UNIVERSITY OF BIRMINGHAM

Synergies between fuel, powertrain & aftertreatment systems

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Motivation. Challenges

Academic/Research positions		
Position	**University**	**Date**
PhD in Mechanical Engineering	University of Castilla-La Mancha	2006-2009
Visiting Researcher	Penn State University	2007
Post-doctoral Research Fellow	University of Birmingham	2010-2014
Lecturer in Mechanical Engineering	Nebrija University	2014
Lecturer in Vehicle Systems	Coventry University	2015-2017
Lecturer in Mechanical Engineering	University of Birmingham	2017-currently

Future Power Systems. Vehicle Research Technology Group
Dept. of Mechanical Engineering, School of Engineering
College of Engineering and Physical Sciences

Challenges:
- Non renewable fuels (Scarcity)
- GHG emissions (CO_2)
- Other pollutants emissions

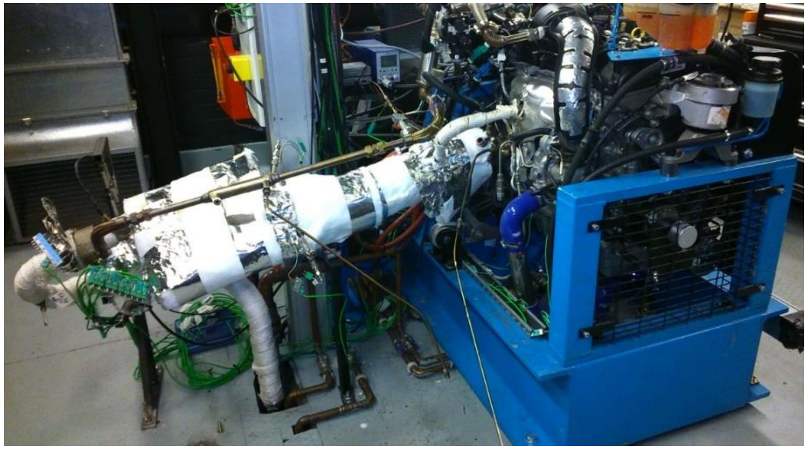
Motivation. Challenges

Gaseous and Particulate Emissions

Diesel and GDI Engines

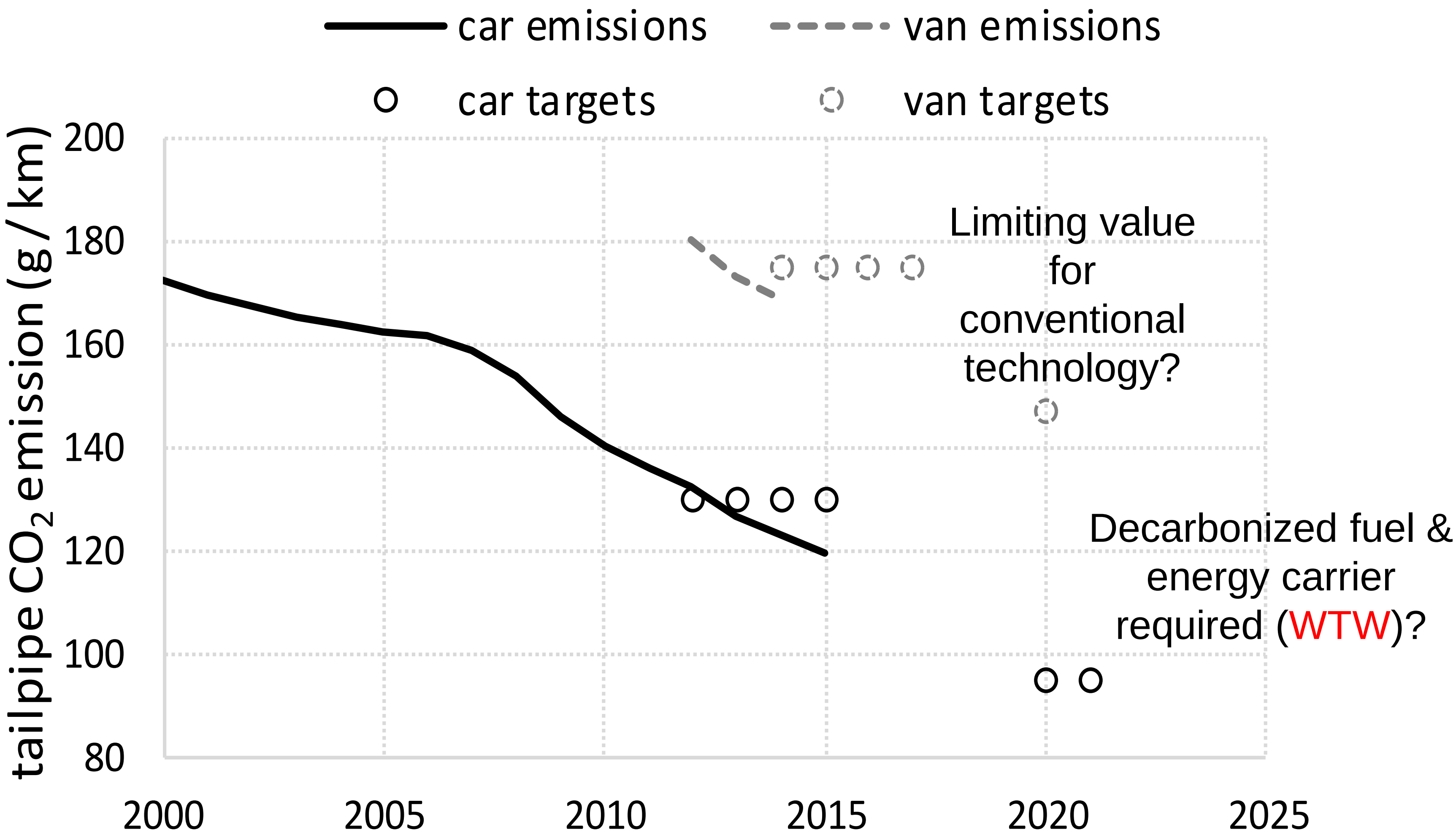
DRIFT
Catalyst Characterisation

H_2 Analysis
HSense (V&F)



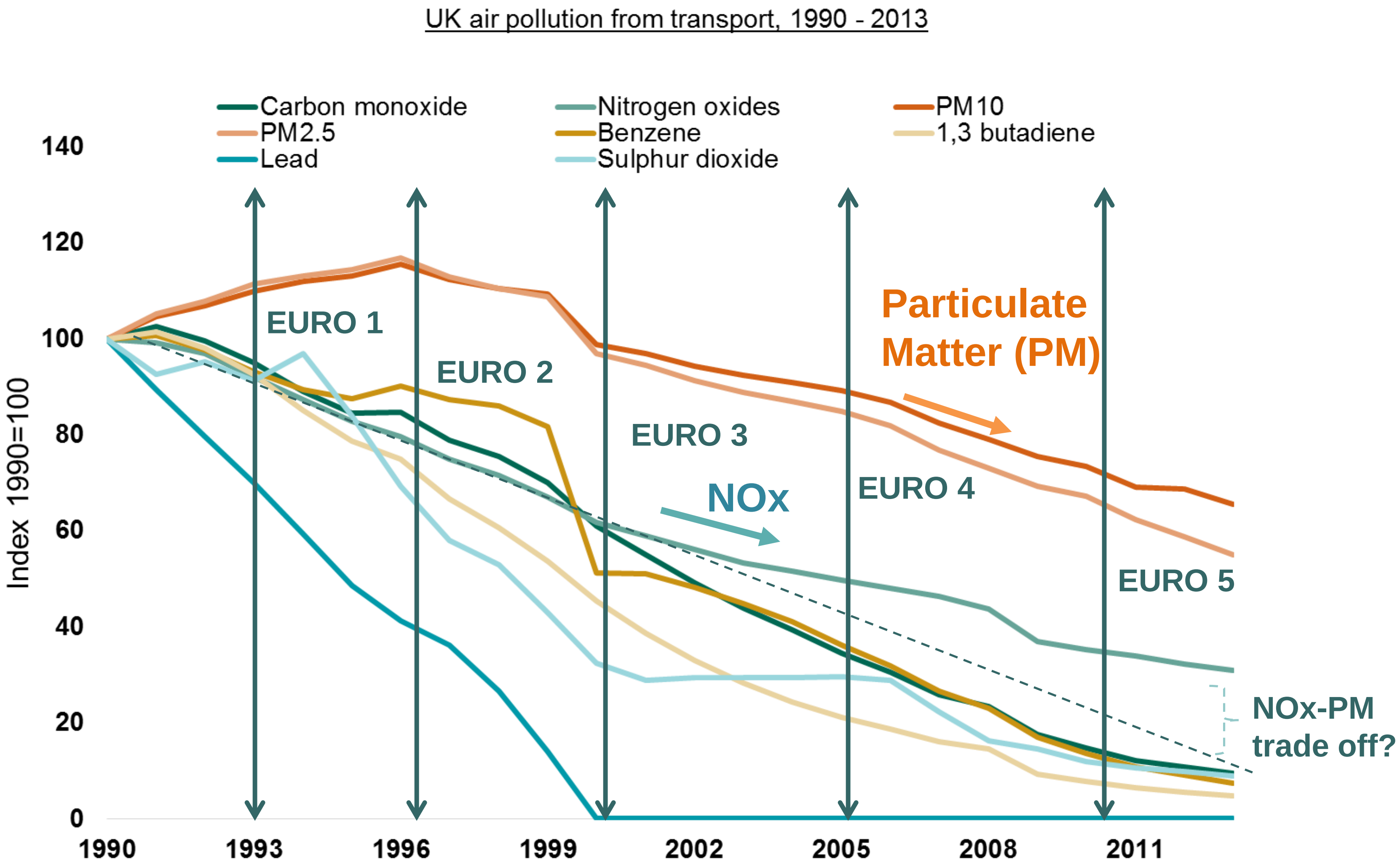
Motivation. Challenges

GHG and CO_2 emissions ➔ Fuel economy & low carbon fuels



Source: European Commission, Climate Action.

Motivation. Challenges

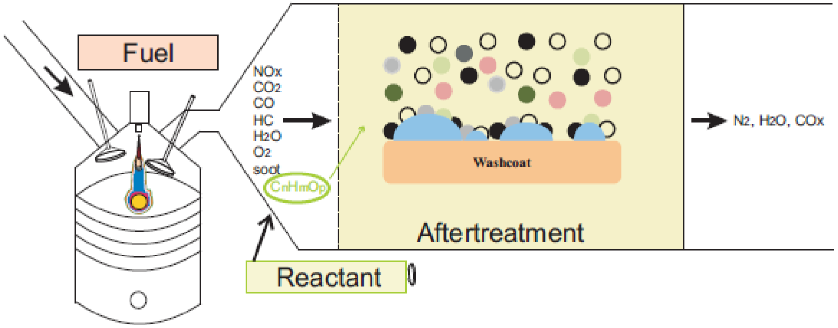


Source: DECC, ECUK.

Motivation. Aim

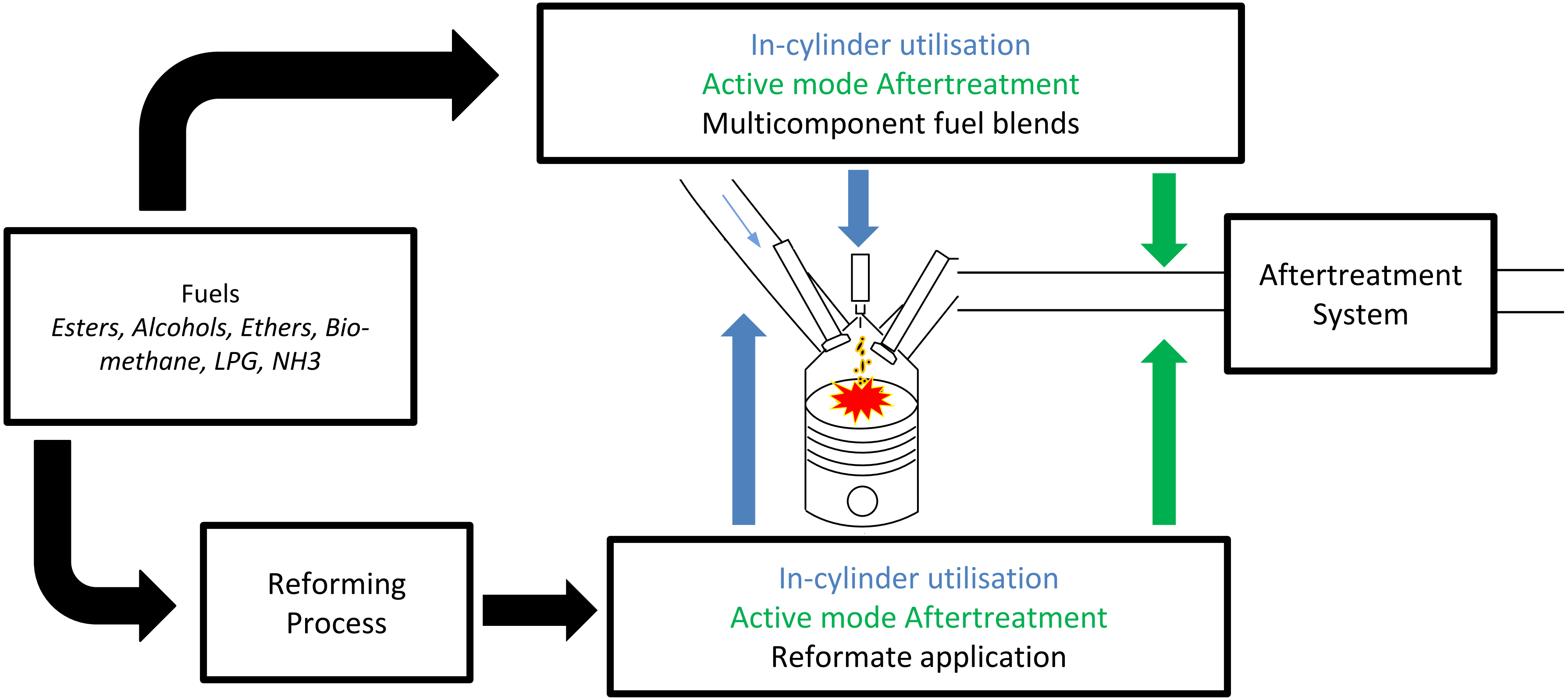
Develop existing and new areas of excellence and high impact research in mobility and transportation underpinned by major stakeholder and industrial collaborations

- Alternative Fuels and Blend Components
- Advanced combustion & alternative powertrains
- Aftertreatment system



Fuel, Powertrain and After-treatment technologies work together to beat energetic and environmental challenges
Synergies Fuel, Powertrain and After-treatment technologies

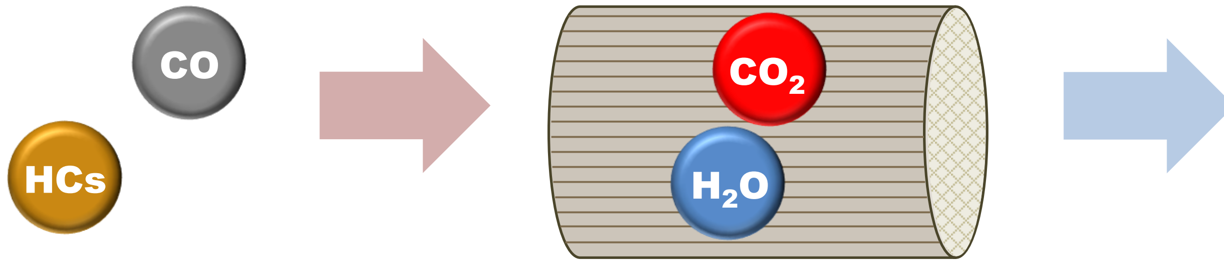
Synergies Fuel, Powertrain & After-treatment



- I Lefort, J.M. Herreros, A. Tsolakis. Reduction of Low Temperature Engine Pollutants by understanding the Exhaust Species Interactions in a Diesel Oxidation Catalyst. Environmental Science and Technology 48(4) 2361-2367, 2014.
- D. Fennell, J.M. Herreros, A. Tsolakis. Improving gasoline engine efficiency, emissions and PM with hydrogen from exhaust gas fuel reforming. International Journal of Hydrogen Energy 39 5153-5162, 2014.
- M. Bogarra, J.M. Herreros, A. Tsolakis, A. York, P. Millington. Reformate exhaust gas recirculation (REGR). Effect on PM, Soot Oxidation and Three Way Catalyst (TWC) Performance in Gasoline Direct Injection (GDI) Engines. SAE Int. J. Engines 9 (1), 2016.

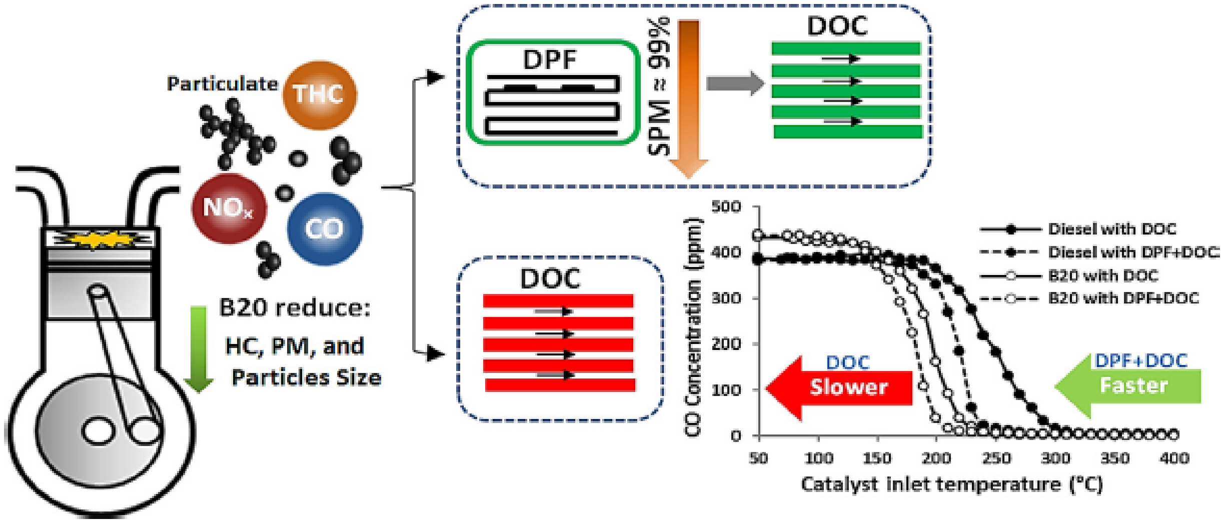
Synergies Fuel, Powertrain & After-treatment

Fuel (biodiesel) and aftertreatment (diesel oxidation catalyst, DOC)



$CO + ½\ O_2 \rightarrow CO_2$

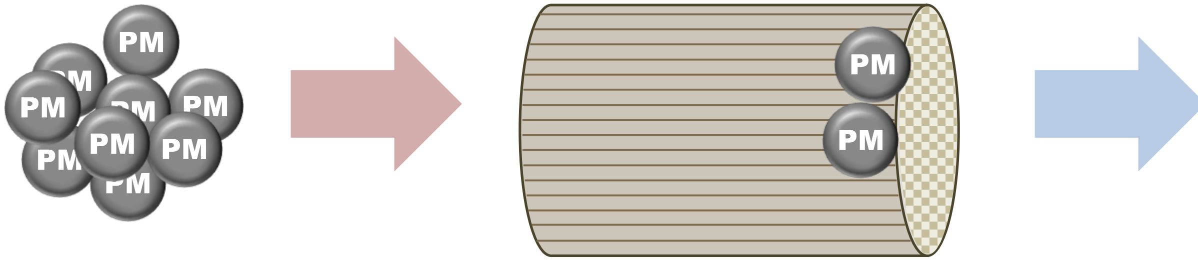
$C_nH_m + (n+m/2)\ O_2 \rightarrow CO_2 + H_2O$

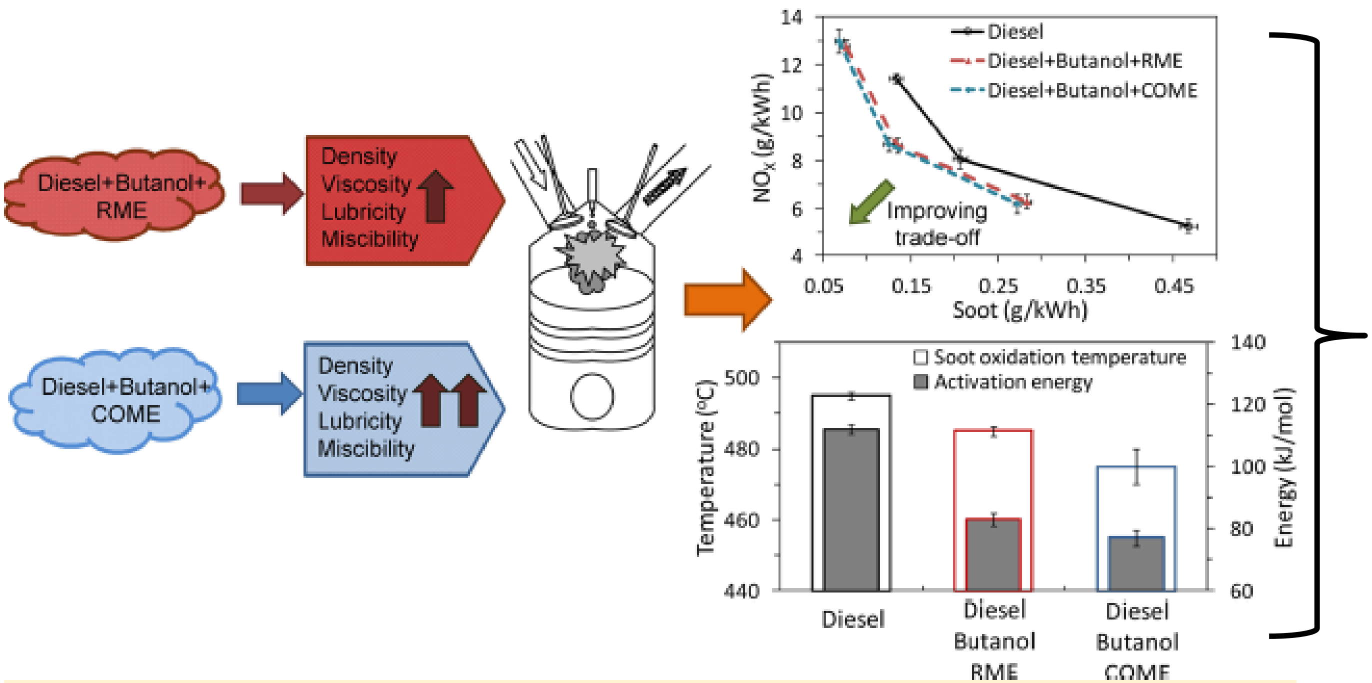


M.A. Fayad, D. Fernández-Rodríguez, J.M. Herreros, F.J. Martos, M. Lapuerta, A. Tsolakis. Interactions Between Aftertreatment Systems Architecture and Combustion of Oxygenated Fuels for Improved Low Temperature Catalysts Activity. Fuel, 229, 189-197, 2018.

Synergies Fuel, Powertrain & After-treatment

Fuel (Castor oil biodiesel) and aftertreatment (diesel particulate filter, DPF)



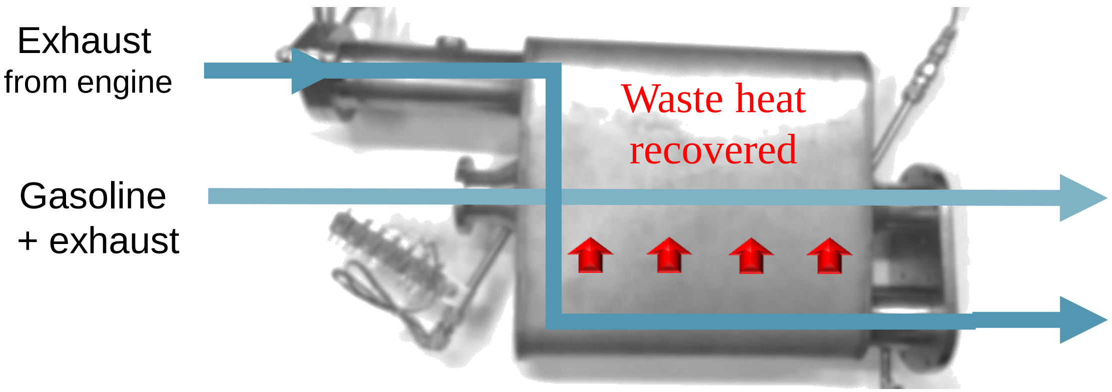


DPF Regeneration benefits with the OH group

Sukjit, Herreros, Piaszyk, Tsolakis. Finding synergies in fuels properties for the design of renewable fuels – Hydroxilated biodiesel effects on butanol-diesel blends. Environmental Science and Technology, 47, 3535-3542, 2013.

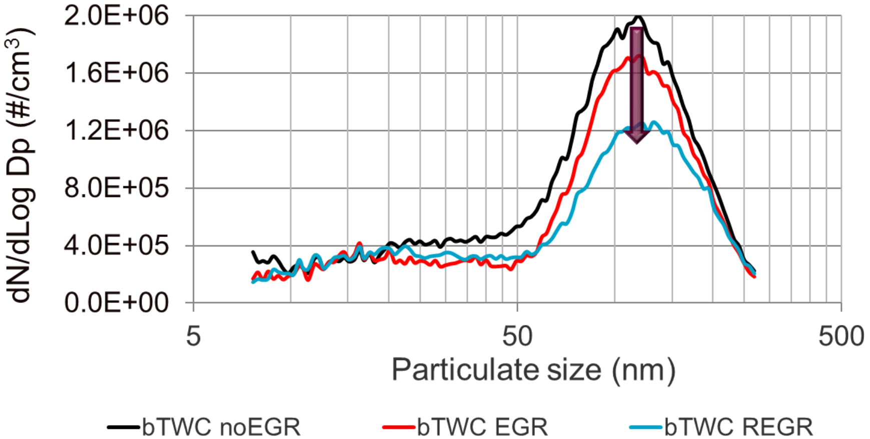
Synergies Fuel, Powertrain & After-treatment

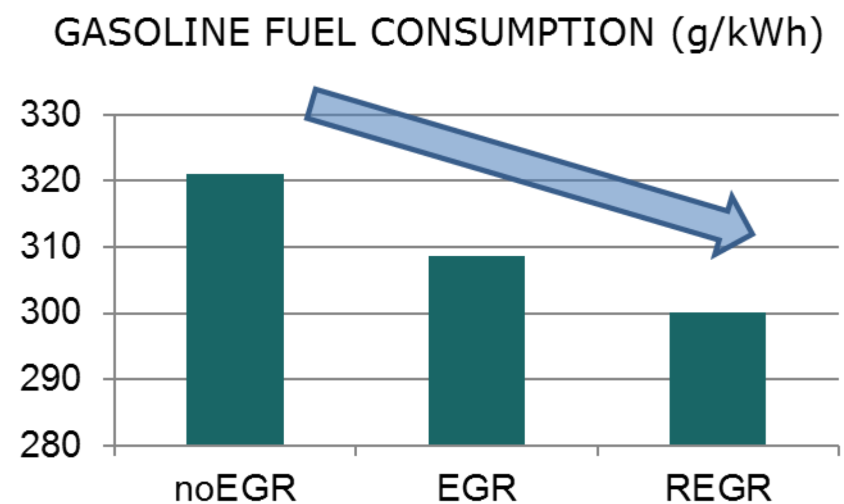
Fuel (Hydrogen) via Reformed Exhaust Gas Recirculation (REGR)



Reformate products
H_2 + CO
(REGR)
back to intake

Exhaust to atmosphere

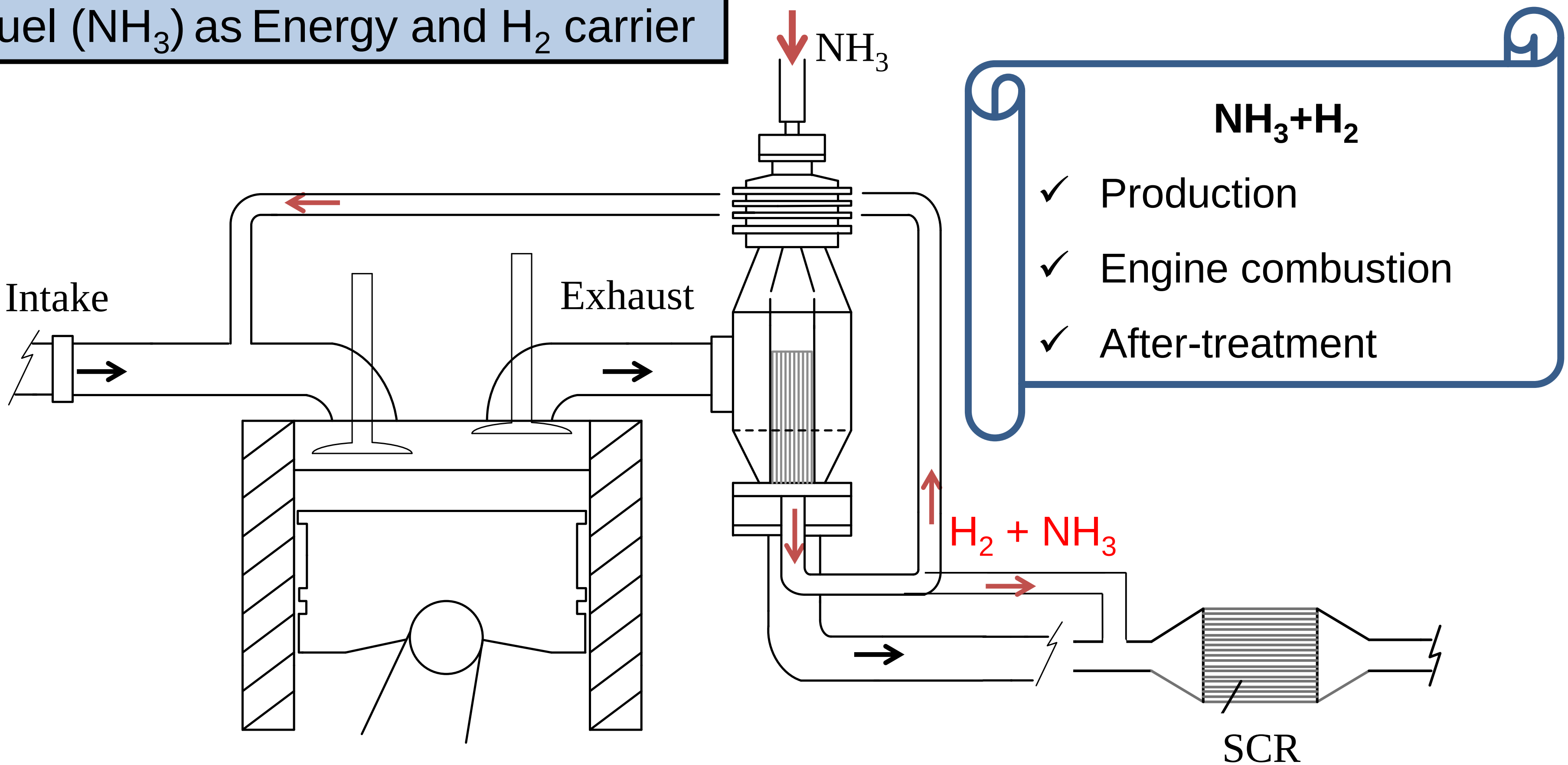




Bogarra, M., Herreros, J.M., Tsolakis, A., York, A., and Millington, P. Study of particulate matter and gaseous emissions in gasoline direct injection engine using on-board exhaust gas fuel reforming. Applied Energy, 180, 2016, 245-255.

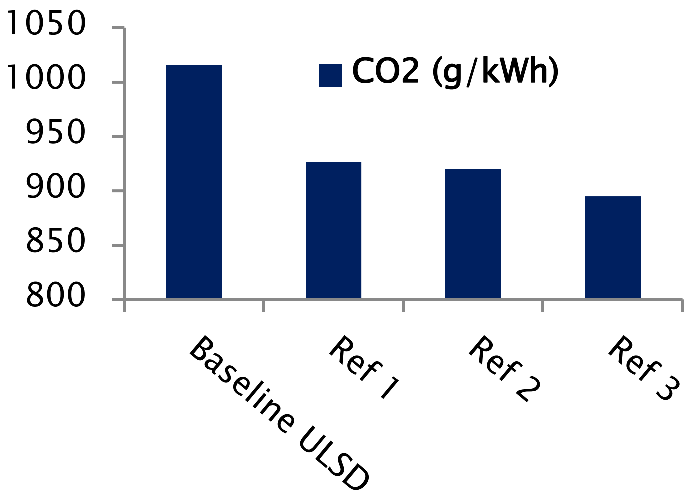
Synergies Fuel, Powertrain & After-treatment

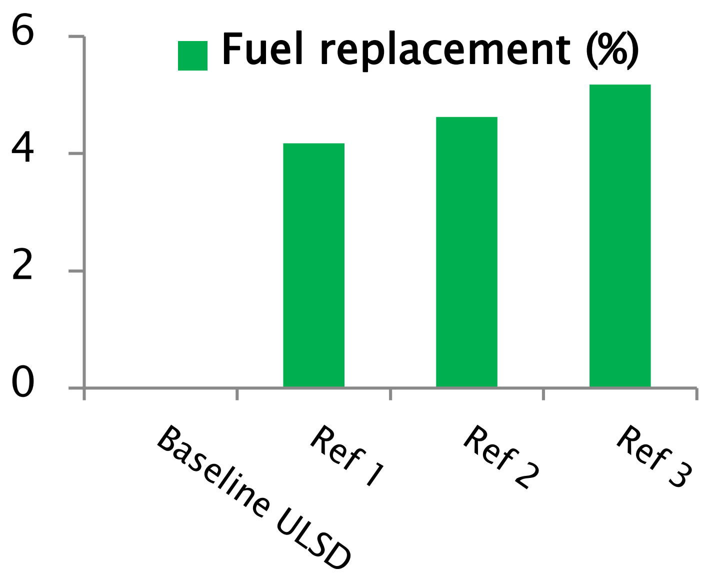
Fuel (NH_3) as Energy and H_2 carrier



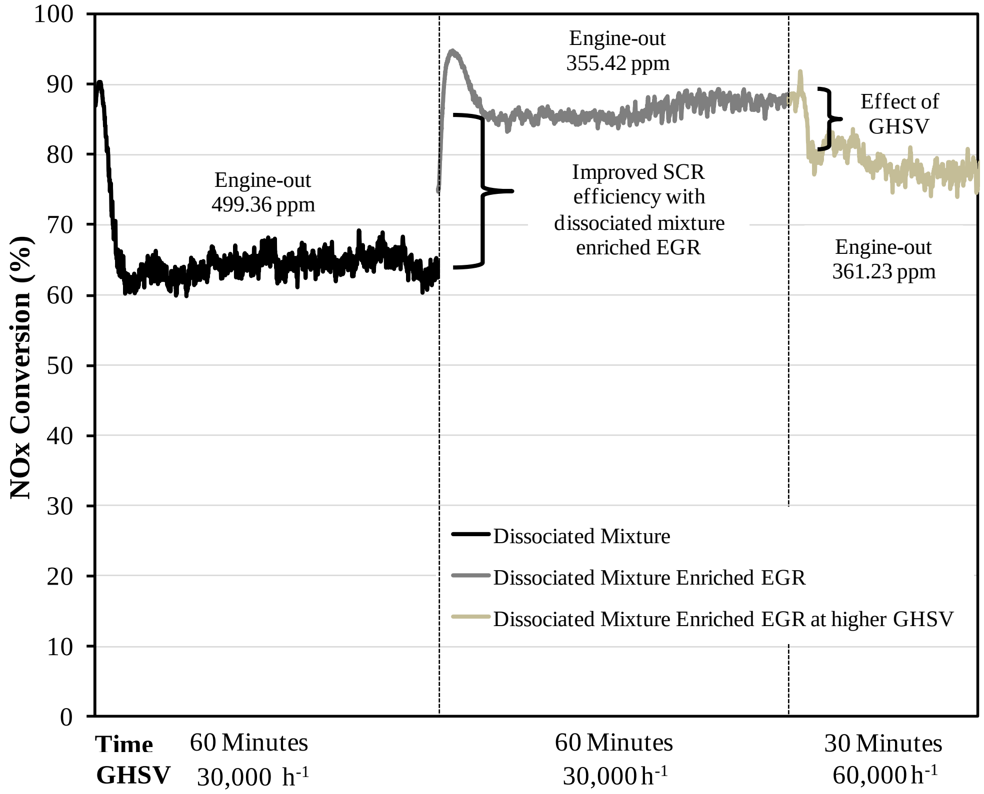
- W. Wang, J.M. Herreros, A. Tsolakis, A.P.E. York. Hydrogen production via ammonia on-board exhaust gas reforming and its utilisation in diesel combustion and emission control. International Journal of Hydrogen Energy, 38, 9907-9917, 2013.
- S.Sittichompoo, H.Nozari, J.M.Herreros, N.Serhan, J.A.M.da Silva, A.P.E.York, P.Millington, A.Tsolakis. Exhaust energy recovery via catalytic ammonia decomposition to hydrogen for low carbon clean vehicles. Fuel, 2020.

Synergies Fuel, Powertrain & After-treatment



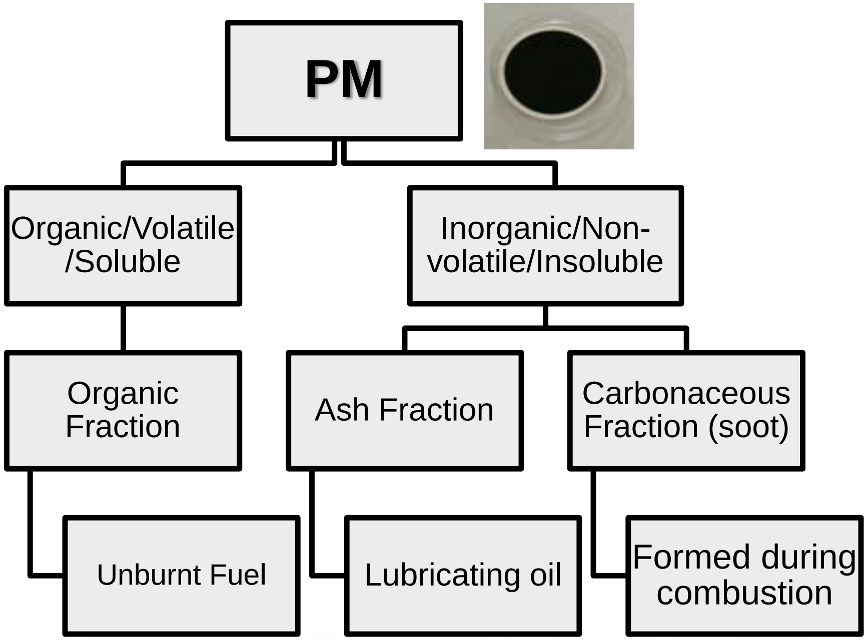


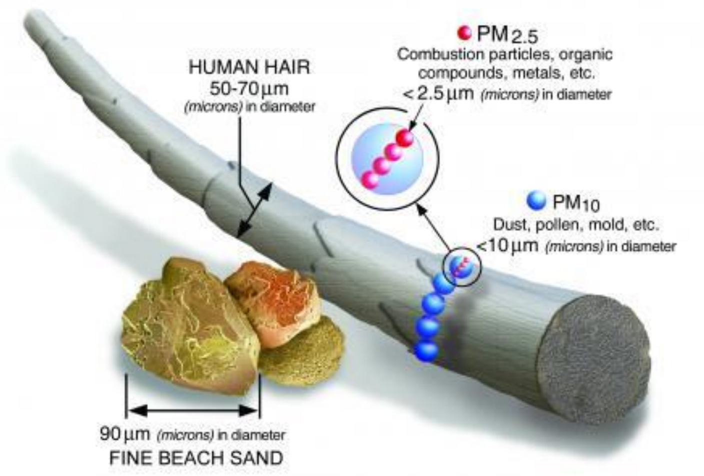
NH_3 Energy and H_2 carrier

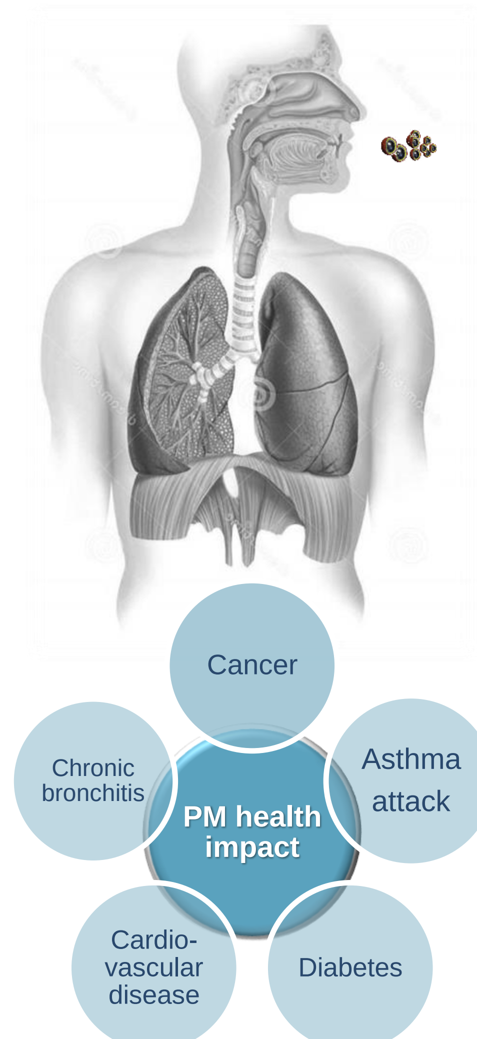


W. Wang, J.M. Herreros, A. Tsolakis, A.P.E. York. Hydrogen production via ammonia on-board exhaust gas reforming and its utilisation in diesel combustion and emission control. International Journal of Hydrogen Energy, 38, 9907-9917, 2013.

Particle Characterization

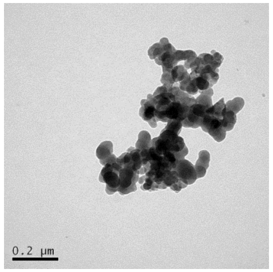






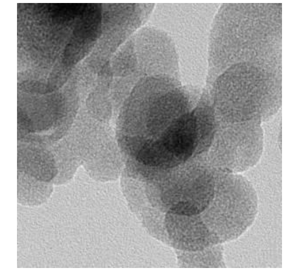
K.-H. Kim et al. Environment International 74, 136–143, 2015.

Particle Characterization



Transmission Electron microscopy (TEM)

Morphological and nanostructural characteristics

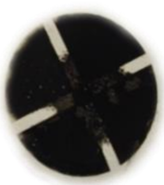


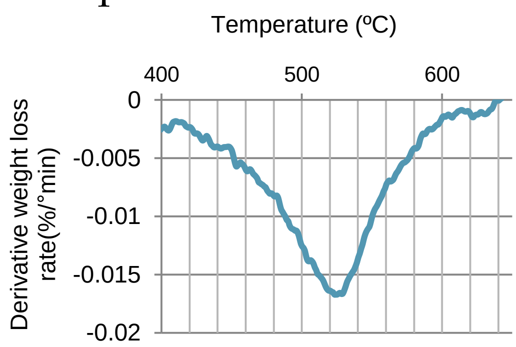
High Resolution TEM
X-ray diffraction
Raman

PARTICULATE MATTER CHARACTERISTICS

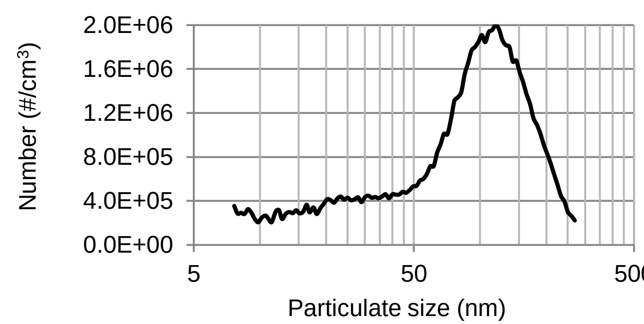
Impact on atmosphere residence time, lung deposition and regeneration strategies for filters

Soot oxidation patterns



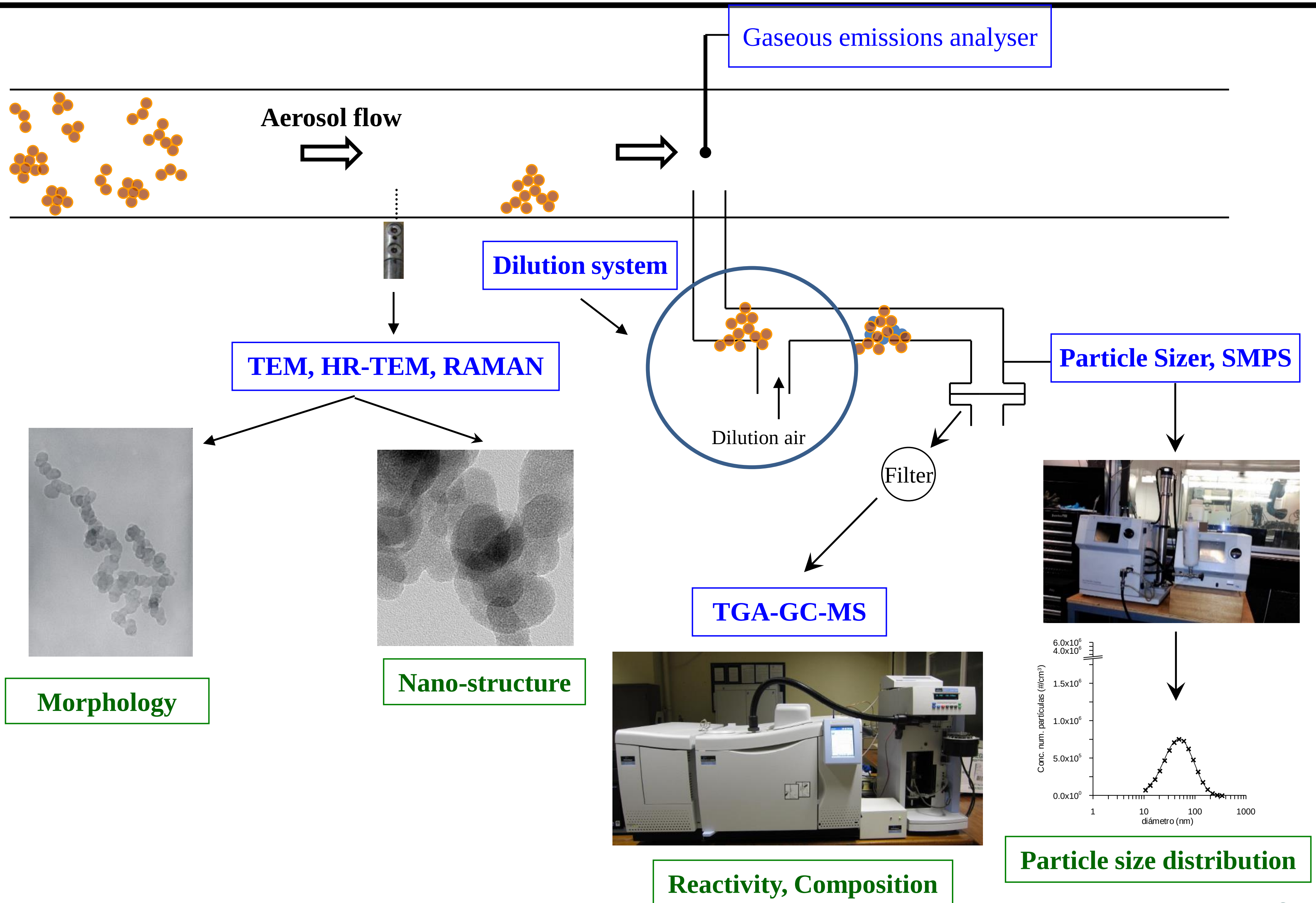


Particulate size distribution



Scanning Mobility Particle Sizer
Electric Low Pressure Impactor
Differential mobility spectrometer

Particle Characterization



Particle Characterization

Morphology

Micrograph acquisition → Jeol 1200 → **Image processing** → **Primary particle diameter** → **Morphology parameters**

Image processing
- Background cleaning
- Scale measurement

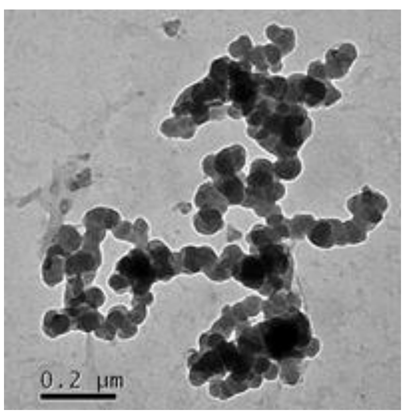
Primary particle diameter

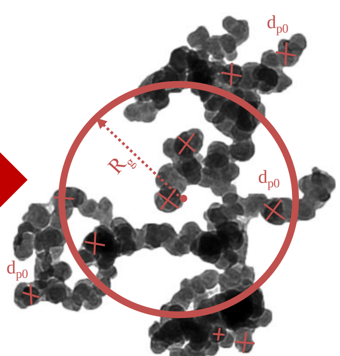
Statistic analysis

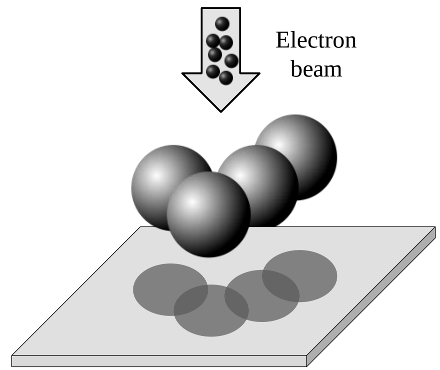
↓

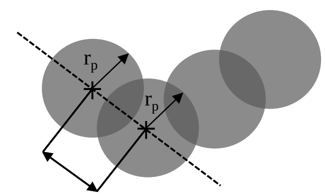
Normality of the sample

Morphology parameters
- n_{p0}
- Rg
- Fractal dimension









$$n_{p_0} = \left(\frac{A_m}{A_p}\right)^{\alpha}$$

A_m projected area
A_p area of the primary particles
α overlapping factor (1.09)

Particle Characterization

Nano-structure

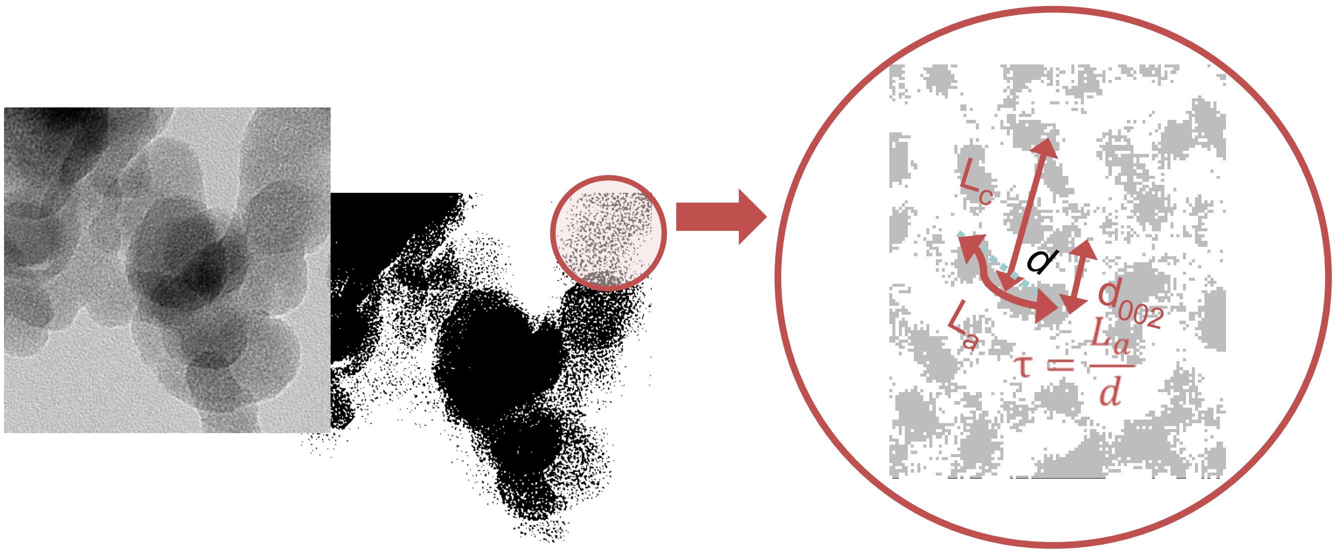
Micrograph acquisition → FEI Talos F200X

Image processing

Filtering
Contrast enhancement
Morphological operation
Binarisation
Skeletonisation

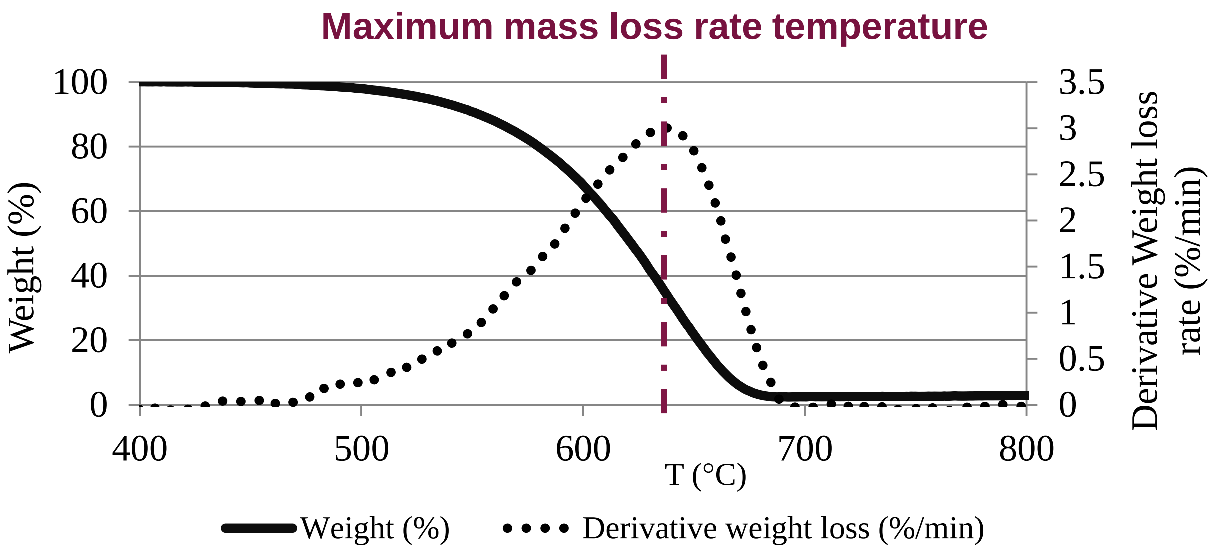
Parameters

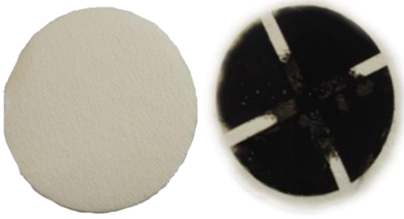
- Crystallite height (L_c)
- Crystallite width (L_a)
- Interlayer spacing (d_{002})
- Tortuosity (τ)



Particle Characterization

Oxidation





$$-\frac{dm}{dt} = A \cdot e^{\frac{-E_a}{RT}} \cdot f(m) \quad \Rightarrow \quad -\frac{dm}{dt} = A \cdot p_{O_2}^{r} \cdot e^{\frac{-E_a}{RT}} \cdot m^n = A' \cdot e^{\frac{-E_a}{RT}} \cdot m^n$$

m soot sample mass

t the time, E_a, the activation energy,

R the gas constant (8.314 J/mol·K),

T sample temperature

n soot mass reaction order

r oxygen reaction order

Ea Activation Energy

Next steps

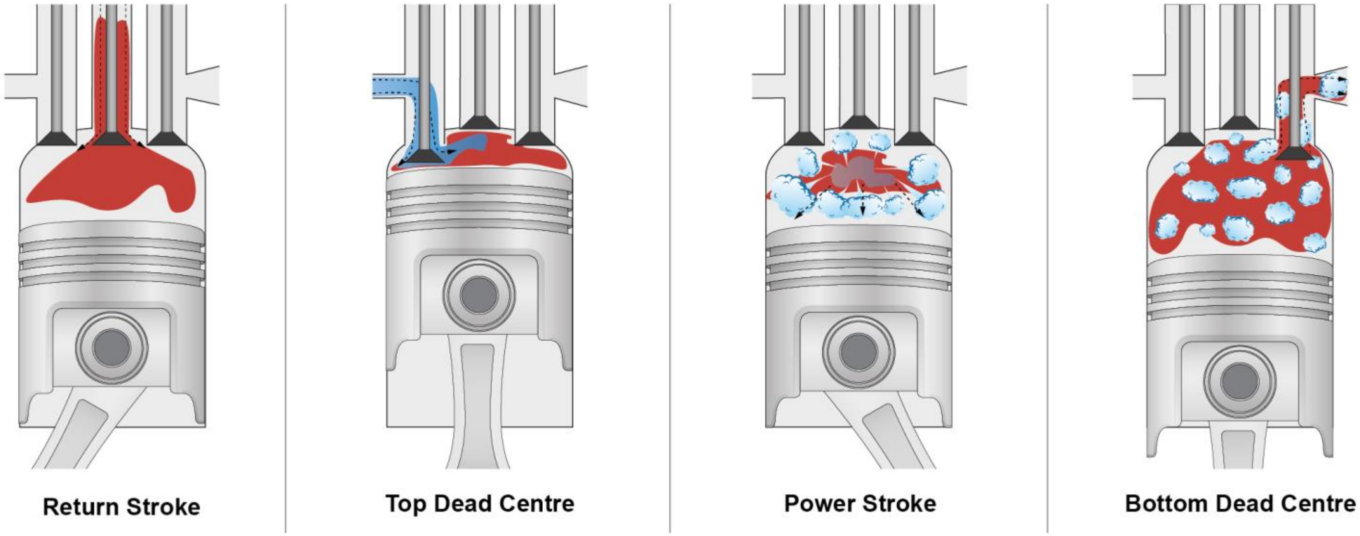
- Synergetic effects fuel/powertrain/aftertreatment. Fuels from waste, zero carbon technologies and electrified vehicles.

- Non exhaust (oil, tyres, brakes, road) and non-combustion oil derived emissions understanding the impact of vehicle electrification and autonomy

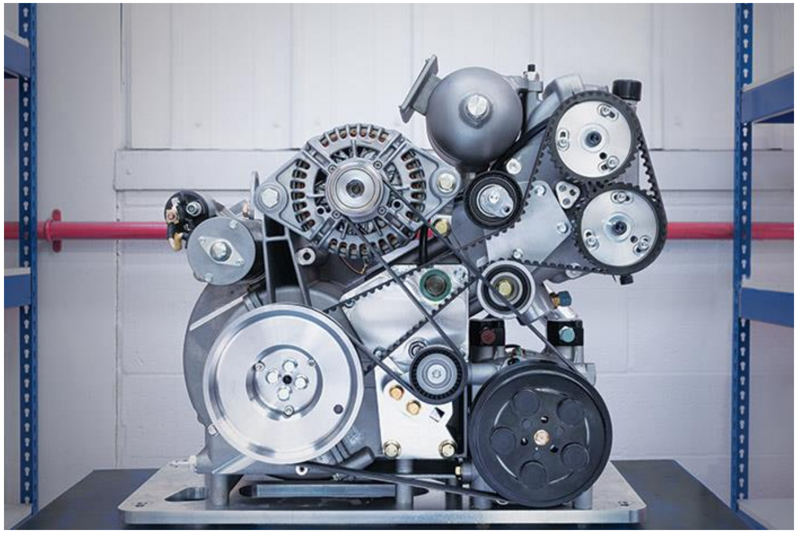
- Investigate formation mechanisms particle emissions from manufacturing processes (3-D printers)

Next steps

Liquid Air/Nitrogen powertrain

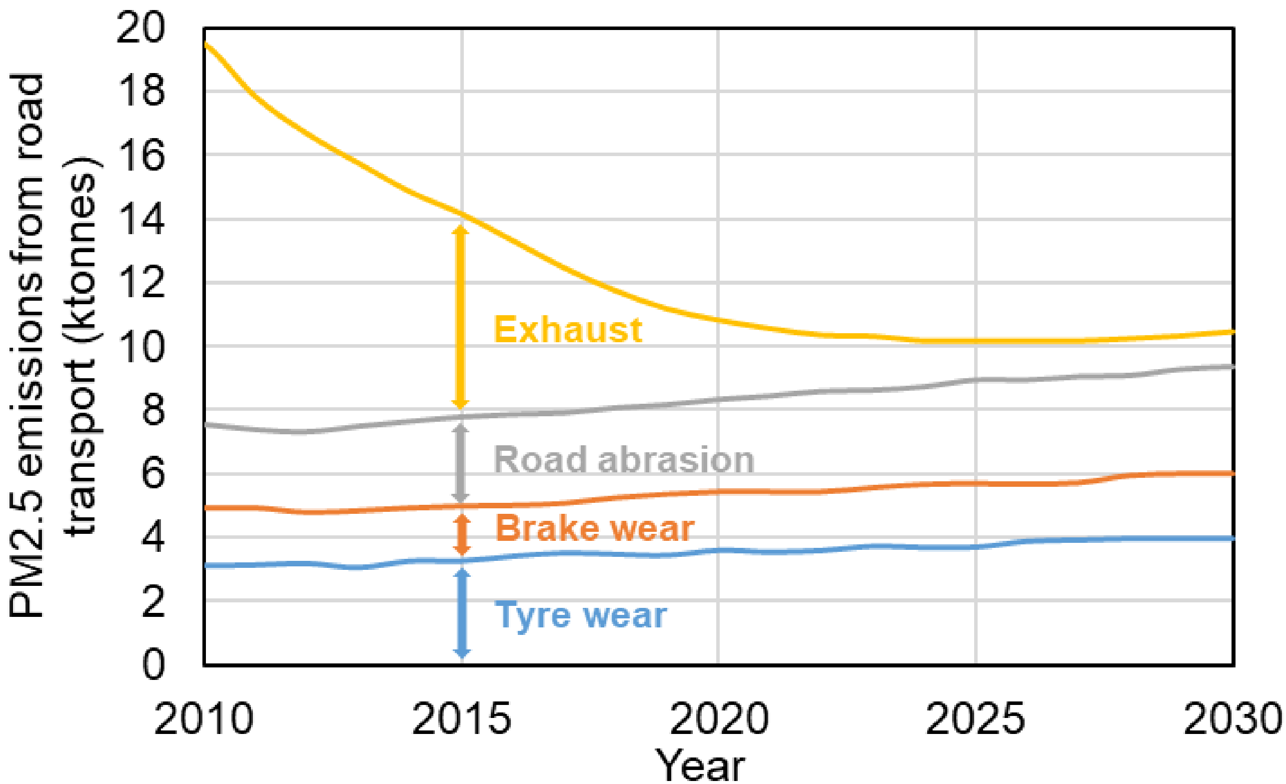


Source: Clean Cold Power



Next steps

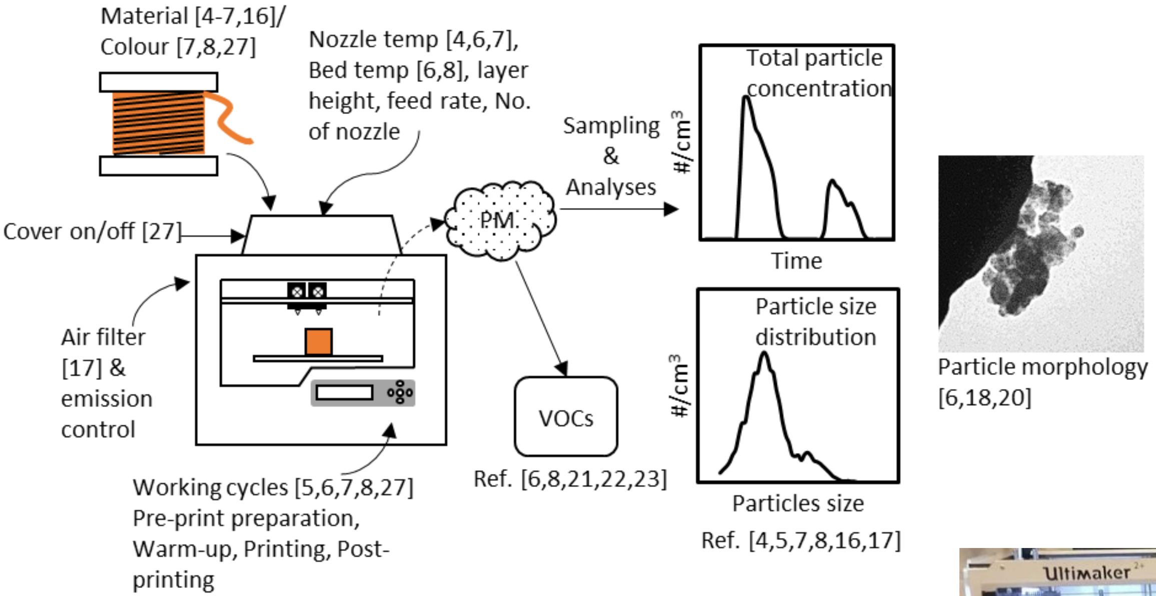
Non-exhaust emissions



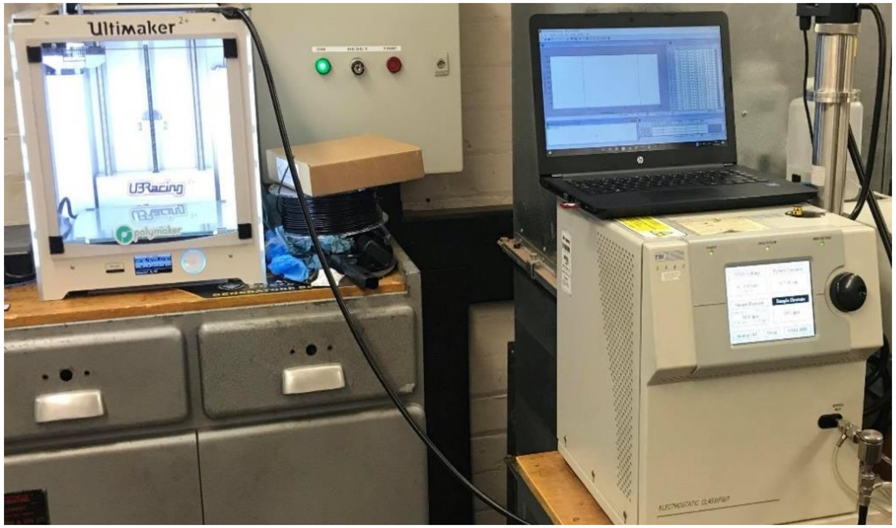
Source: UK $PM_{2.5}$ emissions from road transport. Air Quality Expert Group. Non-exhaust emissions from road traffic. DEFRA, Scottish Government, Welsh Government and DOE in Northern Ireland. 2019.

Next steps

3D printing emissions



S. Sittichompoo, S. Kanagalingam, L.E.J. Thomas-Seale, A. Tsolakis, J.M. Herreros. Characterization of particle emission from thermoplastic additive manufacturing. Atmospheric Environment, 2020.



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Thank you