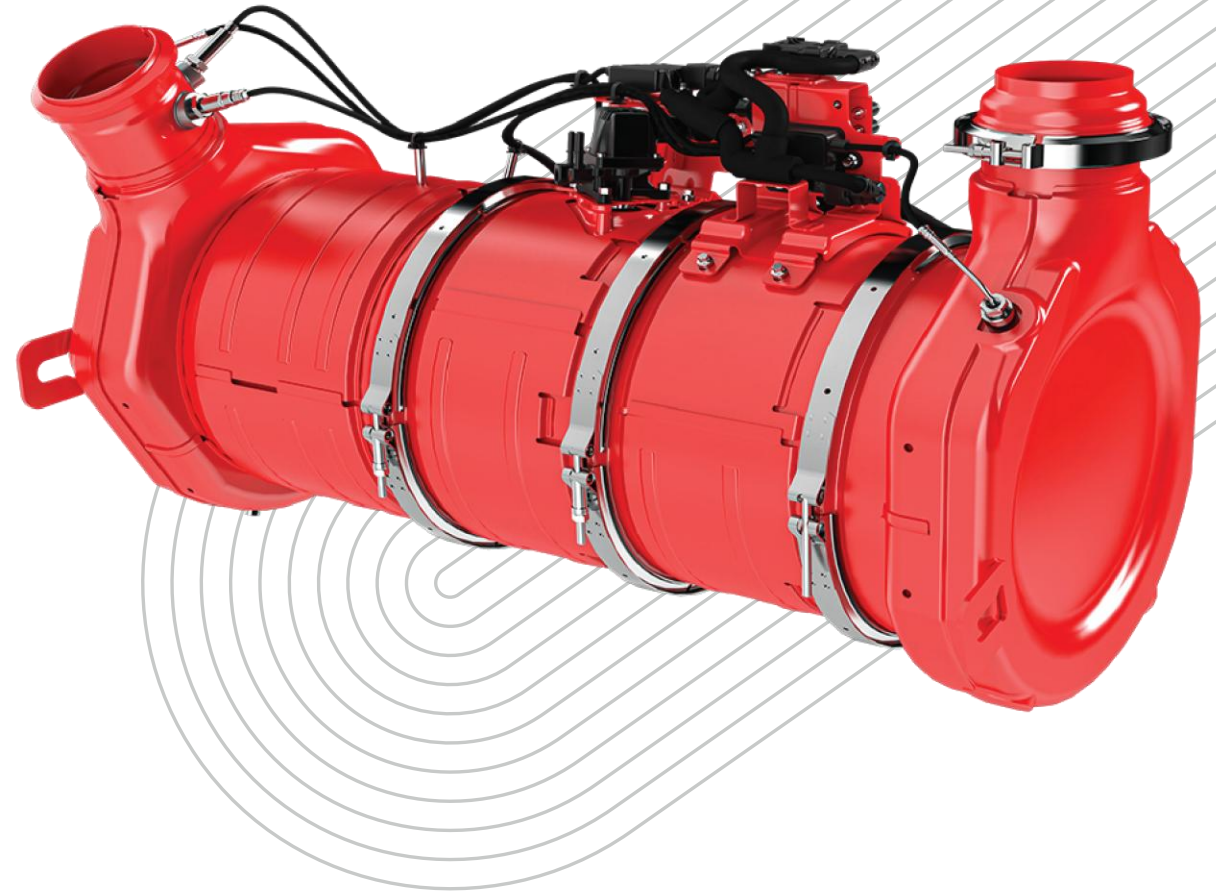




**Emission
Solutions**

Robust Simulation Framework for eHeater Integration in Aftertreatment Systems to Meet Stringent Emission Norms

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Nanduru, Kalpeshbapu Sonar



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Cummins

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- CES : Aftertreatment Solutions
- Evolving Emission Norms Trends and Challenges
 - Technology Offerings
 - eHeater aftertreatment solution
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 - flow and thermal
 - structural and durability

Five operating segments

Cummins has a long track record of delivering leading power solutions. As we look ahead, we know our industries and regions will continue to change, and we are committed to bringing our customers the right technology at the right time.



Engine



Power Systems



Components



Distribution



**Accelerator™ by
Cummins**

Cummins Emission Solutions

Reliable aftertreatment systems and technologies to meet or exceed emissions regulations and custom integration capabilities for unique challenges

Market Reach

DIVERSE MARKETS

WE WORK WITH CUSTOMERS IN ALMOST EVERY INDUSTRY IMAGINABLE



MINING



MARINE



OIL & GAS



RAIL



DEFENSE



**CUMMINS
GENERATOR
TECHNOLOGIES**



**MOBILE
POWER**



**INDUSTRIAL
POWER**



**MISSION
CRITICAL
POWER**



**DATA
CENTERS**



**ENERGY
MANAGEMENT
SOLUTIONS**

Aftertreatment solutions

CUMMINS EMISSIONS SOLUTIONS

Leading

Global designer, integrator, manufacturer and distributor of exhaust aftertreatment systems and components

20+

Years of
aftertreatment
experience

13

Manufacturing
facilities

AND

7

Technical centers
around the globe

CORE TECHNOLOGIES



Diesel Oxidation
Catalyst (DOC)



Diesel Particulate
(DPF) Filter



Selective Catalytic
Reduction (SCR)
System



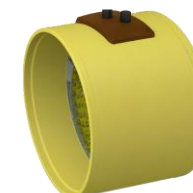
Doser Technology



Ammonia delivery
system



Controls

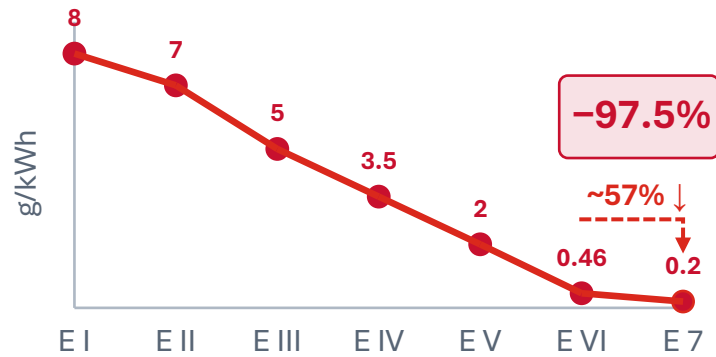


Thermal
Management

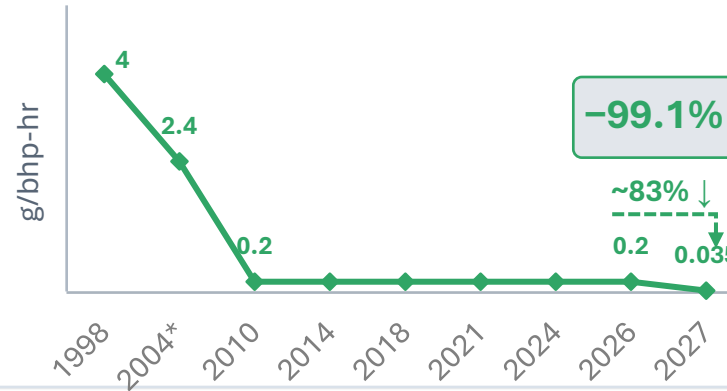
Multiple **integration programs** with non-Cummins OEMs and engine manufacturers

Emission norms trajectory

EU heavy-duty NOx evolution



EPA heavy-duty NOx evolution



Success now depends on controlling emissions beyond the certification cycle: low load, cold start, off-cycle operation and extended useful life.

EVOLVING EMISSION NORMS ADVOCATE AND PUSH FOR

01 LOW-TEMPERATURE NOx

Maintain catalyst activity through cold start, idle, low load and transient operation.

02 REAL-WORLD COVERAGE

RDE, low-load and off-cycle control beyond a single certification cycle.

03 MULTI-POLLUTANT BALANCE

NOx, PM/PN10, N₂O, NH₃ and NMOG require coordinated catalyst and dosing decisions.

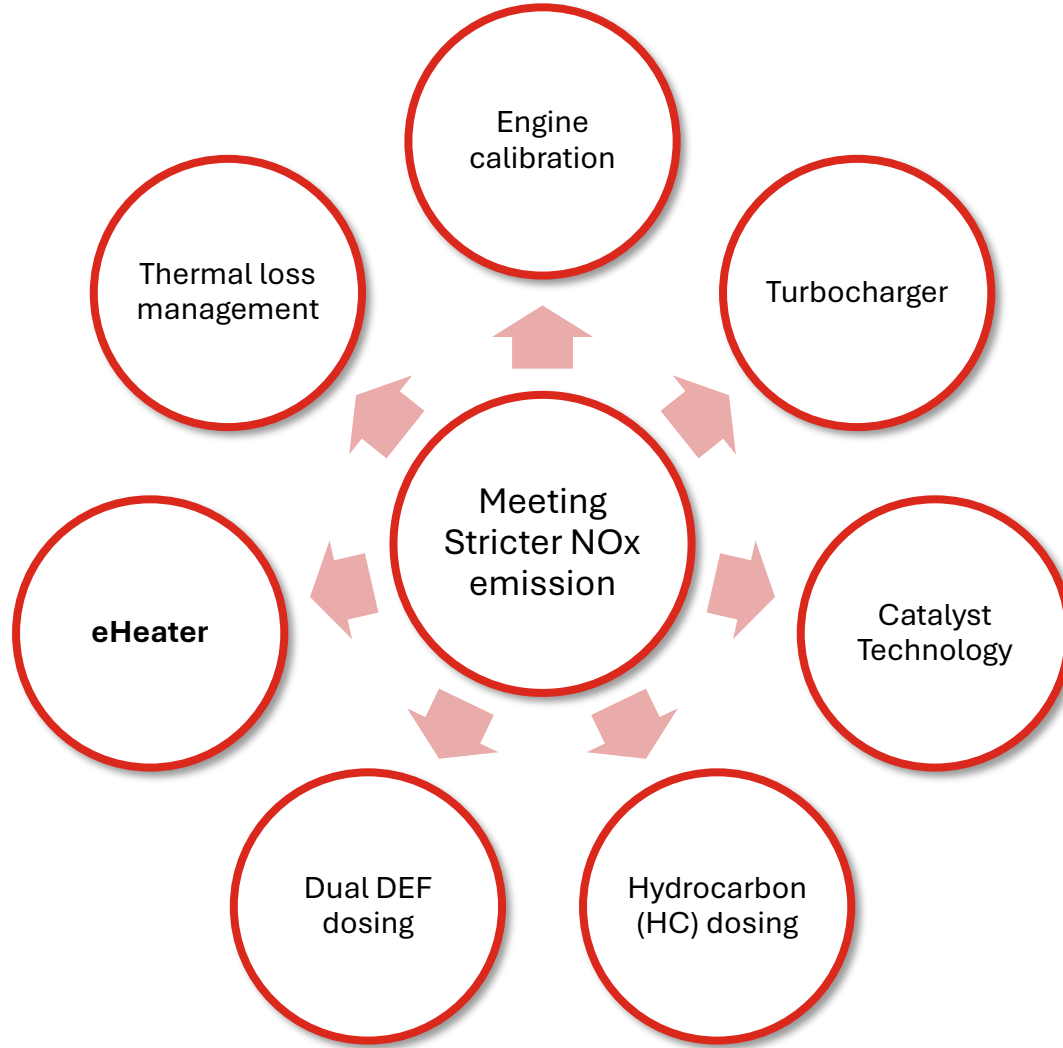
04 CO₂ + FUEL EFFICIENCY

Reduce fuel and carbon without losing the exhaust thermal energy needed for conversion.

05 LIFETIME COMPLIANCE

Control aging, drift, diagnostics and in-use performance over longer operating life.

Meeting stricter NO_x emission



Cummins offers wider variety of options for

Global VII (EU, NS, BS), EPA 27 & Beyond

Cummins portfolio includes eHeater : a innovative solution

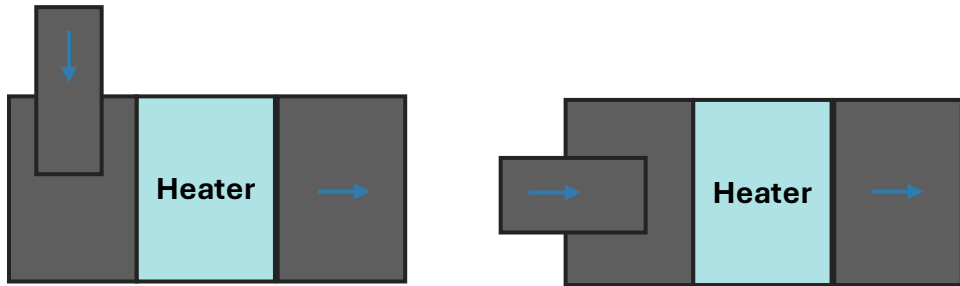
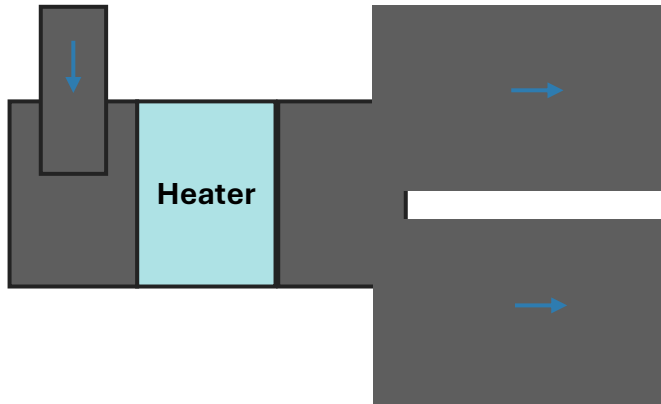
A proven solution

More compact

Eliminates complexity

Scalable design

Challenges involved in eHeater design and development



LAYOUT & ROUTING

PACKAGING SPACE

HEATER MASS

MOUNTING & BCs

PERFORMANCE

- Inlet-flow maldistribution
- Flow bypass paths
- Non-uniform velocity
- Uneven gas heating
- Local hot and cold regions
- Temperature-feedback sensitivity

Pressure drop • Flow distribution Index (FDI) • Heating efficiency
• Thermal gradient

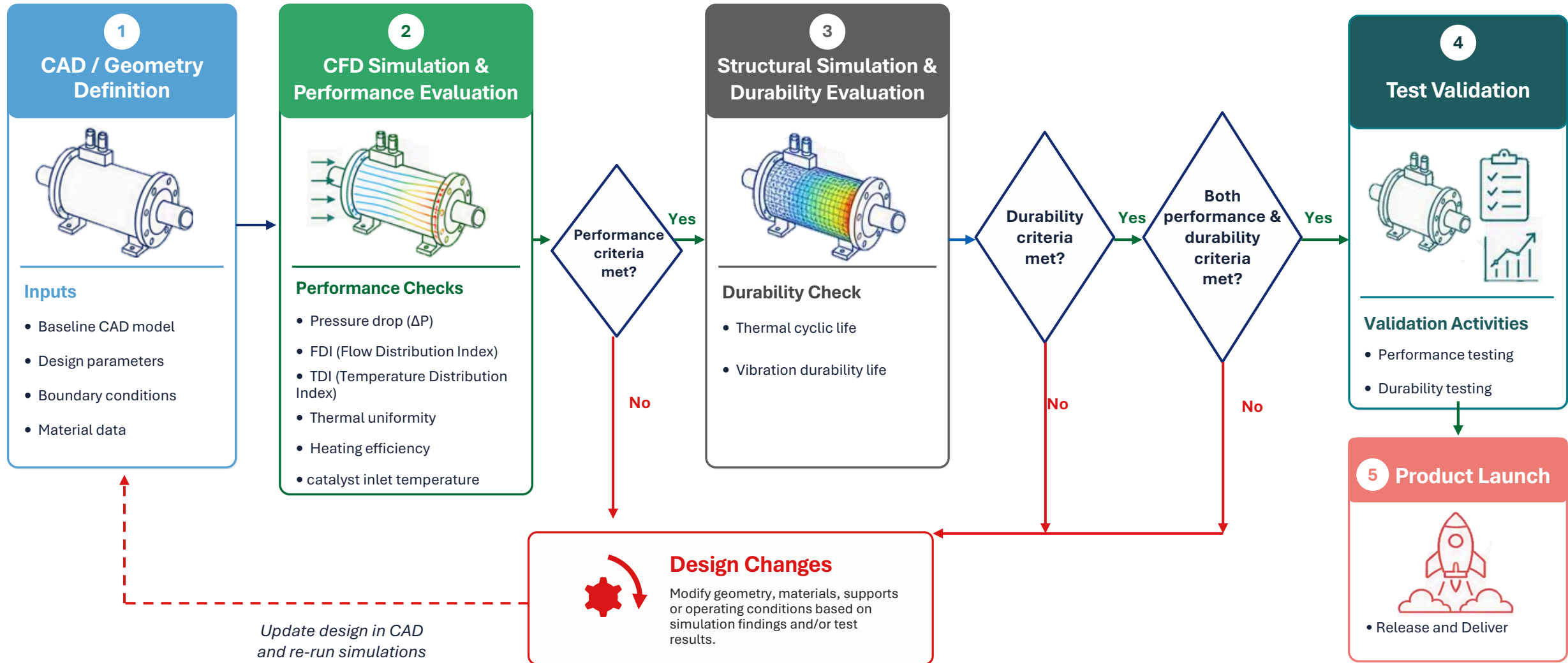
DURABILITY

- Overhung mass and longer load path
- Higher bending moments
- Low frequency local modes
- Higher inlet Power spectral density (PSD) responses
- High cycle fatigue life reduction

Thermal cyclic life • Structural integrity • PSD response • RMS stress
• Vibratory fatigue life

Robust eHeater integration requires a coupled CFD and structural durability assessment to deliver optimized performance, durability, and design confidence

eHeater design and development workflow



eHeater: Simulation modelling challenges

1 MODEL PREPARATION

- Complex heater structure and close proximities
- CAD clean-up and geometry simplification
- Mesh quality and high cell count
- Solver stability and convergence

2 CFD: FLOW & THERMAL

- Joule heating: electric current and resistive heating
- Heat transfer: conduction, convection and radiation
- Flow dynamics: separation and turbulence
- Coupled thermal-flow solution and convergence

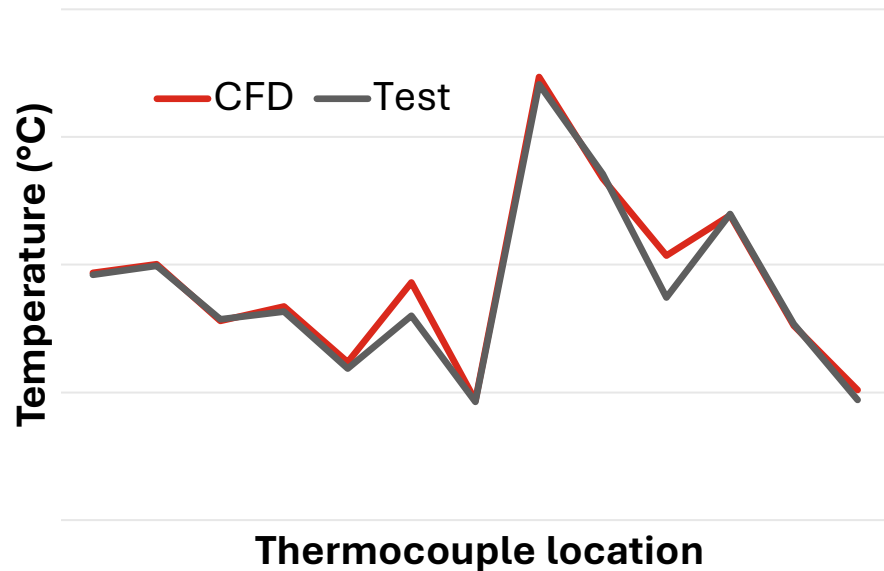
3 STRUCTURAL & DURABILITY

- Manufacturing and assembly effects
- Friction and contact-based variations
- High-temperature material response
- Nonlinear behaviour
- Durability characterization

Flow and thermal simulation

Simulation Validation

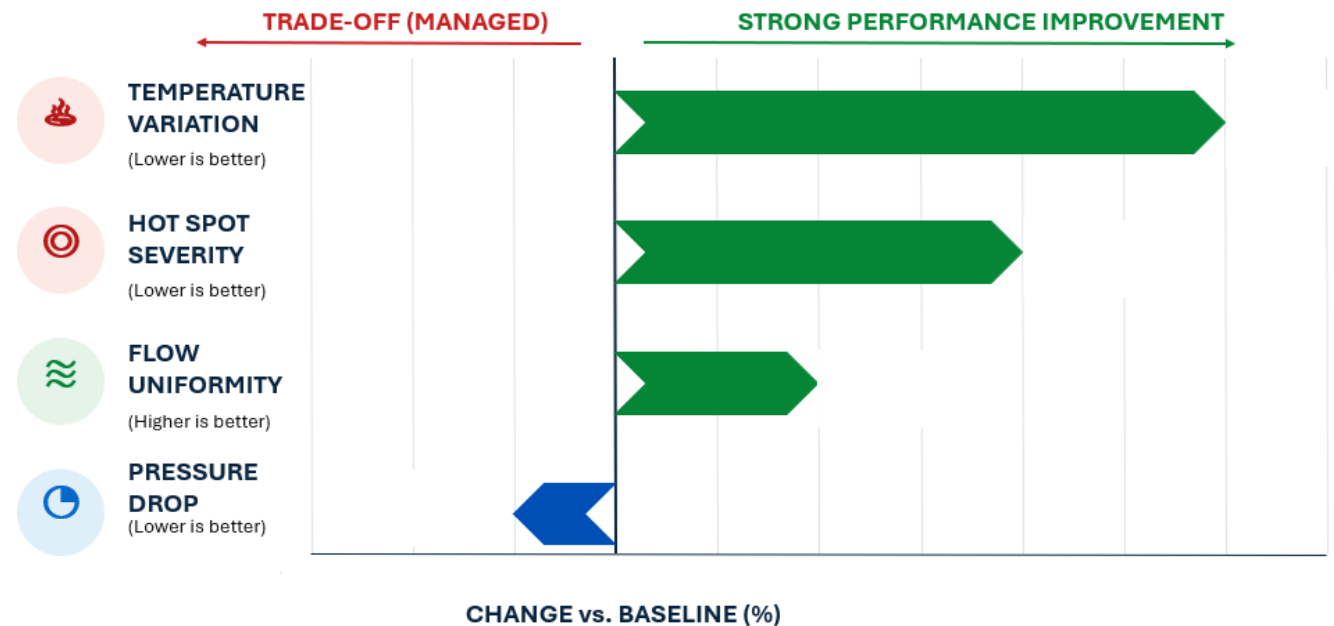
Gas Temperature Distribution



Simulation correlation > 95% accuracy

Simulation Led Concepts Development

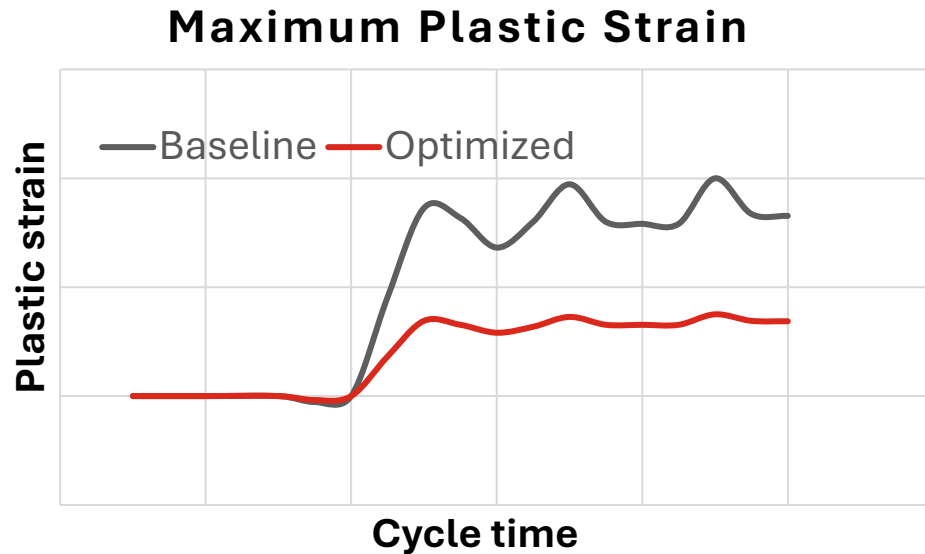
Baseline vs Optimized – Performance Improvements



Optimized concept showed Improved NOx Reduction and BSFC performance

eHeater TMF and PSD Simulation

Thermo Mechanical Fatigue (TMF)

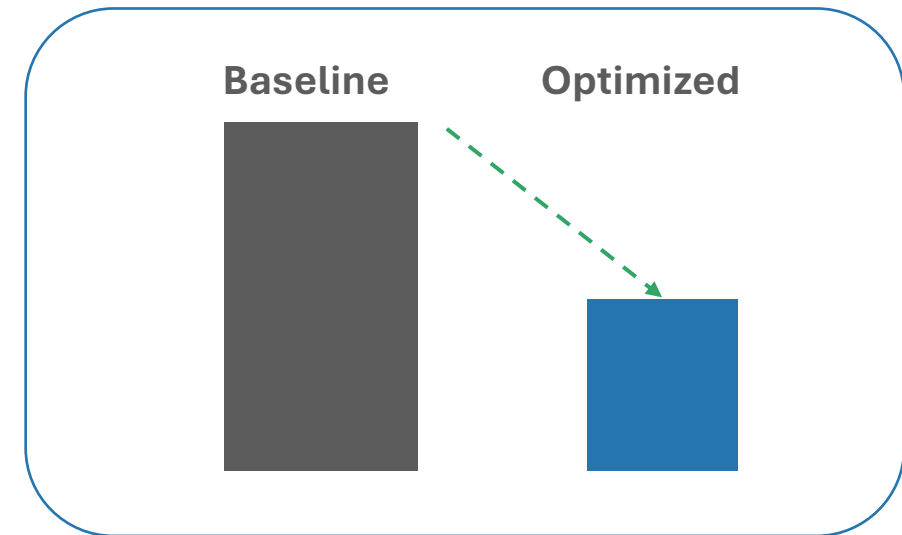


TMF STRAIN

60% ↓

vs. baseline

Power Spectral Density (PSD)



PSD STRESS

70% ↓

vs. baseline

TMF and PSD assessment for optimized concept showed durability improvement across thermal cycling and vibration loading

SUMMARY



Cummins' broad technology portfolio enables application-specific solutions for future emission requirements



Validated CFD and structural eHeater simulation methodologies identify performance and durability challenges early, accelerating right-first-time design



Simulation led product development delivered improved thermal performance and lower backpressure, while improving durability with lower TMF plastic strain, and lower PSD stresses



Established a robust and scalable pathway for application-ready eHeater integration

Future Scope

- Future work will focus on integration and co-simulation of performance and durability simulation workflows

Q+A

