# A negative emission internal combustion engine vehicle?

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# Pollution worldwide

- There are some very polluted places in the world

# Where do emissions come from?

- Ideal combustion

$C_xH_y + O_2 \rightarrow CO_2 + H_2O$

- Combustion in air

$C_xH_y + [O_2+(79/21)N_2] \rightarrow CO_2 + H_2O + N_2$

- Real combustion is hot and happens quickly

$C_xH_y + [O_2+(79/21)N_2] \rightarrow CO_2 + H_2O + N_2 + CO + NO_x + C + C_xH_y + \ldots$

Particulate

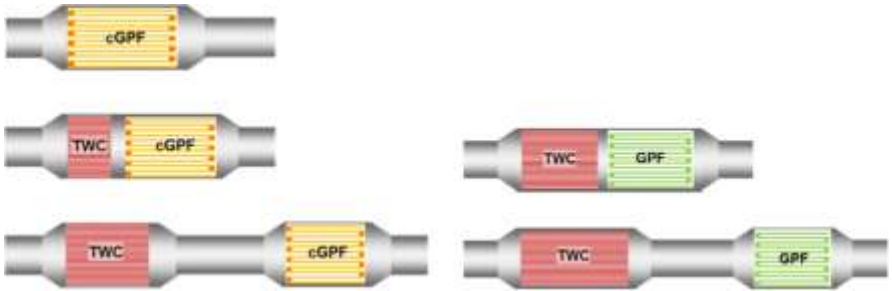
GHG

Pollutants

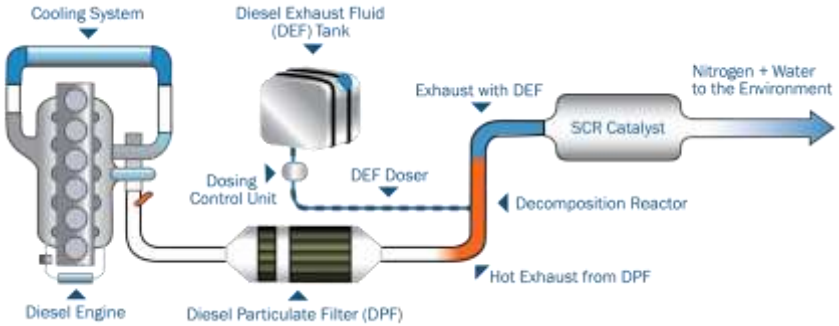
# Cleaning up these emissions

- Today these emissions are cleared by “aftertreatment”
  - Historically known as a catalytic converter
- Modern internal combustion engines have excellent aftertreatment
- This leads to many vehicles having zero / “zero” pollutant emissions

Gasoline (petrol)




Diesel



# Modern engines are clean – can that help?

- RDE levels measured as low as “zero” from many vehicles
  - But this instrumentation has a measurement accuracy
- Given vehicles carry around a “chemical factory” can we use this for good – people think so!

Editorial

International Journal of ENGINE RESEARCH

**IJER editorial: The future of the internal combustion engine**

International J of Engine Research
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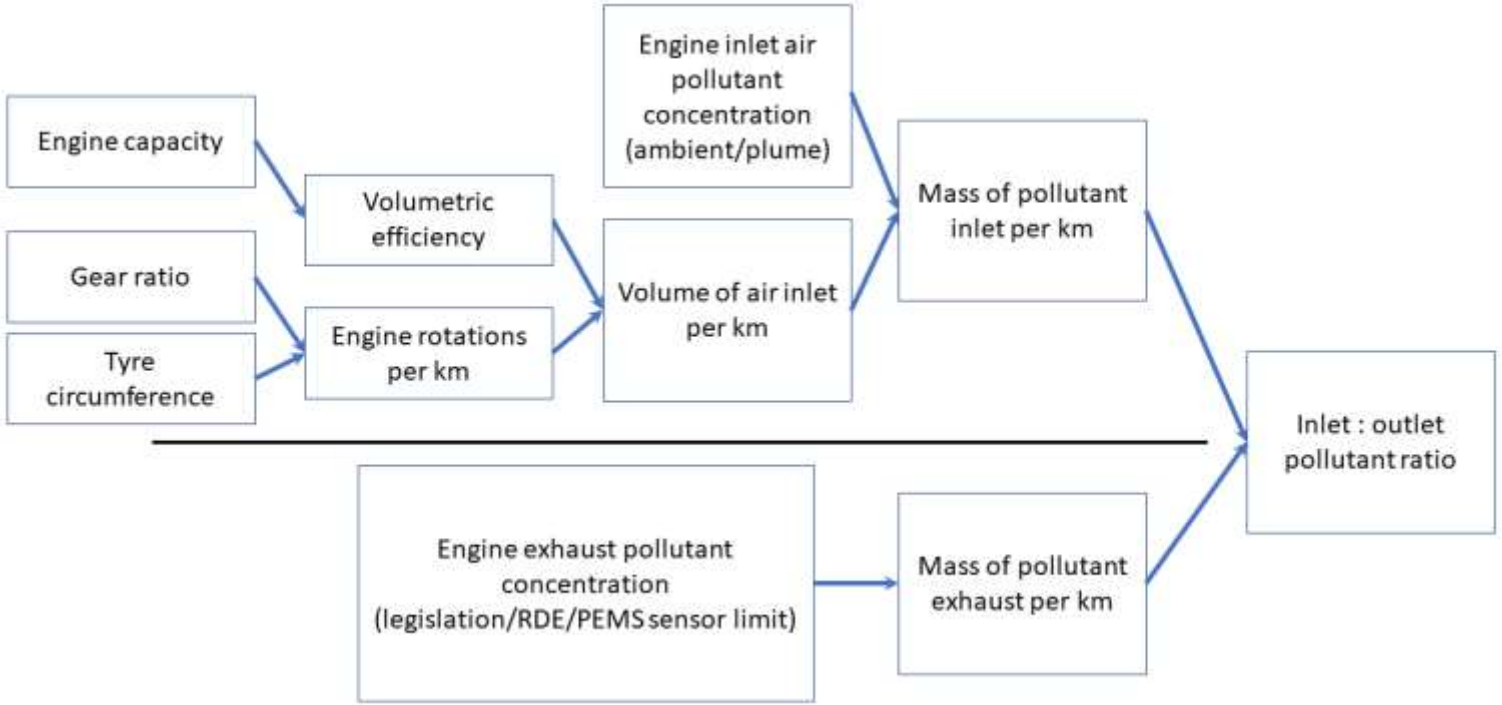
SAGE

sions (e.g. 0.02 g/bhp-h or 15–20 mg/km). Indeed, there are even examples of vehicles having tailpipe unburned HC emissions below those in the ambient air at the engine’s intake, so-called negative emission vehicles!

# Methodology



# Inlet concentrations

Inlet $NO_2$ concentration values considered in this work.

| | $NO_2$ (μg/$m^3$) | Source |
|---|---|---|
| Beijing, China, 2013 | 120 | Cheng et al. (2018) |
| London, UK, 2014 | 463 | Griffiths (2014) |
| Delhi, India, 2015 | 233 | Nandi (2018) |
| WHO 24-h exposure guideline | 25 | World Health Organisation WHO (2021) |
| WHO annual mean exposure guideline | 10 | World Health Organisation WHO (2021) |
| Plume 1 from preceding vehicle[a] | 2927 | Janssen and Hagberg (2020) |
| Plume 2 from preceding vehicle[a] | 1250 | Tajdaran et al. (2022) |

[a] These plumes will be comprised of $NO_x$ rather than $NO_2$, but are treated as $NO_2$.

Inlet PM concentration values considered in this work.

| | PM (μg/$m^3$) | Source |
|---|---|---|
| Moradabad, India, 2020 ($PM_{2.5}$) | 999 | World's Air Pollution |
| Baoding, China, 2015 ($PM_{2.5}$) | 900 | Huang et al. (2018) |
| Sama, Asturias, Spain, 2022 ($PM_{10}$) | 883 | World's Air Pollution |
| WHO 24-h exposure guideline ($PM_{10}$) | 45 | World Health Organisation WHO (2021) |
| WHO annual mean exposure guideline ($PM_{10}$) | 15 | World Health Organisation WHO (2021) |
| WHO 24-h exposure guideline ($PM_{2.5}$) | 15 | World Health Organisation WHO (2021) |
| WHO annual mean exposure guideline ($PM_{2.5}$) | 5 | World Health Organisation WHO (2021) |

# Outlet concentrations

Vehicle exhaust $NO_2$ concentration values considered in this work.

| | $NO_2$ (mg/km) | Source |
|---|---|---|
| Euro 6d | 60 | Senecal and Leach (2021) |
| China 6 | 35 | Senecal and Leach (2021) |
| Best RDE | 1 | Transport for London (2014) |
| "Zero" (as defined by the accuracy of the PEMS) | 23.8 (μg/km) | Weiss et al. (2011) |

Vehicle exhaust PM concentration values considered in this work.

| | PM (mg/km) | Source |
|---|---|---|
| Euro 6d | 4.5 | Senecal and Leach (2021) |
| China 6 | 3.0 | Senecal and Leach (2021) |
| Best RDE | 0.3 | Transport for London (2014) |
| "Zero" (as defined by the accuracy of the PEMS) | 5 (μg/km) | Oberguggenberger et al. (2012) |

# Two cases considered

Vehicle parameter values for typical and extreme cases.

| | Typical case | Extreme case |
|---|---|---|
| Tyre circumference (m) | 1.95 | 2.20 |
| Gear ratio (−) | 1.121 (fourth gear) | 10 (first gear) |
| Engine capacity (L) | 1.199 | 7.998 |
| Engine volumetric efficiency (%) | 40 | 100 |


# Results – typical case

Inlet:outlet $NO_2$ ratio for various inlet and outlet scenarios for the typical case. Highlighted cells indicate where the ICEV acts as a $NO_2$ reduction device.

| Inlet\Exhaust | Euro 6d | China 6 | Best RDE | "Zero" as measured by PEMS |
|---|---|---|---|---|
| Plume 1 | 0.01 | 0.01 | 0.40 | 16.95 |
| Plume 2 | 0.00 | 0.00 | 0.17 | 7.24 |
| London, UK, 2014 | 0.00 | 0.00 | 0.06 | 2.68 |
| WHO 24-hour exposure guideline | 0.00 | 0.00 | 0.00 | 0.14 |
| WHO annual mean exposure guideline | 0.00 | 0.00 | 0.00 | 0.06 |

Inlet:outlet PM ratio for various inlet and outlet scenarios for the typical case. Highlighted cells indicate where the ICEV acts as a PM reduction device.

| Inlet\Exhaust | Euro 6d | China 6 | Best RDE | "Zero" as measured by PEMS |
|---|---|---|---|---|
| Moradabad, India, 2020 ($PM_{2.5}$) | 0.03 | 0.05 | 0.46 | 27.54 |
| WHO 24-hour exposure guideline ($PM_{10}$) | 0.00 | 0.00 | 0.02 | 1.24 |
| WHO annual mean exposure guideline ($PM_{10}$) | 0.00 | 0.00 | 0.01 | 0.41 |
| WHO 24-hour exposure guideline ($PM_{2.5}$) | 0.00 | 0.00 | 0.01 | 0.41 |
| WHO annual mean exposure guideline ($PM_{2.5}$) | 0.00 | 0.00 | 0.00 | 0.14 |

# Results – extreme case

Inlet:outlet $NO_2$ ratio for various inlet and outlet scenarios for the extreme case. Highlighted cells indicate where the ICEV acts as a $NO_2$ reduction device.

| Inlet\Exhaust | Euro 6d | China 6 | Best RDE | "Zero" as measured by PEMS |
|---|---|---|---|---|
| Plume 1 | 0.89 | 1.52 | 53.20 | 2235.03 |
| Plume 2 | 0.38 | 0.65 | 22.72 | 954.49 |
| London, UK, 2014 | 0.04 | 0.06 | 2.18 | 91.63 |
| WHO 24-hour exposure guideline | 0.01 | 0.01 | 0.45 | 19.09 |
| WHO annual mean exposure guideline | 0.00 | 0.01 | 0.18 | 7.64 |

Inlet:outlet PM ratio for various inlet and outlet scenarios for the extreme case. Highlighted cells indicate where the ICEV acts as a PM reduction device.

| Inlet\Exhaust | Euro 6d | China 6 | Best RDE | "Zero" as measured by PEMS |
|---|---|---|---|---|
| Moradabad, India, 2020 ($PM_{2.5}$) | 4.04 | 6.05 | 60.53 | 3631.82 |
| WHO 24-hour exposure guideline ($PM_{10}$) | 0.18 | 0.27 | 2.73 | 163.60 |
| WHO annual mean exposure guideline ($PM_{10}$) | 0.06 | 0.09 | 0.91 | 54.53 |
| WHO 24-hour exposure guideline ($PM_{2.5}$) | 0.06 | 0.09 | 0.91 | 54.53 |
| WHO annual mean exposure guideline ($PM_{2.5}$) | 0.02 | 0.03 | 0.30 | 18.18 |

## Conclusions

- Can a modern internal combustion engine vehicle emit less PM / $NO_2$ than background – i.e. clean the air?
- YES!
- BUT: the circumstances when this happens are likely to be extremely limited
- However, when considering the plume of a vehicle in front (where data is limited) this is more likely, particularly for gross emitters
- Simple spreadsheet tool available for your own values:
  - https://ars.els-cdn.com/content/image/1-s2.0-S1352231022005532-mmc1.xlsx

ELSEVIER

Atmospheric Environment

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# Thank you for your attention

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