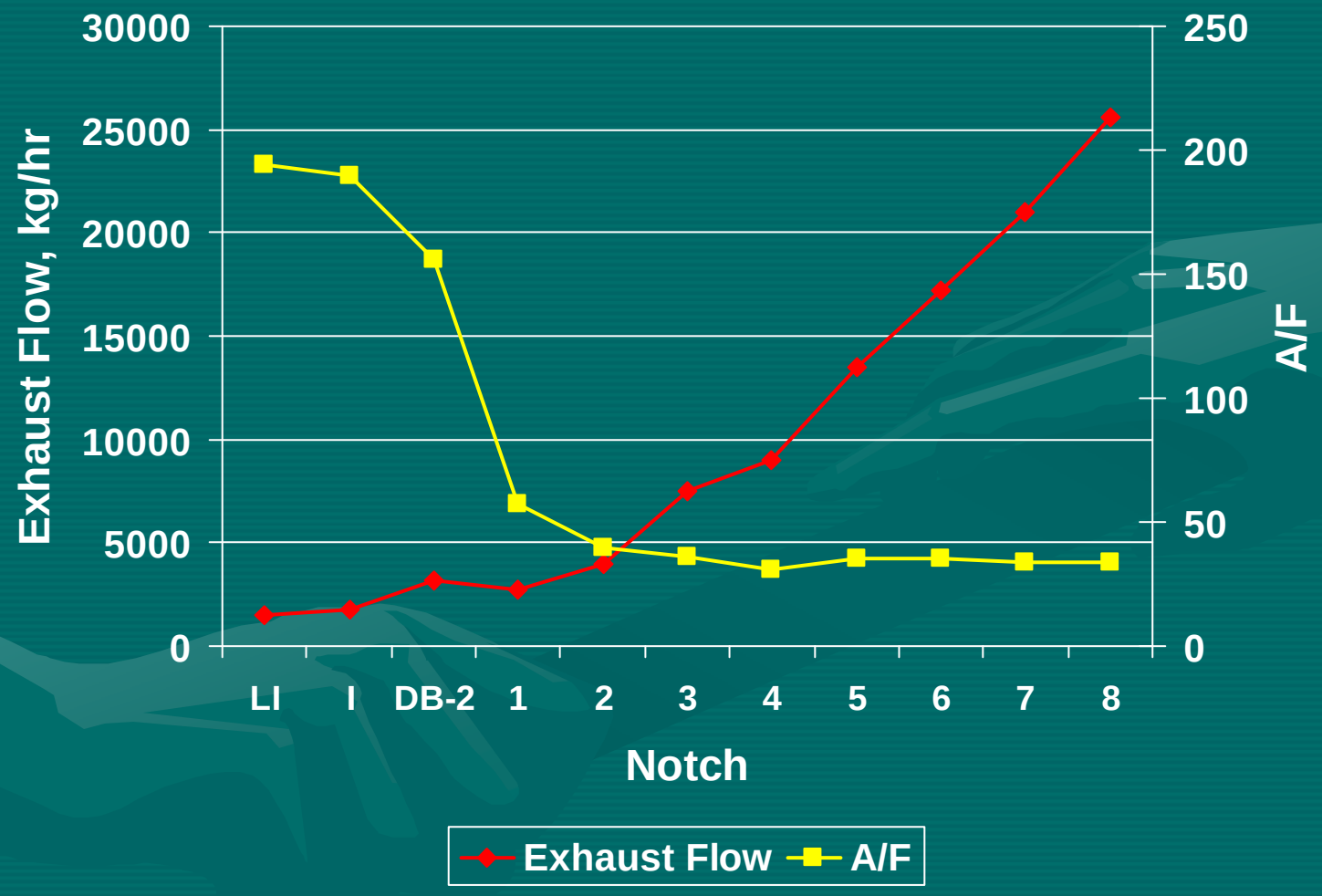
GE Emissions

GE Emissions



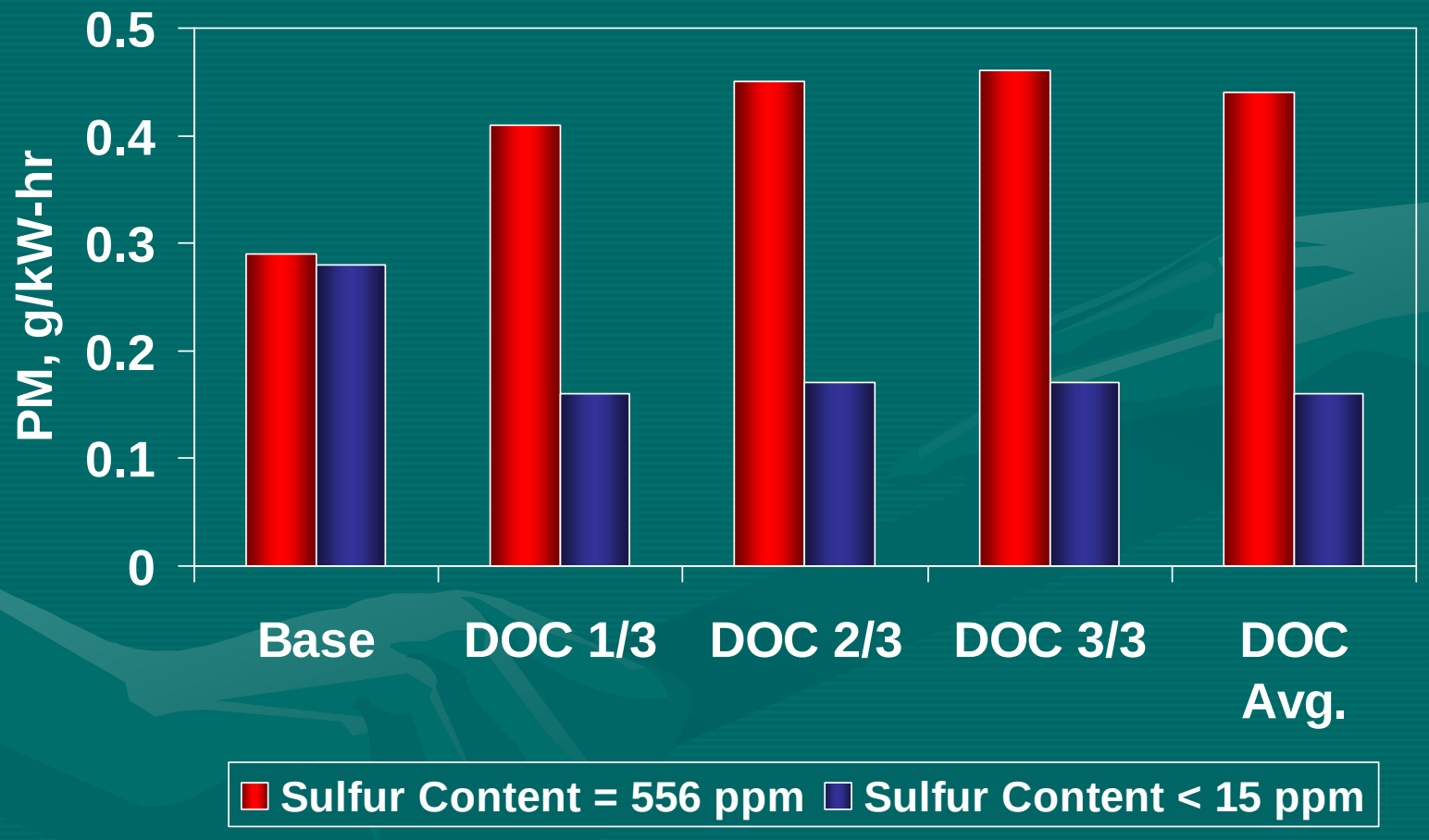
NO_x Scale if 1/10th actual valve

GE A/F and Exhaust Flow

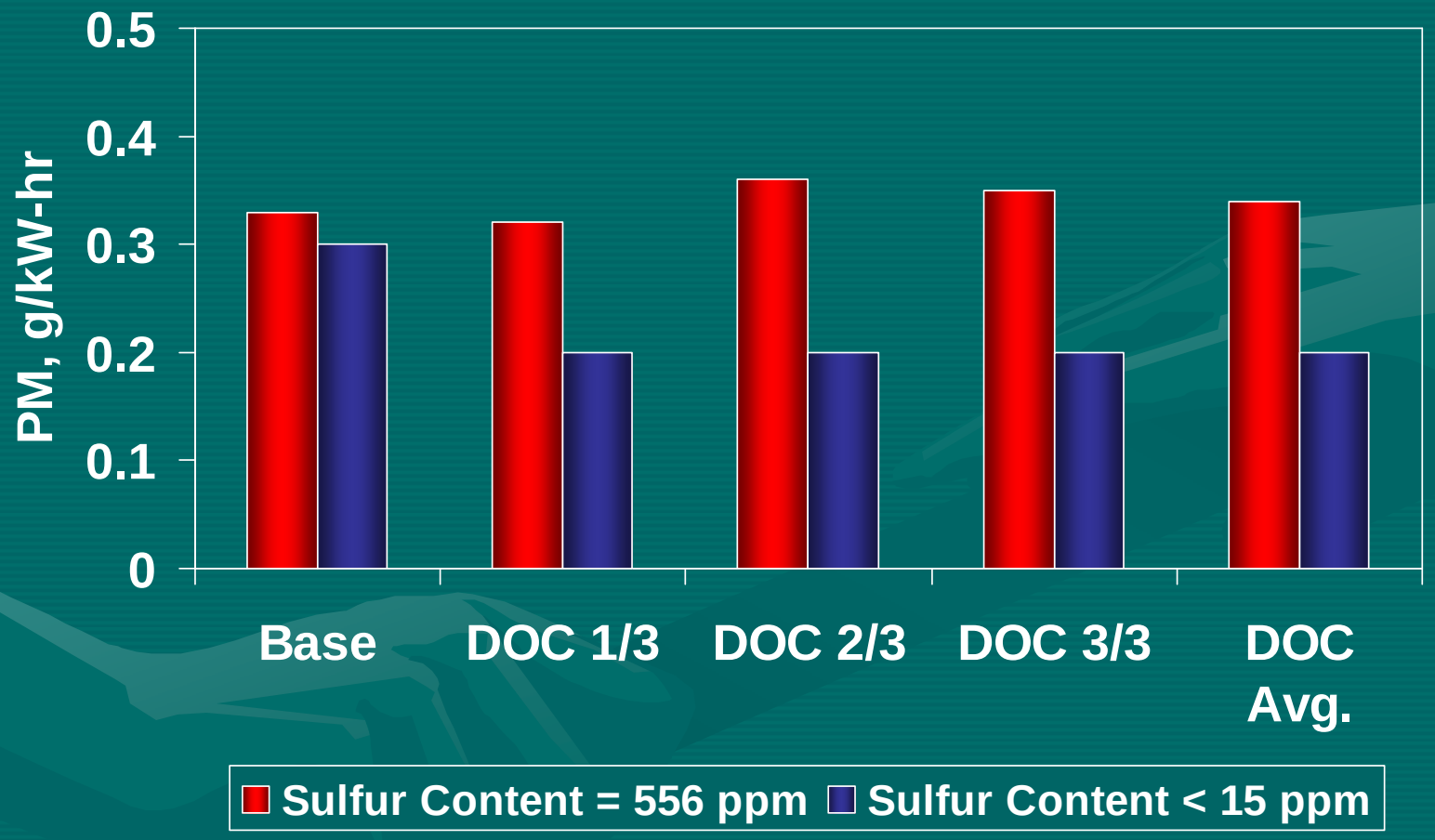


DOC – Sulfur Effects
EMD TIER 0 - SD60

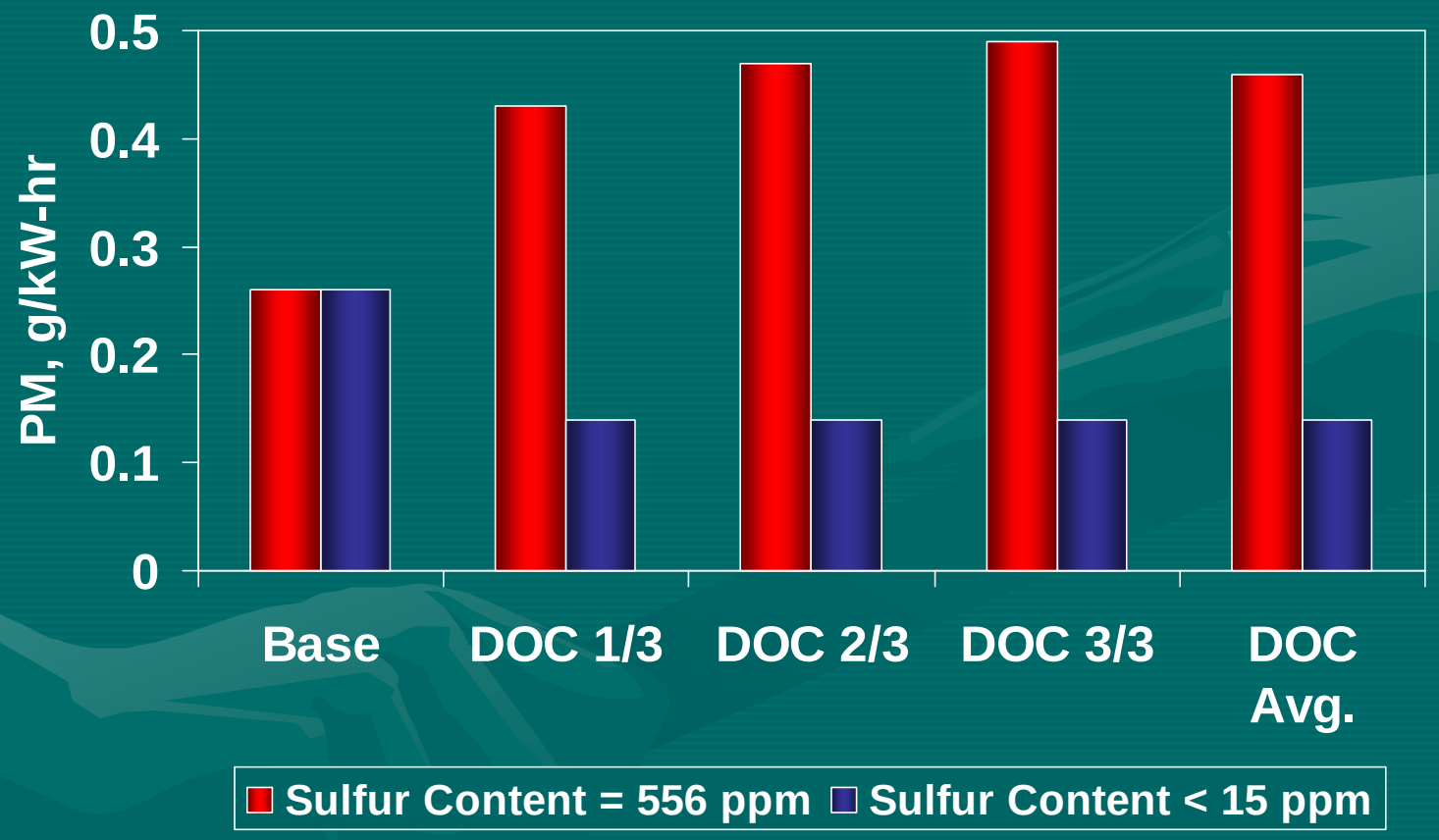
DOC PM Reduction Efficiency
(Freight Cycle)



DOC PM Reduction Efficiency
(Switch Cycle)



DOC PM Reduction Efficiency
(Notch 8)



Thank you

Magdi Khair
(210) 522-5311/mkhair@swri.org
Southwest Research Institute
San Antonio, TX – 12/12/06