# Optimization of an Advanced Passive/Active Diesel Emission Control System

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RYPOS

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# Objectives

- To quantify emission levels from an off-road engine equipped with aftertreatment technologies provided by Rypos, Inc.
  - Total Hydrocarbons (HC)
  - Oxides of Nitrogen (NOx), Nitric Oxide (NO), Nitrogen Dioxide ($NO_2$)
  - Carbon Monoxide (CO)
  - Carbon Dioxide ($CO_2$)
  - Diesel Particulate Matter (PM)
- Utilize the ISO 8178-C1 test cycle
- Compare results of actively and passively regenerated Diesel Particulate Filters

# Test Equipment

- Tests conducted using 40 CFR Part 1065 designed Constant Volume Sampling (CVS) system
- Eaton 400 hp Alternating Current Dynamometer
- Emission measurement technologies
  - HC: Flame Ionization Detector (FID) (reported as ppm$C_1$)
  - NOx, NO: Dual Heated Wet Chemiluminescent Detection
  - $NO_2$: Difference of NOx and NO Results
  - CO, $CO_2$: Non-Dispersive Infrared (NDIR) Detection
  - PM: Gravimetric Analysis

# Engine Specifications

- 2006 Caterpillar 3054C (Tier II Certification Level)
  - 4.4 L Displacement
  - 4 Cylinder
  - 93 hp @ 2223 rpm
  - 292 ft-lb @ 1393 rpm
  - 200 scfm air flow at rated conditions

- Engine installed on AC engine dynamometer test bed
- Factory radiator and cooling system utilized

# Test Cycle

- ISO 8178-C1 8 Mode

| Mode | Condition | Speed | Torque |
|---|---|---|---|
| | | (rpm) | (ft-lb) |
| 1 | R100 | 2223 | (Full Rack) |
| 2 | R75 | 2223 | 165 |
| 3 | R50 | 2223 | 110 |
| 4 | R10 | 2223 | 22 |
| 5 | I100 | 1393 | (Full Rack) |
| 6 | I75 | 1393 | 219 |
| 7 | I50 | 1393 | 146 |
| 8 | Idle | 785 | 0 |

# Rypos Technology

- Actively Regenerated DPF
  - Electrical regeneration
  - Sintered metal fibers
  - Low exhaust backpressure
  - Regeneration independent of exhaust temperature
- Passively Regenerated DPF
  - Sintered metal fibers
  - Regeneration based on exhaust temperature

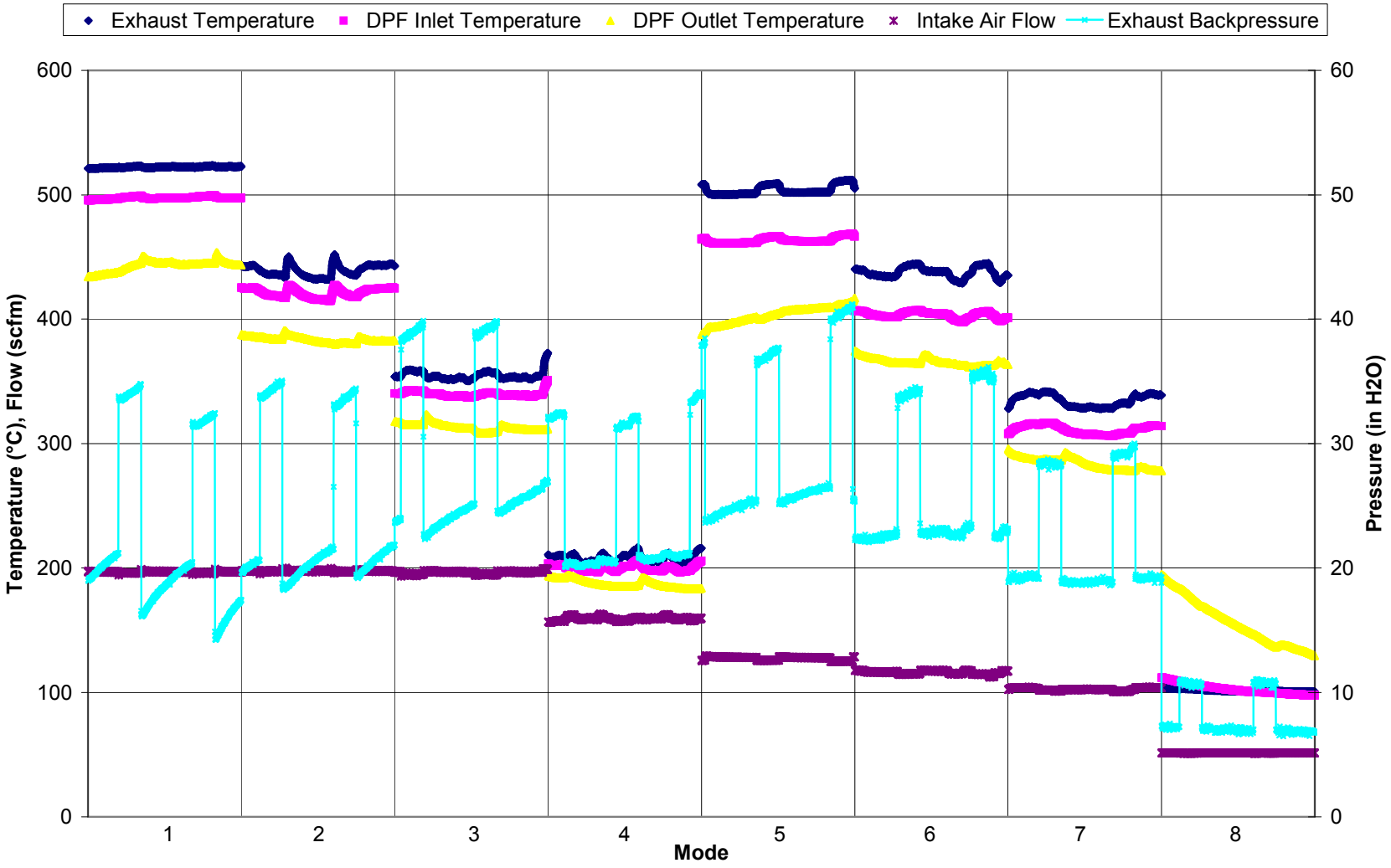
# Test Configurations

- Baseline Engine
- Engine with Actively Regenerated DPF
  - Equipped without Diesel Oxidation Catalyst
  - Equipped with Diesel Oxidation Catalyst
- Engine with Passively Regenerated DPF
  - Equipped with Diesel Oxidation Catalyst

# Actively Regenerated DPF

- Regeneration controlled by external control module
- 2 active legs, 1 passive leg
- Cycle time of approximately 15 minutes
- Can be deactivated to become a passive DPF

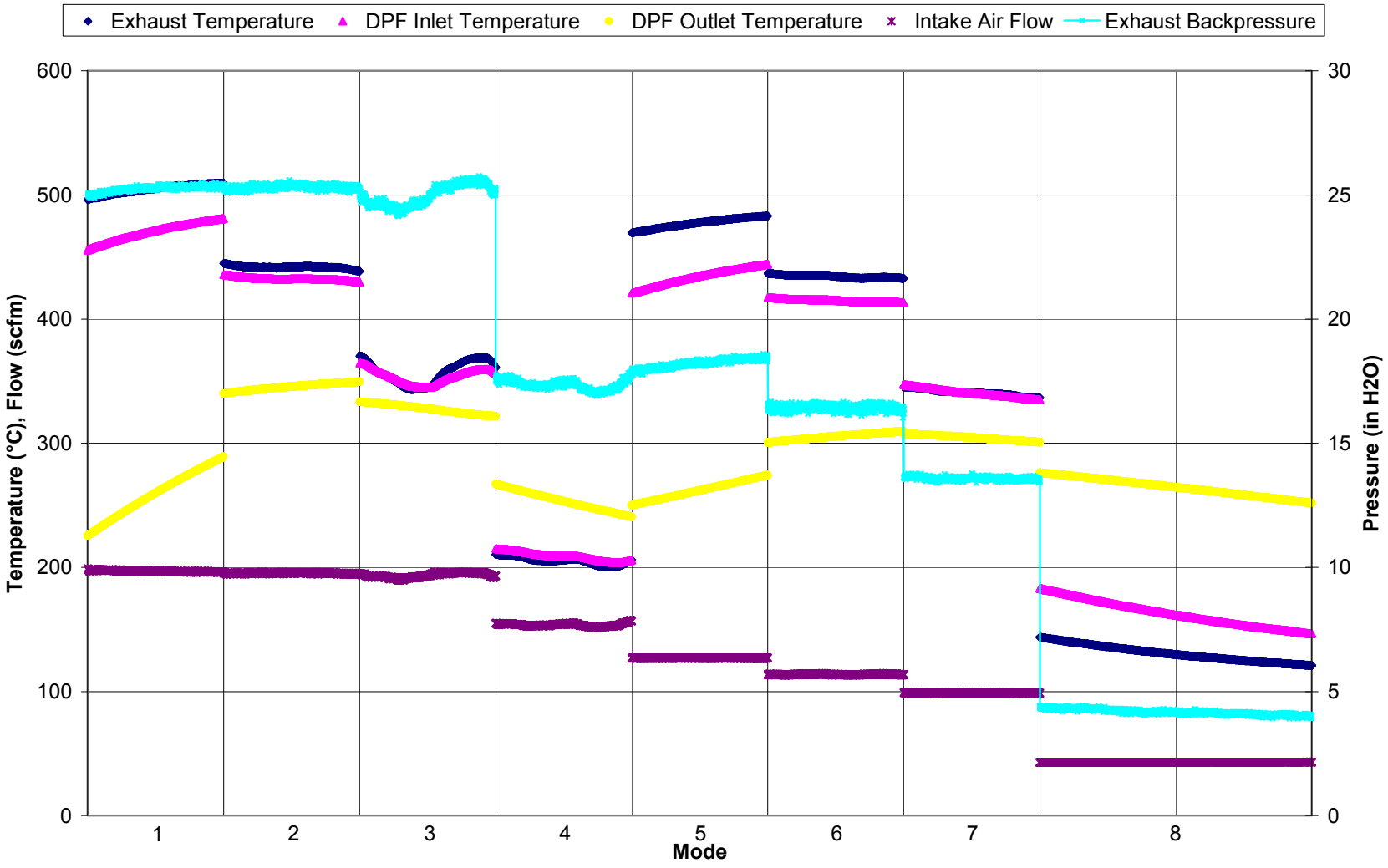
# Actively Regenerated DPF



# Passively Regenerated DPF

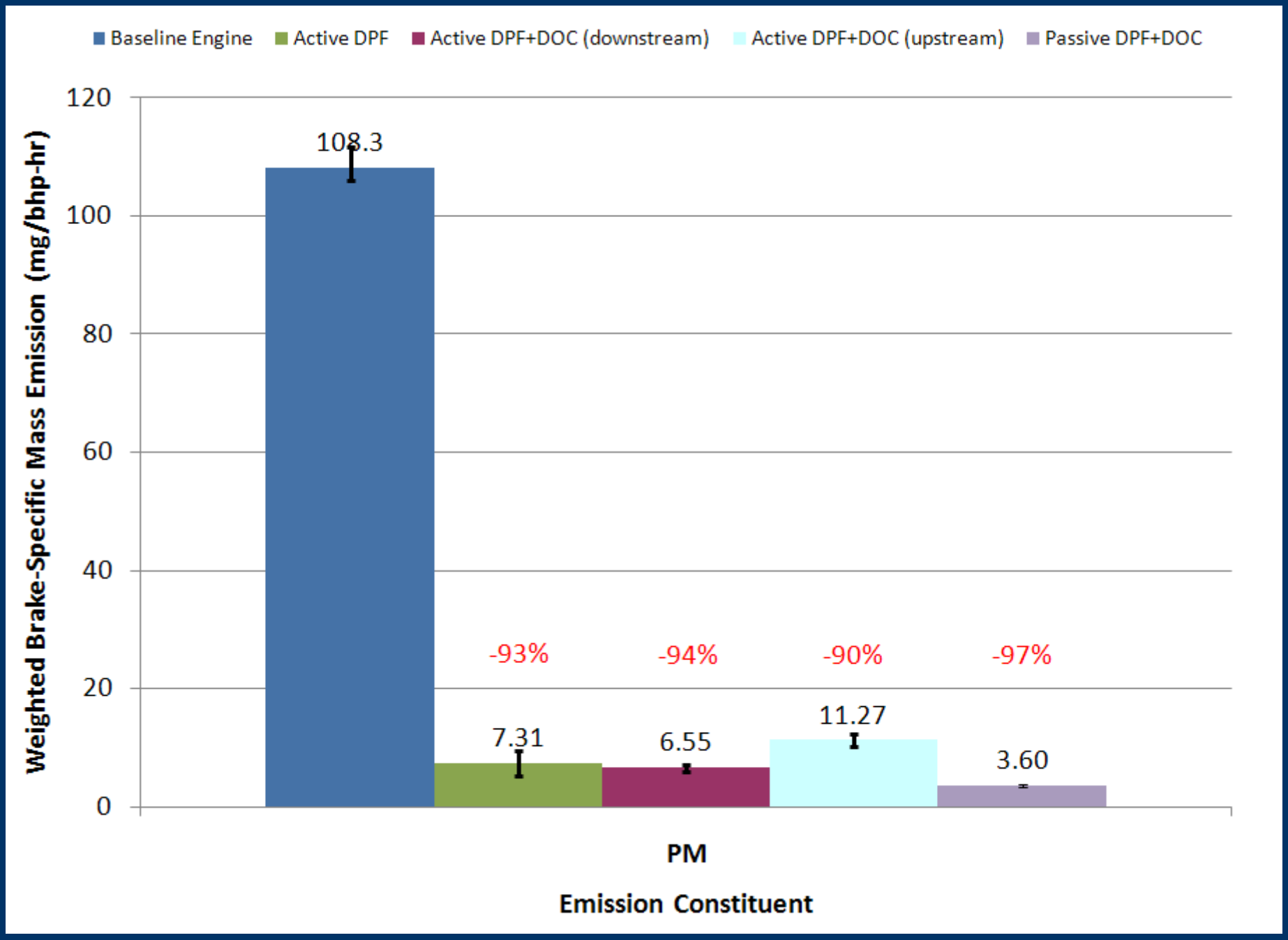
- Regeneration based on exhaust temperature
- Comprised of three sections
- Equipped with internal oxidation catalyst

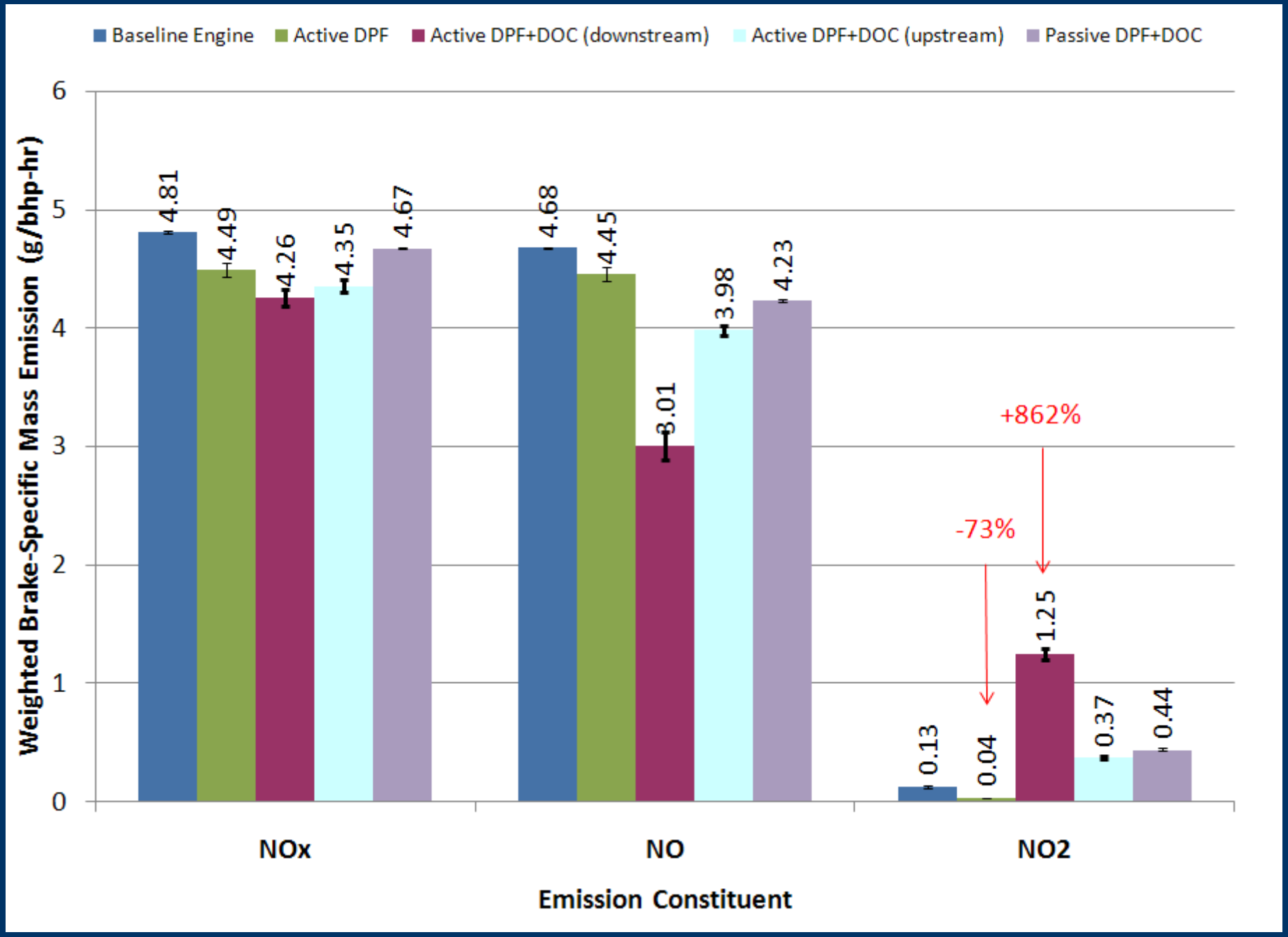
# Passively Regenerated DPF

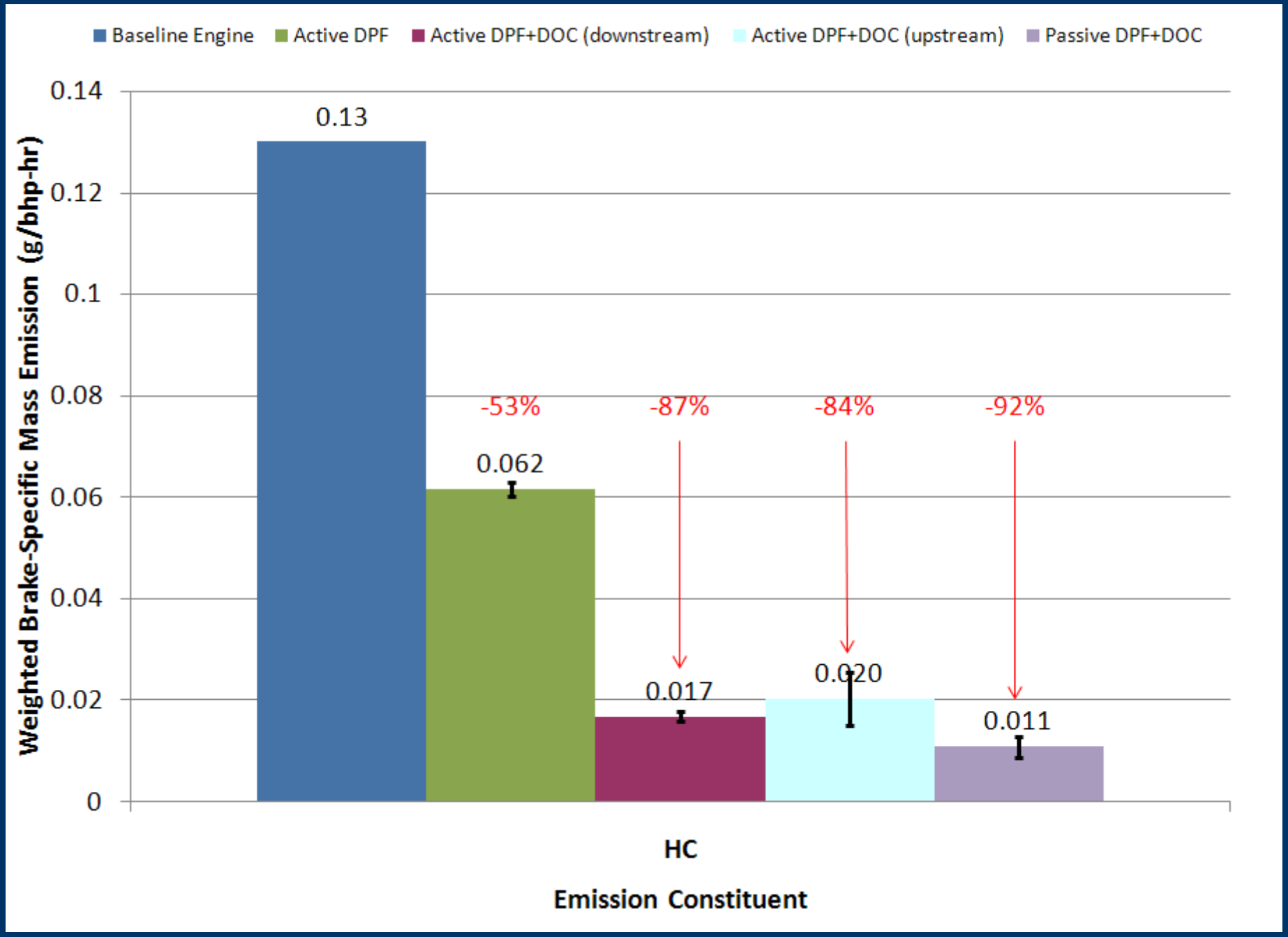


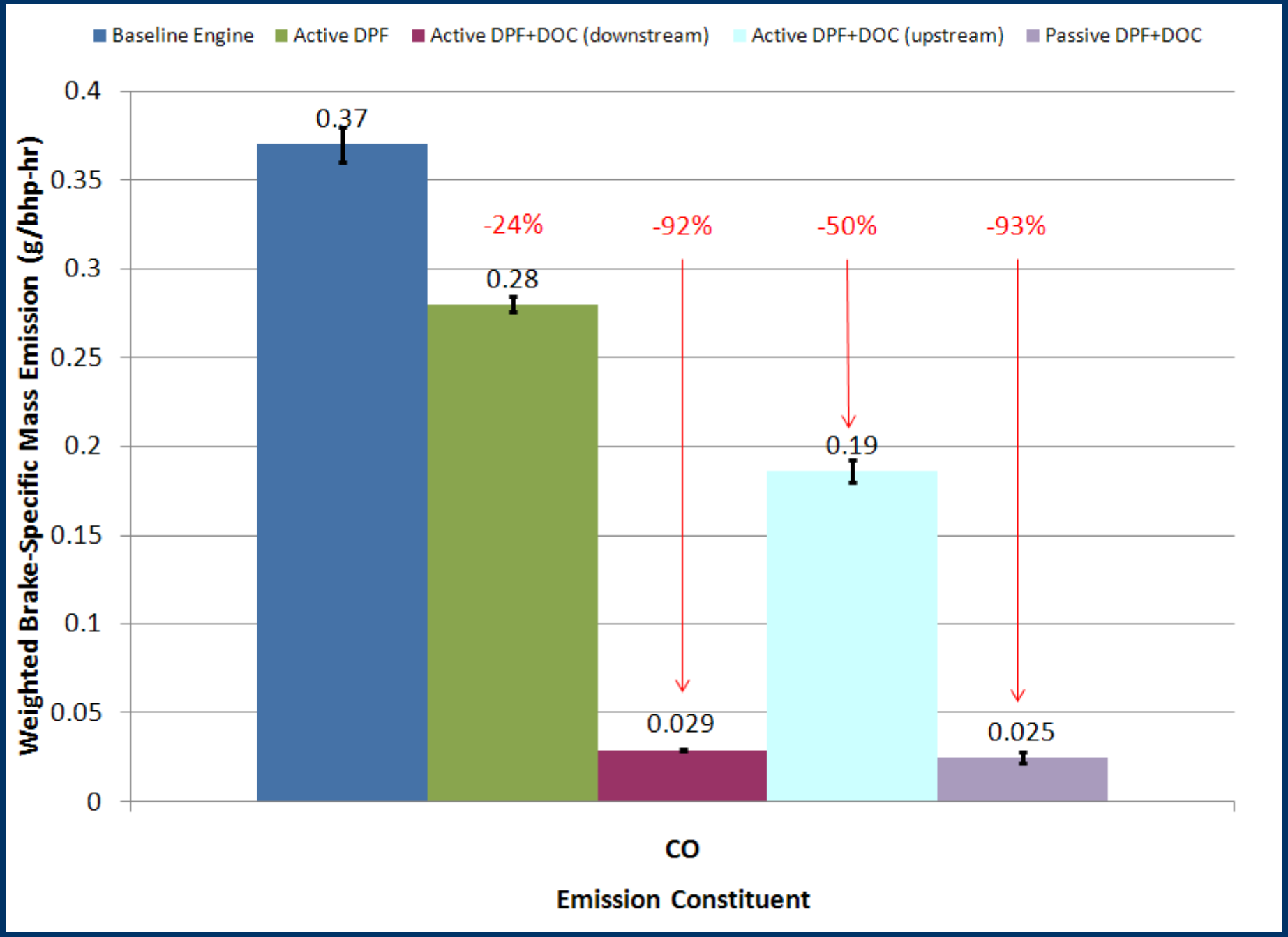
# Results

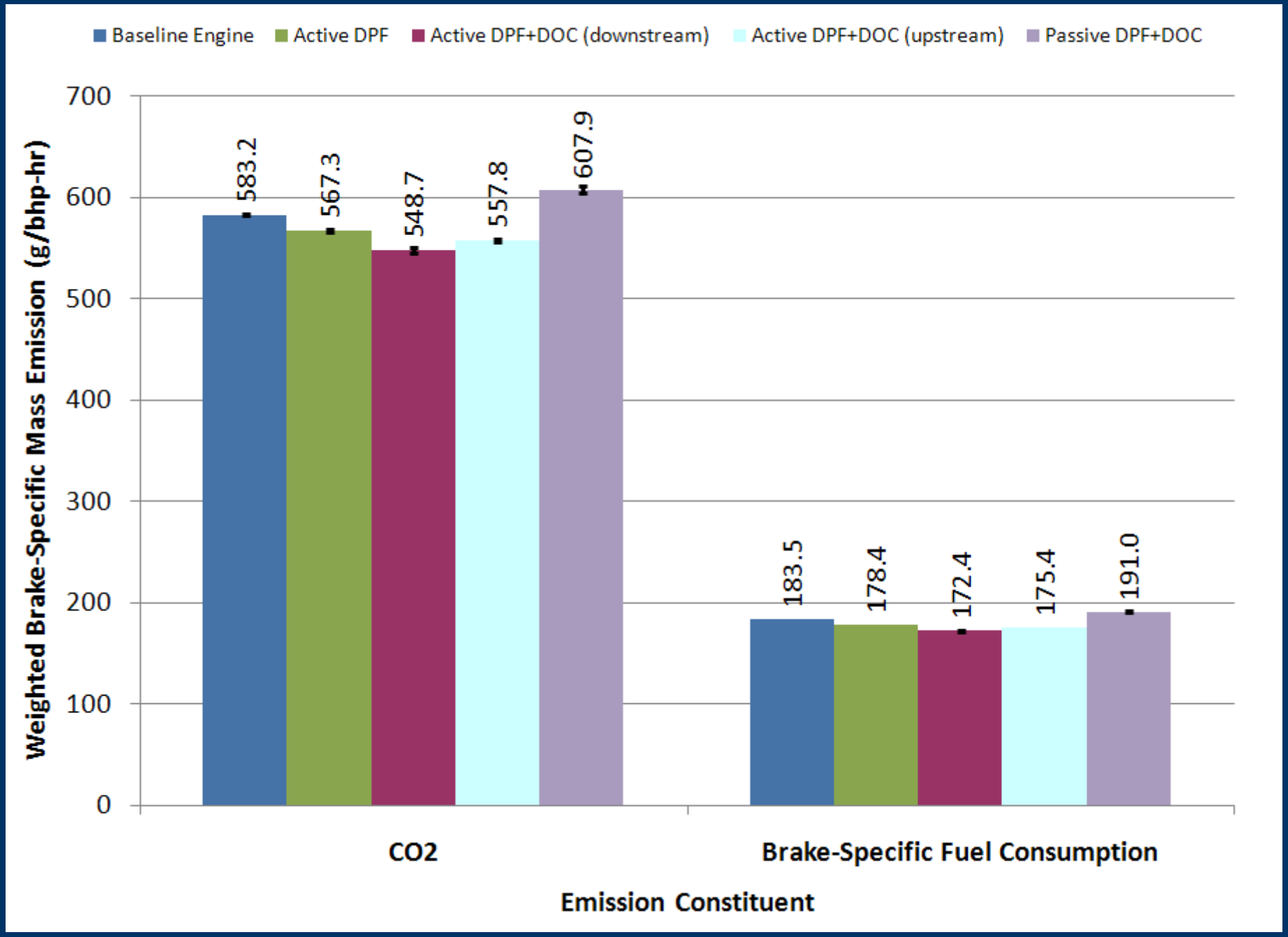
- The following charts show composite emission constituent results for five different engine/exhaust configurations
  - Uses modal weighting factors for ISO 8178-C1
- Configurations
  - Baseline (Engine Out)
  - Active DPF
  - Active DPF with DOC downstream
  - Active DPF with DOC upstream
  - Passive DPF with internal DOC


Baseline Engine
Active DPF
Active DPF+DOC (downstream)
Active DPF+DOC (upstream)
Passive DPF+DOC
Weighted Brake-Specific Mass Emission (mg/bhp-hr)
120
100
80
60
40
20
0
108.3
7.31
6.55
11.27
3.60
-93%
-94%
-90%
-97%
PM
Emission Constituent


Baseline Engine
Active DPF
Active DPF+DOC (downstream)
Active DPF+DOC (upstream)
Passive DPF+DOC
Weighted Brake-Specific Mass Emission (g/bhp-hr)
0
1
2
3
4
5
6
4.81
4.49
4.26
4.35
4.67
4.68
4.45
3.01
3.98
4.23
0.13
0.04
1.25
0.37
0.44
+862%
-73%
NOx
NO
NO2
Emission Constituent


Baseline Engine
Active DPF
Active DPF+DOC (downstream)
Active DPF+DOC (upstream)
Passive DPF+DOC
Weighted Brake-Specific Mass Emission (g/bhp-hr)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.13
0.062
0.017
0.020
0.011
-53%
-87%
-84%
-92%
HC
Emission Constituent


Baseline Engine
Active DPF
Active DPF+DOC (downstream)
Active DPF+DOC (upstream)
Passive DPF+DOC
Weighted Brake-Specific Mass Emission (g/bhp-hr)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.37
0.28
0.029
0.19
0.025
-24%
-92%
-50%
-93%
CO
Emission Constituent


Baseline Engine
Active DPF
Active DPF+DOC (downstream)
Active DPF+DOC (upstream)
Passive DPF+DOC
Weighted Brake-Specific Mass Emission (g/bhp-hr)
700
600
500
400
300
200
100
0
583.2
567.3
548.7
557.8
607.9
183.5
178.4
172.4
175.4
191.0
CO2
Brake-Specific Fuel Consumption
Emission Constituent

# Conclusions

- Both active and passive DPF technology shows high (≥90%) reduction of PM emissions
- Rypos proprietary technology has potential to reduce $NO_2$ emissions during a retrofit application
- DPF and DOC combined technologies show reduction of PM, HC (~85%), and CO (~90%)
- Minimum impact on fuel consumption
  - Variation in $CO_2$ emissions can be due to modal oscillations

# Current and Future Work

- Further evaluate $NO_2$ reduction performance by increasing $NO_2$ concentrations in the engine exhaust
  - Use of intercooler
  - $NO_2$ injection
- DOC Technology Evaluation
  - Emphasis placed on $NO_2$ reduction
- Heavy heavy-duty engine research
  - High exhaust flow

Thank you

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