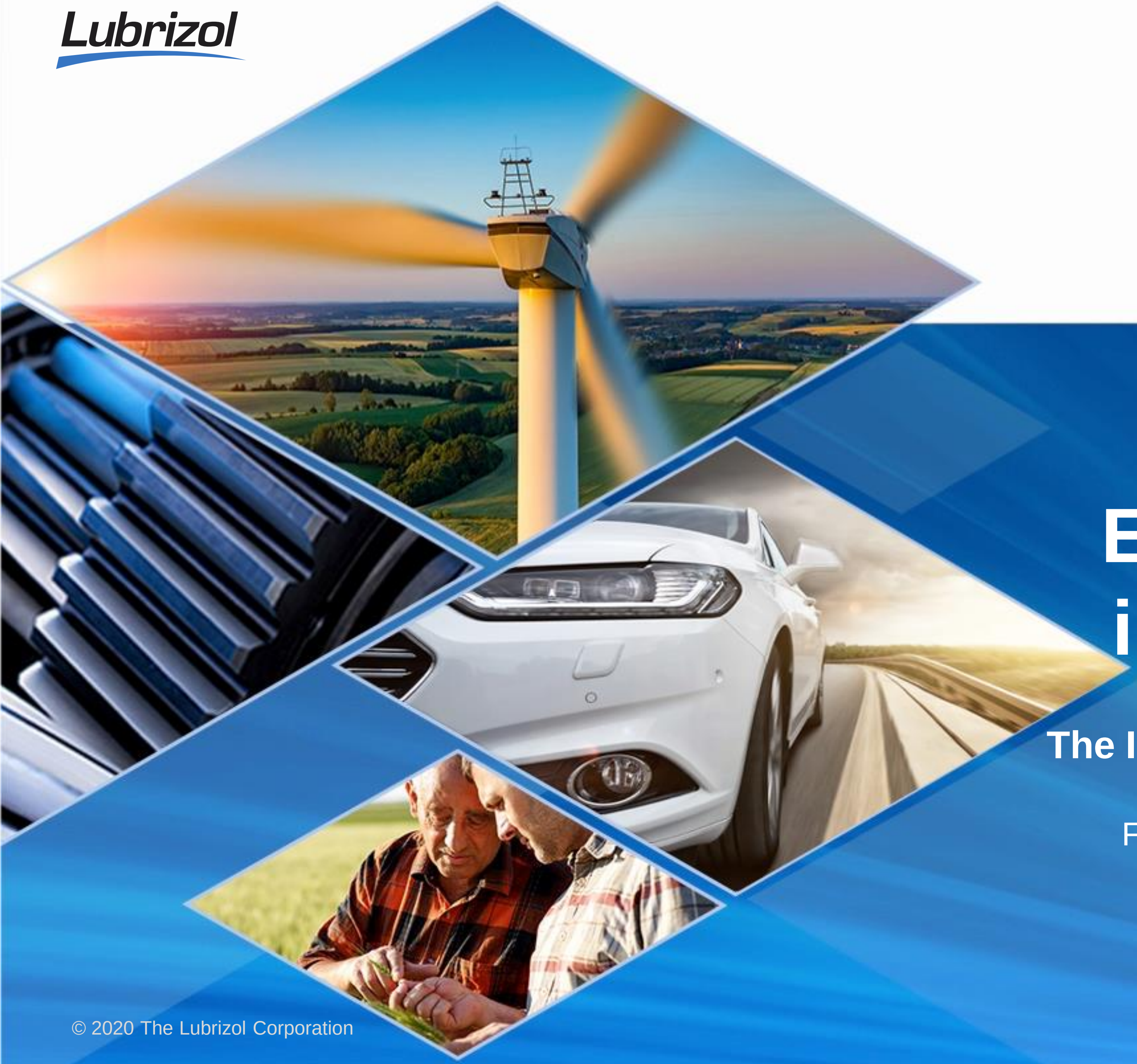

Sustainability, Efficiency & Reliability in Fleets of the Future

The Importance of Fuel & Lubricant Technology

Fleets of the Future, London, January 22nd 2020

Contents

- Why fuels and lubricants matter
- Challenges we face in the future
- Examples of fuel and lubricant impacts
- Anticipating changes in fuels and lubricants for the future
- Summary

Why Fuels & Lubricants Matter

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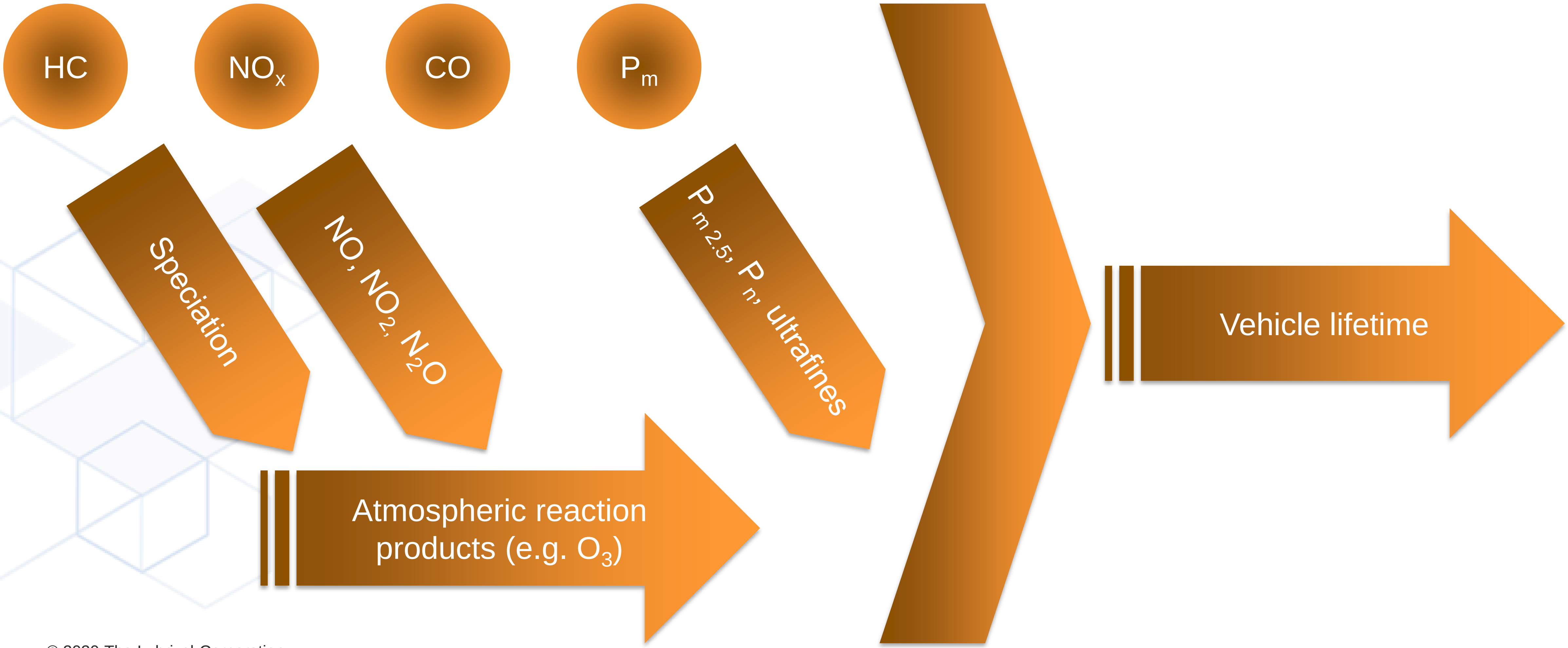
Why Fuels and Lubricants Matter

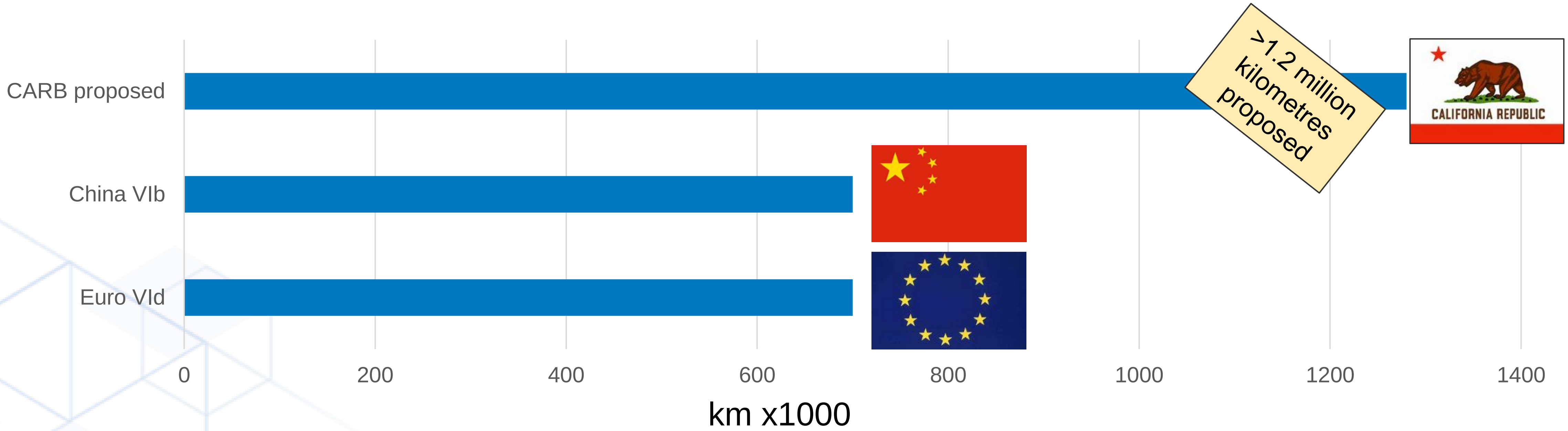
	Energy	Efficiency	Durability	Sustainability
Fuels	Density	Availability Friction	Deposits Wear Noise Combustion quality	Emissions Renewability Footprint
Lubricants	N/A	Viscosity Friction Traction Churn etc.	Wear Deposits	Renewability Footprint

Challenges We Face in the Future

Urban Air Quality and Its Many Dimensions



Emissions Durability Needed to Impact Air Quality



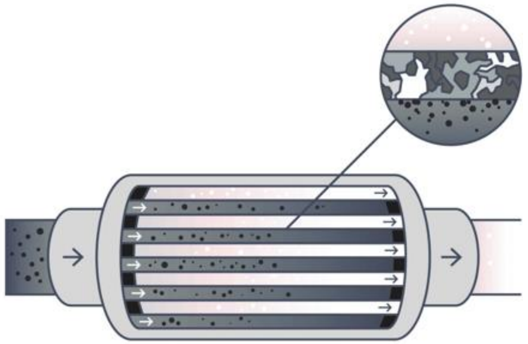
- Means of enforcement not fully defined. Will likely be contentious
- Other pollutants regulated in future (e.g. Euro 7) could add to the challenge
- Increasingly sophisticated aftertreatment needed, including sensors and full closed-loop control

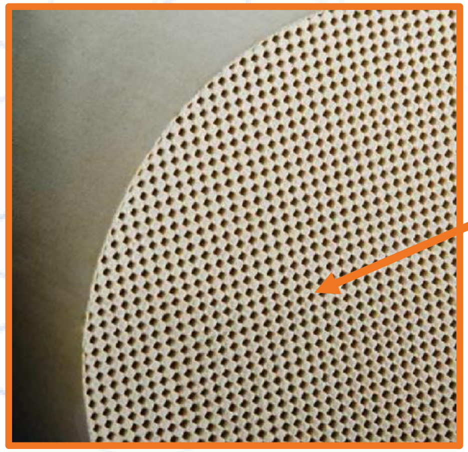
High quality aftertreatment compatible, deposit controlling fluids essential

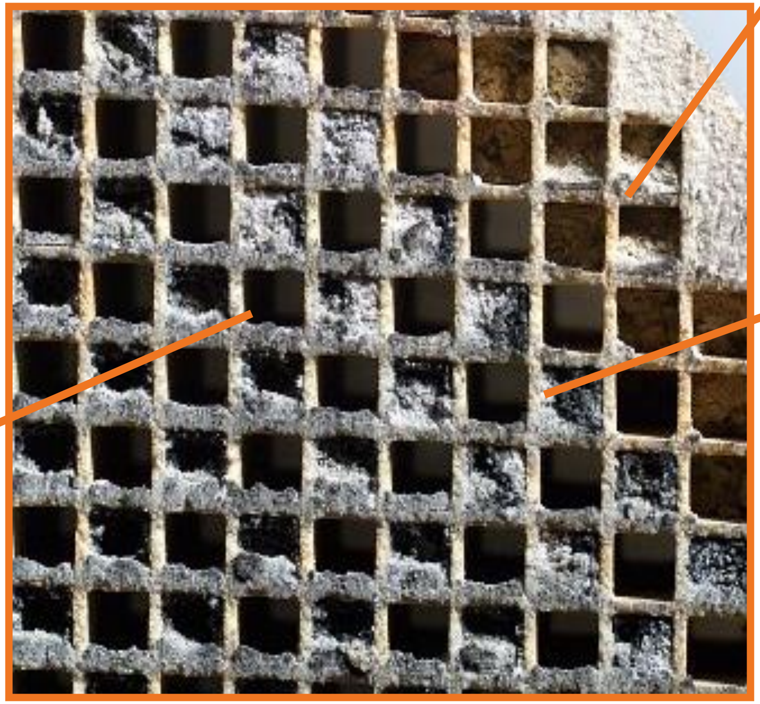
CARB = California Air Resources Board

Engine Oils: Particulate Filter Compatibility

Affected by Lubricant SAPS: Sulfated Ash, Phosphorous, Sulfur







Lubricant Ash

Filter blockage

Increased back-pressure

High fuel consumption

Lubricant Phosphorous

Lubricant Sulfur

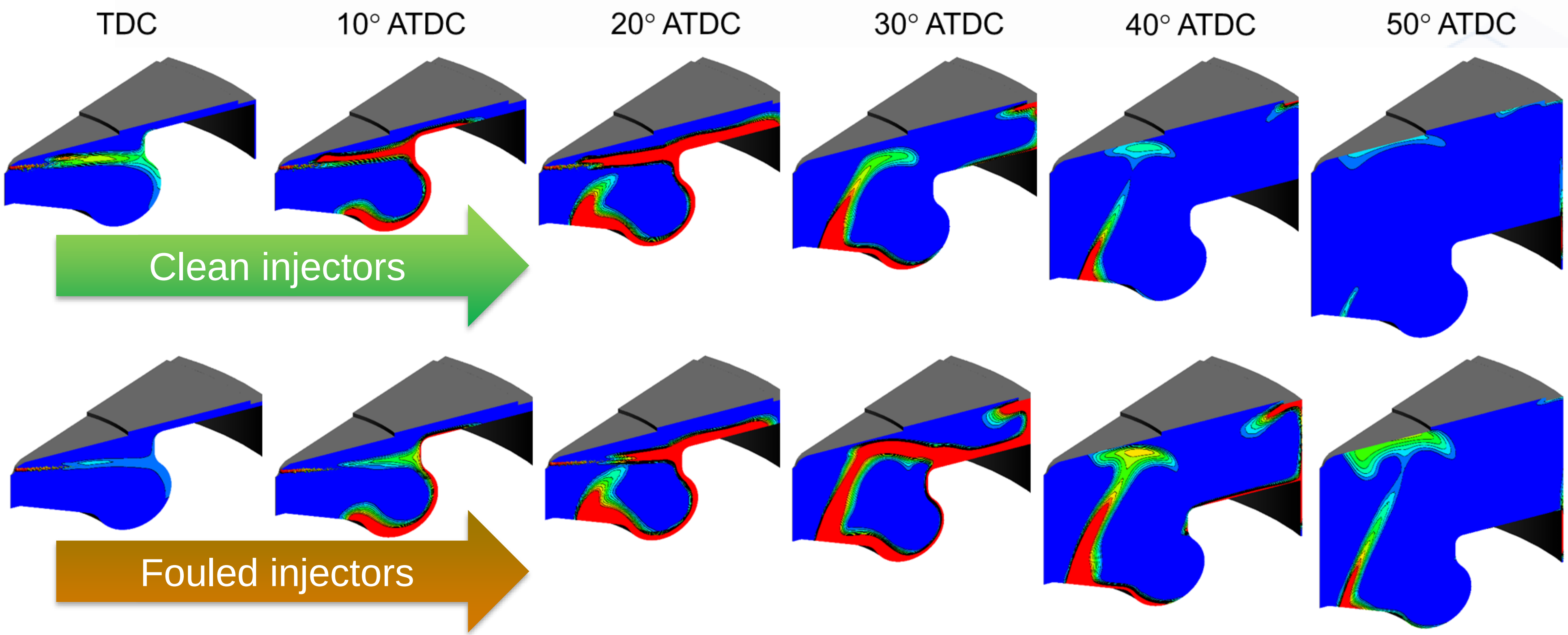
Catalytic coating affected

Poor soot burn-off

Increased back-pressure

Increased fuel consumption

Diesel Soot Formation and Removal During Combustion



CFD simulations show soot persists in combustion cycle longer with injector fouling

ATDC – After top dead centre

CFD – Computational fluid dynamics

Lubrizol Viewpoint: Sensors
Increasingly Important but Contamination Concern

- Extended emissions durability requirements, several hundred thousand kilometers - full life
- Very tight limits for pollutants in forthcoming legislation across the globe
- Complex aftertreatment needing accurate sensors for closed-loop control
- Increased OBD requirements for monitoring / troubleshooting
- Trend towards lighter oils – generally means higher volatility: more oil burned

Contaminated exhaust sensors could mean:

- *False indications of aftertreatment failure*
- *Failure to detect real issues in the system*
- *Poor closed loop control of system resulting in non-compliance*
- *Inaccurate / misleading OBD data*
- *Costs and inconvenience for fleet operator*
- *Warranty costs and loss of reputation for OEM and aftertreatment system /* ***sensor*** *suppliers*

Aftertreatment & sensor compatibility of fuels & engine oils - increasingly important to long-term emissions performance

OBD – Onboard Diagnostics

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Emerging Challenges for Sensor Technology

SCR systems being placed at front of aftertreatment – close coupled

- Higher temperatures
- First in line for poisons
- Subject to ash / soot, unlike post-DPF sensors

Mid-SAPS oils acceptable for current systems, but future requirements evolving

Which sensor type might potentially be vulnerable?

- Oxygen sensors
- Particulate matter sensors
- Temperature sensors
- Nitrogen oxides sensors

Key challenge: low temperature NO_x performance

SAPS - Sulfated Ash, Phosphorous, Sulfur
SCR – Selective Catalytic Reduction
DPF – Diesel Particulate Filter

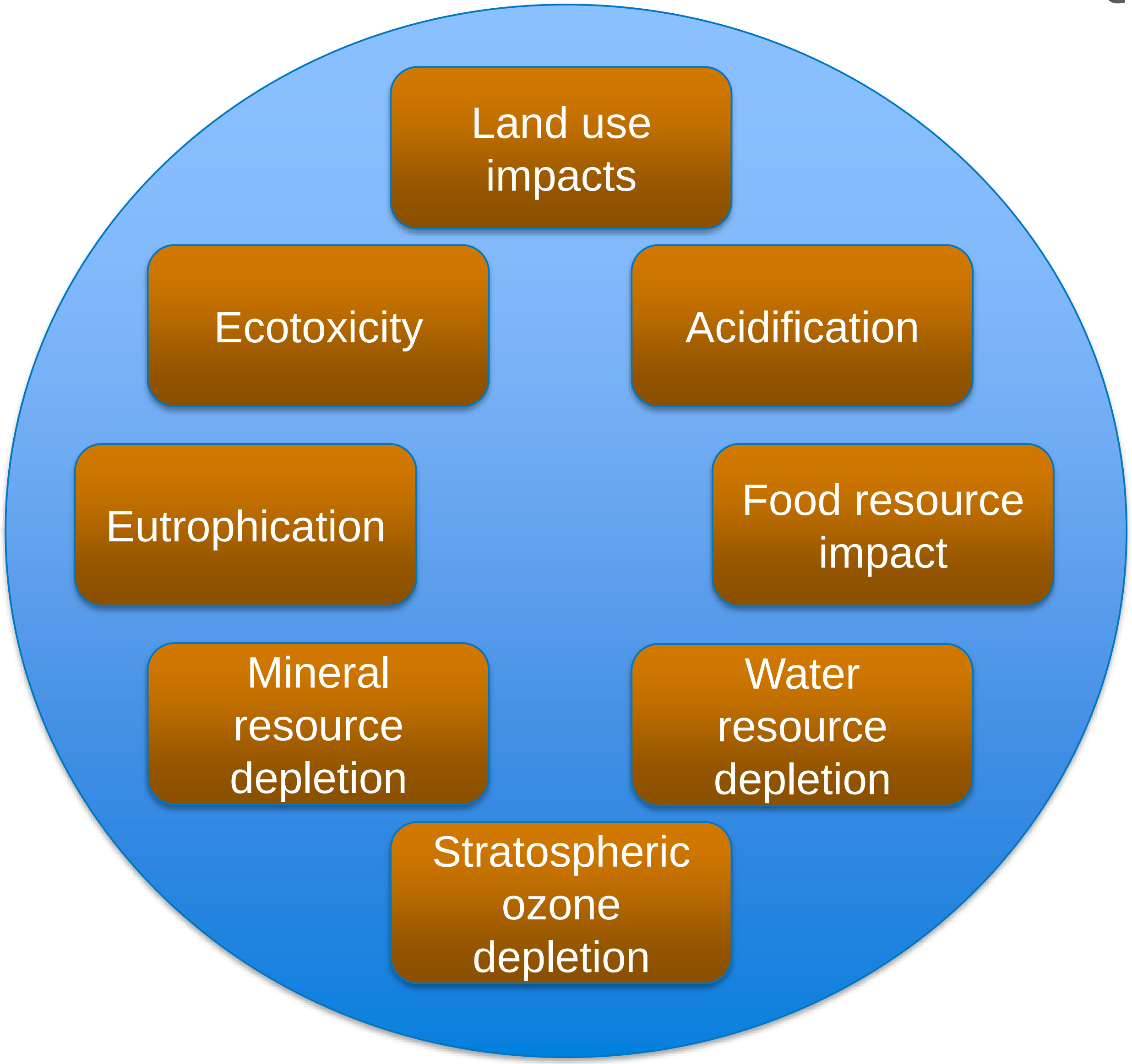
Climate Change - Greenhouse Gas (GHG) Emissions

- 7.6% annual reduction to 2030 required to control to 1.5 deg.C global warming[(1)]
- Current NDCs[(2)] inadequate to meet climate control targets
- Likely action in Europe in coming years
  - Climate neutrality by 2050, and more than 50% reduction by 2030
  - Circular economy action plan
  - Support for climate control initiatives
  - Address incoherent legislation
  - Sustainability focus
  - Bilateral inducements on world stage

1) UN environment programme, emissions gap report, 11/19
2) NDC – Nationally Declared Contribution (to GHG reduction) under 2015 Paris Accord

Impact of climate change and associated legislation potentially drastic

Sustainability - More Than Climate Control and Air Quality



Examples of Fuel & Lubricant Impacts

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Lubrizol Deposit Control Diesel Additive Field Trial Results

Field Trial		Primary Results
	2008 Kenworth™ Truck T800 10.8 litre Heavy Duty Truck	- 3.5% fuel economy improvement - Fuel injector flow increase
	UK Passenger Bus Fleet	- 1.7% increase in output power and torque - All buses treated with additive showed improved fuel efficiency by as much as 4.5%. The average fuel economy improvement was 2.8%
	50 litre engines, HPCR Inland Marine Work Boat	- 112 days using additive, no failures. Previously frequent - >$95K savings during treatment period

HPCR – High Pressure Common Rail – fuel injection

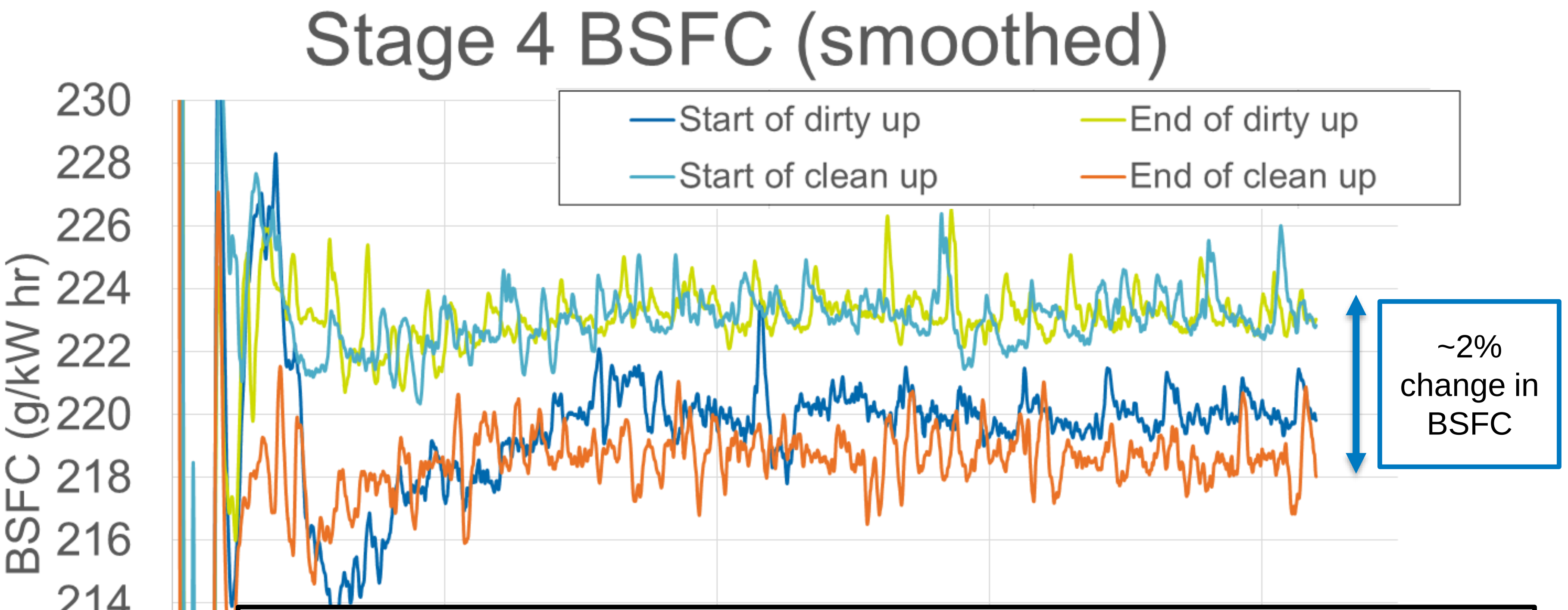
Case Study

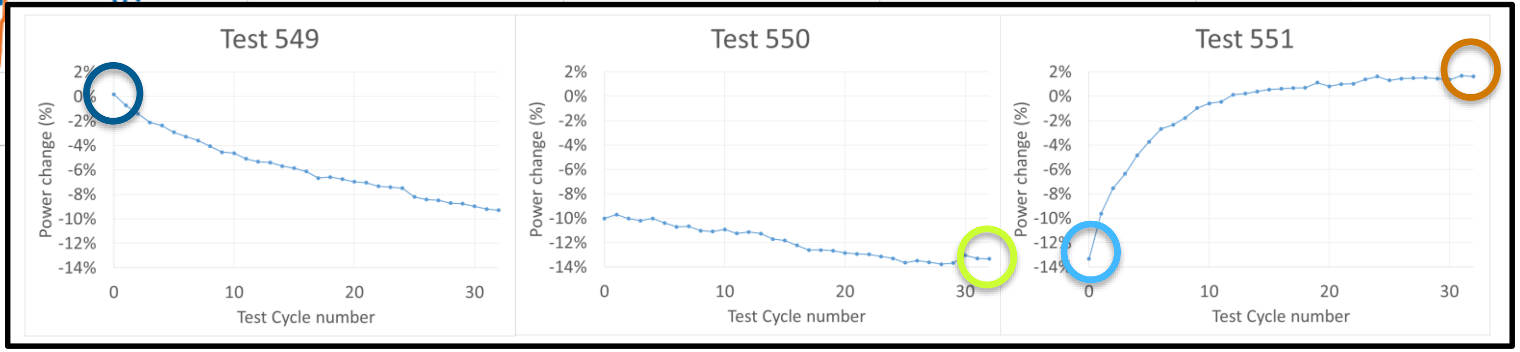
Presented by Assetworks in 2018 Future Fleet Forum

- Cooperation with Wakefield Council and Thomas Group
- Data from Council's Fleet & Fuel Management System (Assetworks) analysed
- Data collected symmetrically pre and during 12-month trial
  - Filtered for extremes and vehicle changes
  - 2,200 fillings per month on 500 vehicles
- Large fuel savings identified

Information & graphic courtesy of Kevin O'Sullivan, Thomas Group

Detailed Data Logging – Stage 4 Fuel Efficiency





- Data logged on CEC F-98-08
- Stage 4 is a high speed load torque controlled stage

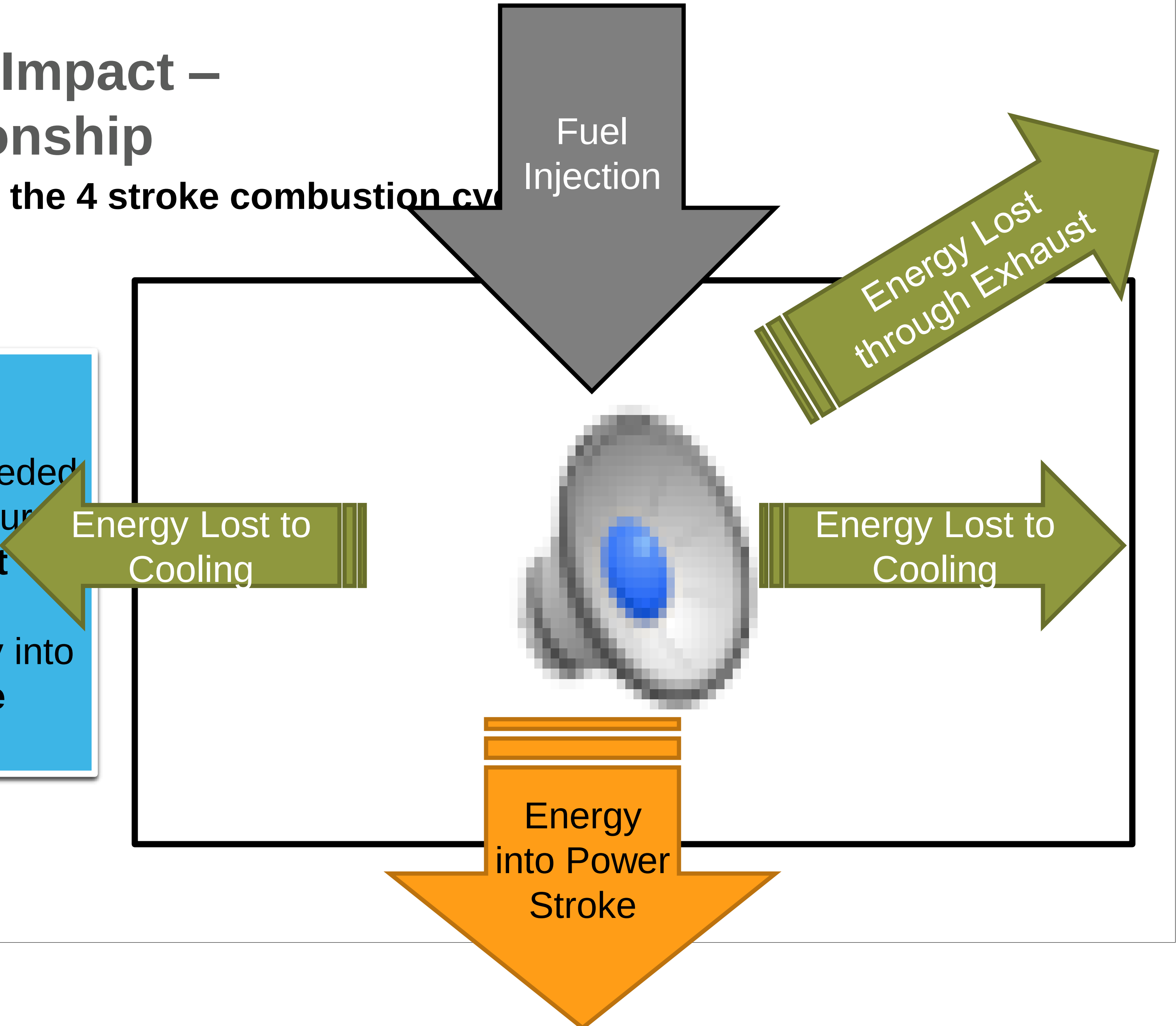
- Data logged at 32 Hz
- Plotted points smoothed over 1 second

BSFC – Brake Specific Fuel Consumption

Fuel Injector Nozzle Fouling Impact – Explaining Causes of Relationship

Fuel Efficiency in the 4 stroke combustion cyc

Precise injection timing and unimpeded spray pattern ensur the most **efficient combustion** and transfer of energy into the **power stroke**



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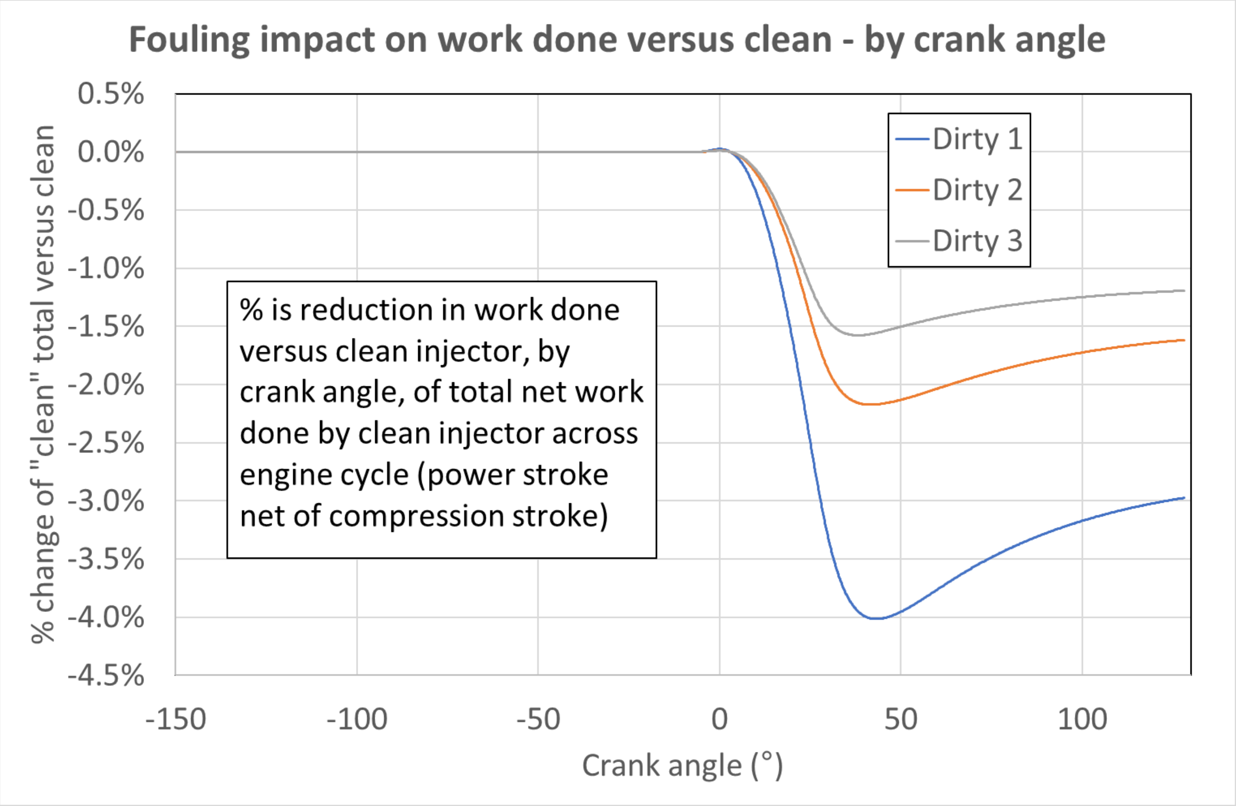
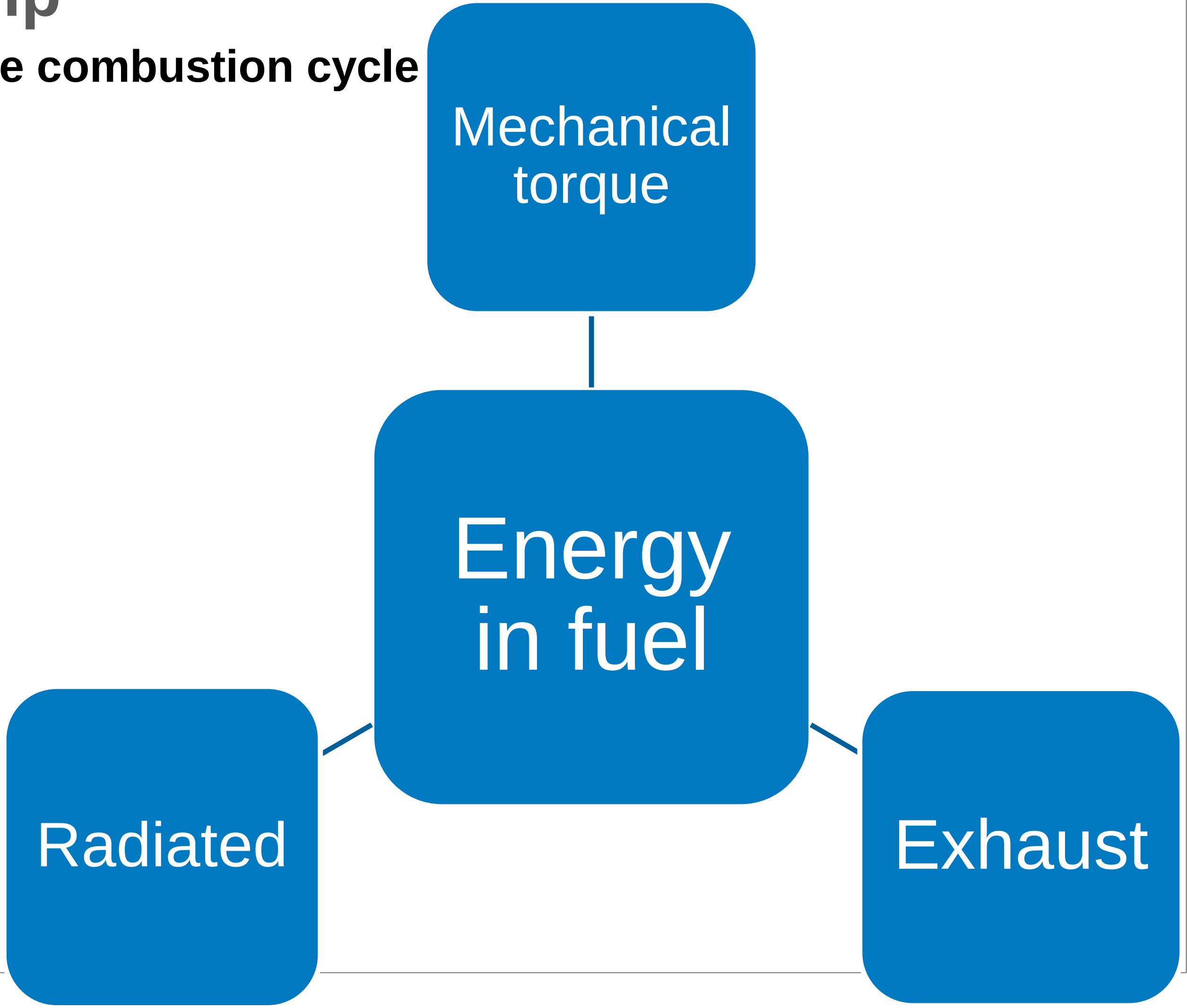
Fuel Injector Nozzle Fouling Impact
Explaining Causes of the Relationship

Fuel Efficiency in the 4 stroke combustion cycle

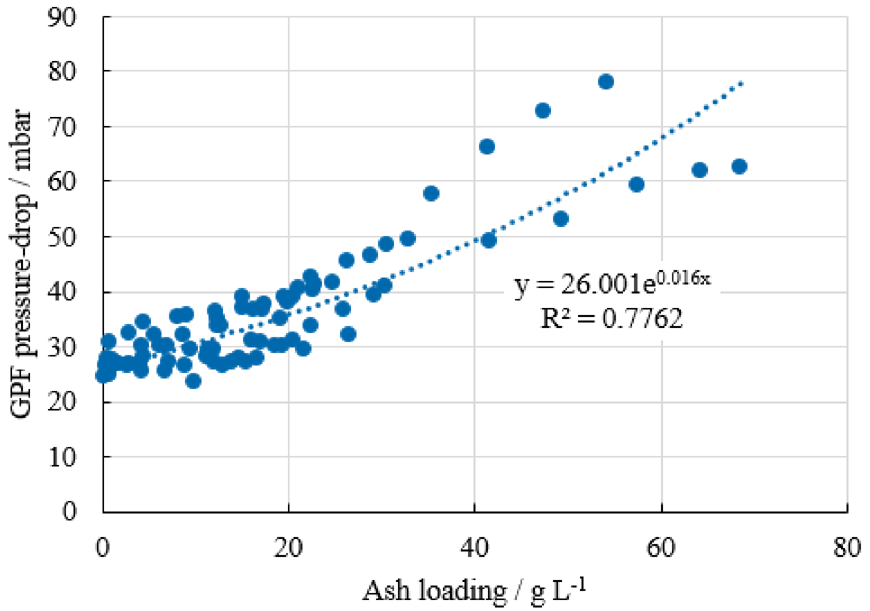


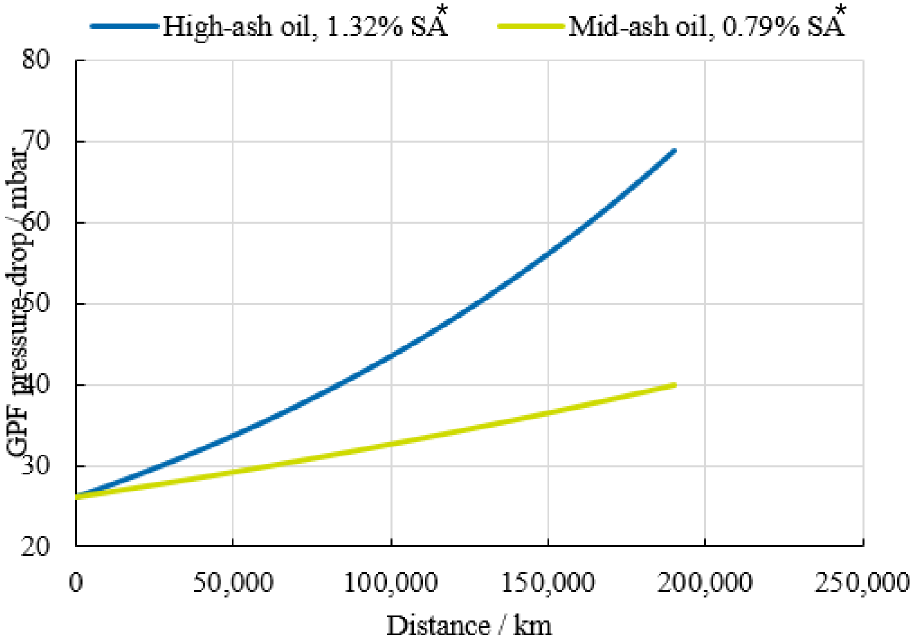
Taken from a CFD simulation



CFD – Computational fluid dynamics

Example of Ash Blocking – Lubrizol Field Trial





High-ash engine oil shows substantially more increase in particulate filter pressure drop over a vehicle lifetime

* SA – Sulphated Ash

Anticipating Changes in Fuels and Lubricants for the Future

Taking the Greenhouse Gas Footprint Out of Fuels

- Ambition in carbon footprint reduction
  - Consideration of efficiency in use and utilisation of existing infrastructure
  - Sustainability

Electrification?

Biofuels?

Alternative fuels?

Drop in power fuels?

The need to reduce dependency on fossil fuels is clear – but what?

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Potential decarbonisation impacts

- **Changes to fuels**
  - **Changed fuel types**: Degrees of usage of gas fuels & electrification. Integrated L.C.A. consideration?
  - **Changes to liquid fuels**: Decarbonisation achievable with drop-in liquid fuels? Could mean GHG reduction in existing vehicles
  - **Changed fuel appetites**: 1) Altered fuels create different performance needs 2) New vehicle hardware changes fuel appetite
- **Changes to lubricants**
  - **Basic type changes**: Balance between engine and driveline lubricants might change
  - **Performance appetite changes**: Hybridisation & I.C.E. changes could impact need for thermal stability & water tolerance etc.
  - **Manufacturing footprint changes**: Increased importance in full decarbonisation scenarios

I.C.E. – Internal Combustion Engine
L.C.A. – Life Cycle Analysis

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Summary

- Action on existing fleet vehicles is an important component of GHG reductions consistent with climate control targets. Action sooner here can buy important time later
- Fuels and lubricants need to be compatible with the latest systems
  - Including the latest types of particulate filters, catalysts and sensors
- Changes in the mix between liquid and gaseous fuels and electric power are anticipated. Factors affecting the optimal choice include
  - GHG reduction energy efficiency and sustainability, both on a lifecycle basis
  - Speed of reduction in GHG emissions delivered
  - Infrastructure investments
- Legislation will
  - Drive air pollutant emissions lower
  - Require fleets to lower GHG emissions drastically. Improved integration of L.C.A. issues and sustainability anticipated
  - Enforce greater durability in emissions performance to improve air quality

High quality fuels and lubricants are essential enablers going forward

Acknowledgements

- Keith Howard — Lubrizol Ltd.
- Kevin O'Sullivan — Thomas Group

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