Real-world emissions of volatile organic compound species between different gasoline formulations

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EMISSIONS ANALYTICS

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Our Belief

When it comes to the pursuit of emissions reduction, we believe in the power of clarity, transparency and integrity. With real -world data we can meet emissions challenges – instilling trust and confidence in our industry partners and public.

It's with our commitment and independence we are able to make a significant contribution toward positive change and to achieve enduring results.

Introduction

- Founded in 2011, headquartered in the UK
- Operations in UK, Germany, USA and South Korea
- Independent testing house specialising in real -world emissions testing
- Over 2,500 vehicles/machines tested across passenger, commercial and off -road
- >100 tyre tests, >100 vehicle interior air quality tests
- Largest commercially available database of real -world emissions data
- Work with regulators, OEMs, Tier 1/2 suppliers, fuel and chemical companies, fleets
- Chair of EU CEN Workshops 90 and 103
- Honorary Research Fellow, Imperial College London

Agenda

1. The fuel and emissions challenge
2. Innovative test methodology
3. Renewable gasoline formulations
4. Regulated and unregulated emissions
5. Fuel chemical composition and provenance

Emissions problem

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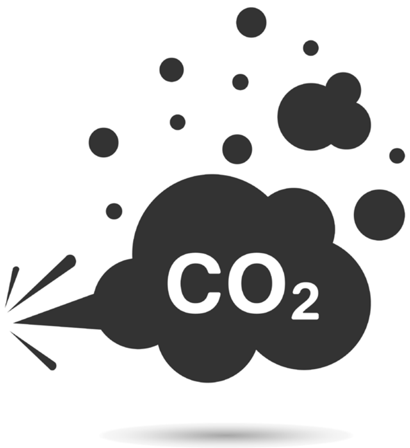
What is the environmental issue?

- Renewable fuels exist primarily to reduce lifecycle CO_2 emissions
- How much do they reduce CO_2 in practice?
- Can they be a material contributor to decarbonisation?
- Do they lead to increases in regulated tailpipe emissions?
- Can increases take emissions above limit values?
- What unregulated emissions may they increases?
- Can these have an impact on air quality and directly on health?

What is a renewable fuel?

- Produced from renewable resources rather than fossil fuels
- Bioethanol, blended into gasoline
- Biodiesel – substitute fats processed using transesterification
- Biomethane/biogas from breakdown of organic matter, e.g. anaerobic digestion
- Advanced biofuels, e.g. HVO Hydrotreated/Hydrogenated Vegetable Oil
- Green hydrogen – electrolysis
- Synthetic/e-fuels, e.g. methanol-to-gasoline

What is the fuels challenge?



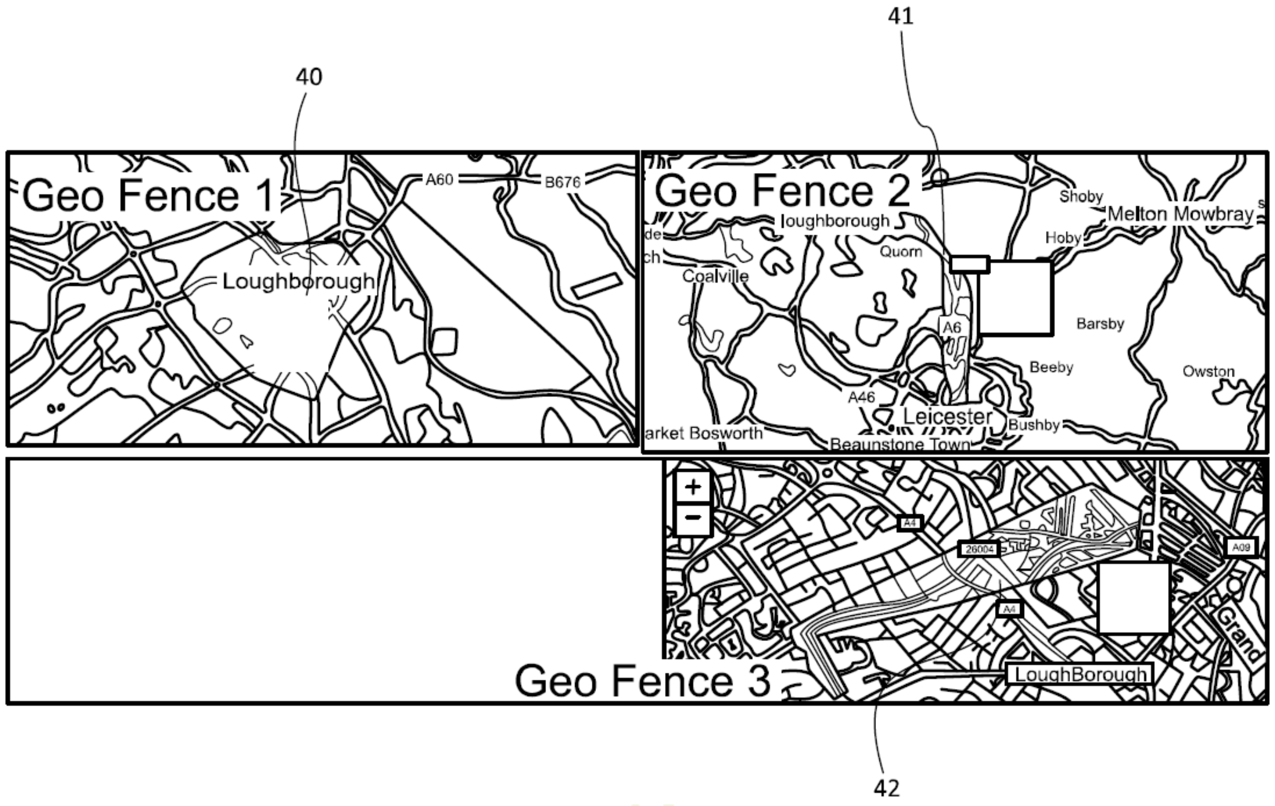
- 'Bio' components may change the combustion characteristics
- Often lower energy density
- Difference in efficiency of combustion
- Different chemical composition leads to alternative mix of tailpipe pollutants
- Bio components may not be as low CO_2 as portrayed, depending on supply chain
- Verification of embedded carbon difficult
- Scalability
- Economics

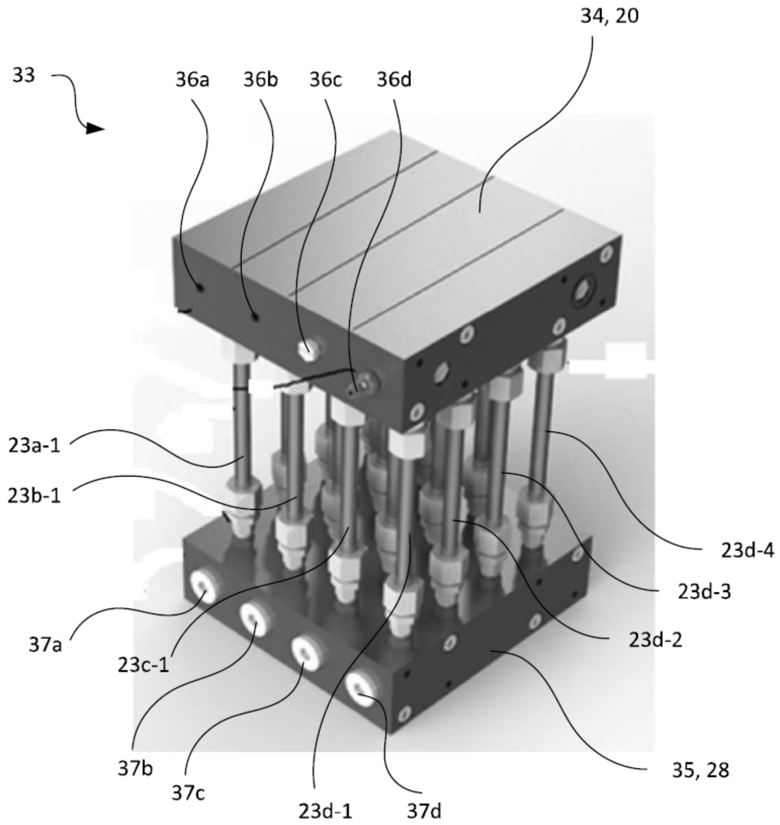
Our proposition: holistic+comprehensive

Measurements – PEMS

- Core: CO_2, CO, NO, NO_2, NO_x, exhaust temperature
- Using regulatory-grade PEMS from Sensors, Inc
- Measurements at 1Hz
- Weather station: temperature, humidity, pressure
- OBD: typically speed, rpm, coolant temperature, engine load, throttle position, manifold pressure
- PN, particularly for EU gasoline and hybrids
- Custom integrated NH_3 sensor

Integrated sample collection on tubes



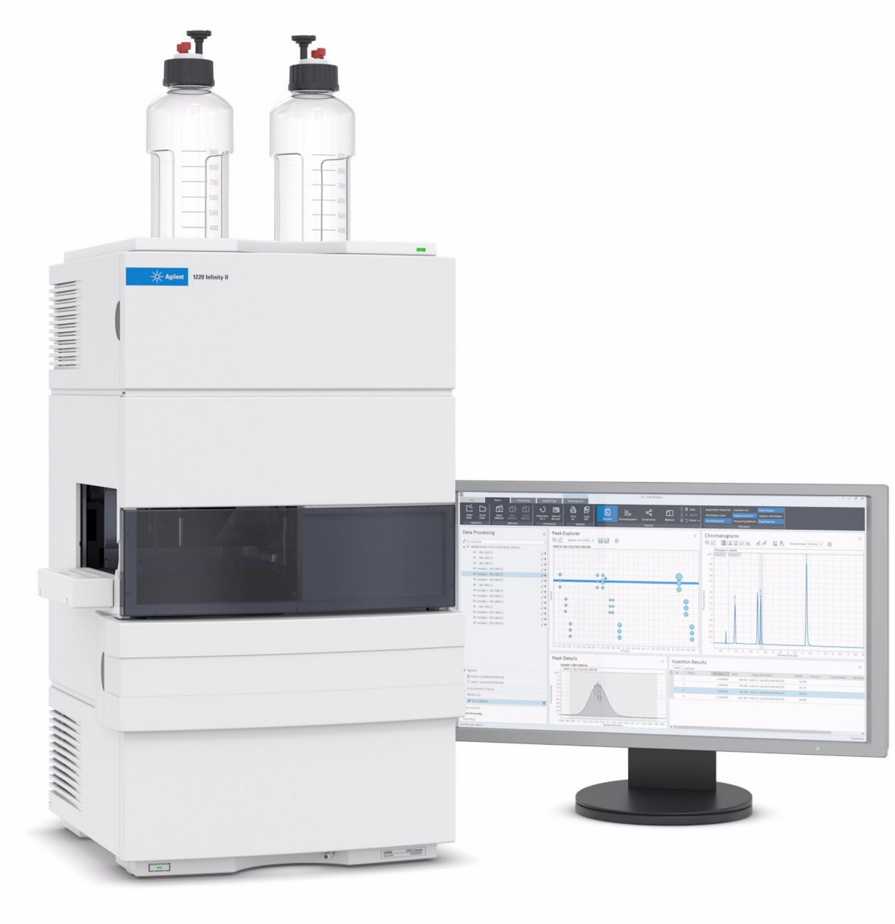


Measurements – volatile organic compounds

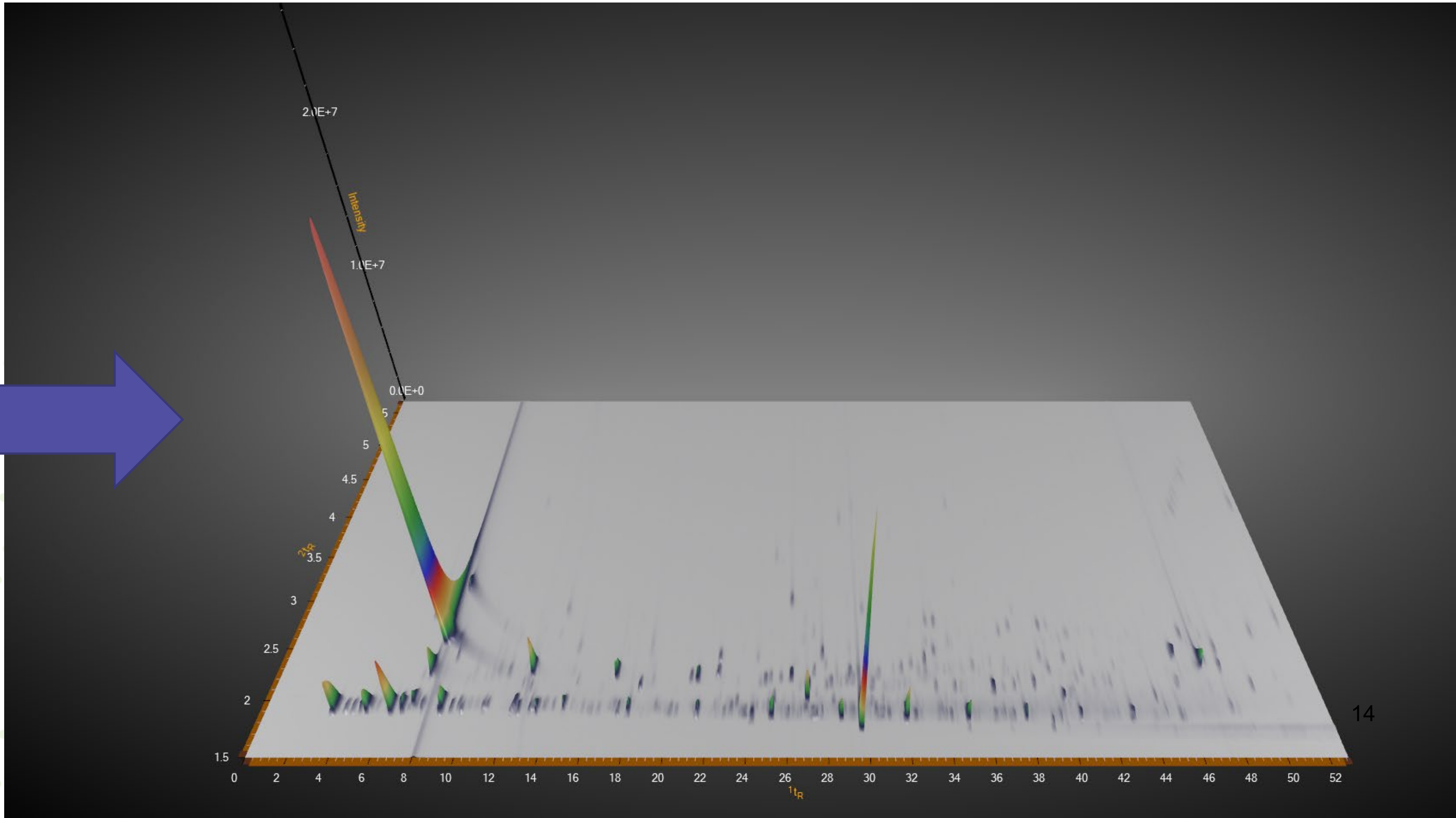
- Two-dimensional gas chromatography with mass spectrometry from Markes International
- INSIGHT flow modulator from SepSolve Analytical for separation
- BENCH-TOF time-of flight mass spectrometer
- Thermal desporption

Measurements – formaldehyde

- High performance liquid chromatography
- Agilent 1220 Infinity II LC
- DNPH cartridges

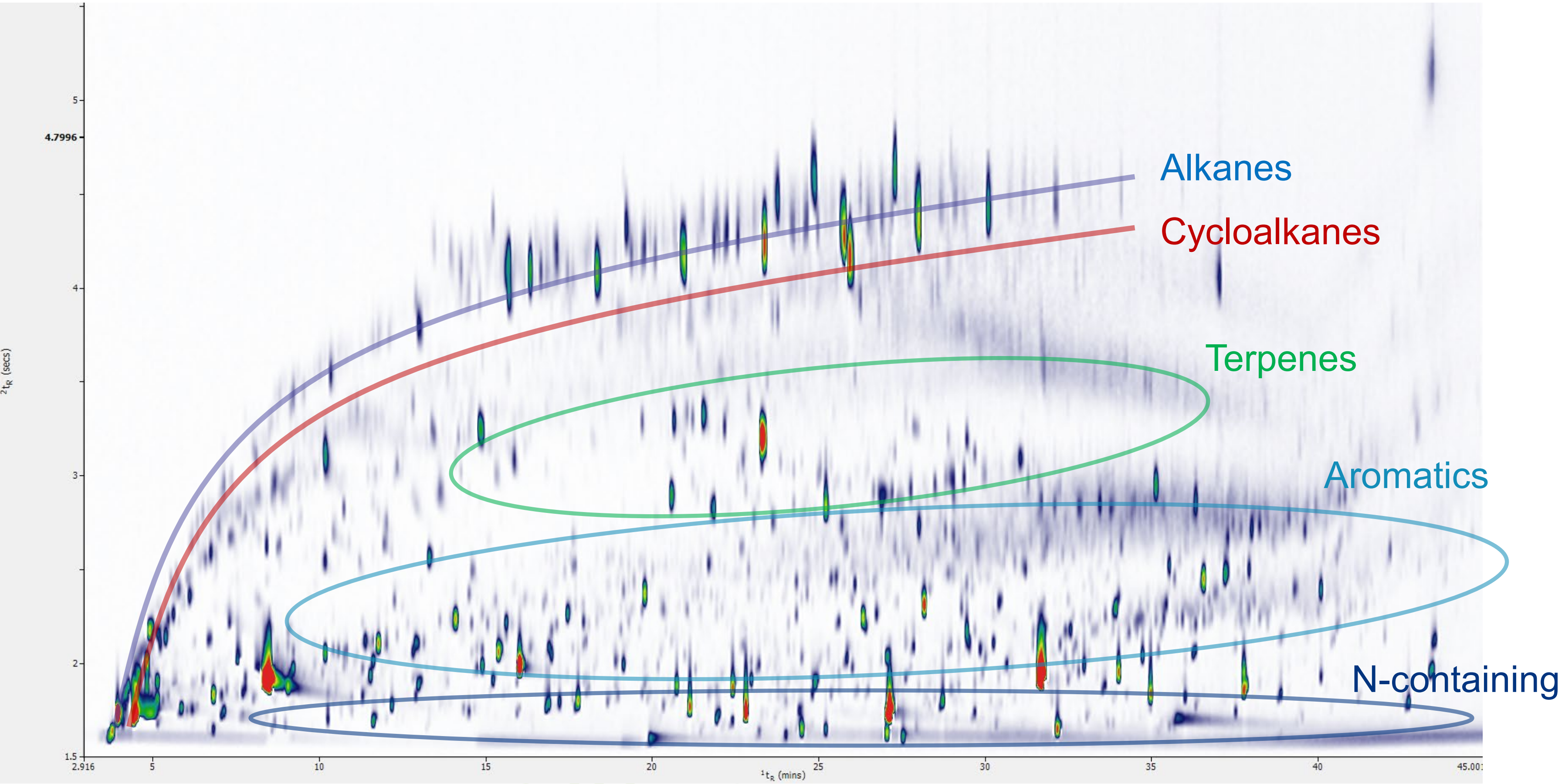


Two-dimensional chromatogram



PEMS real-world emissions testing

Functional group classification



- Wide-ranging analytes identified

- Alkanes: lungs, liver, kidney, brain
- Cycloalkanes: headaches, dizziness
- Terpenes: aromas
- Aromatics: carcinogens
- N-containing: carcinogens

Renewable gasoline

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Different gasoline blends

- What impact is adding ethanol to gasoline having in real-world driving?
- E0 vs E10
- Blended by Coryton Fuels to EN228
- Four small/medium cars
- Tested in the UK, October 2022
- EQUA test route: cold start, urban, rural and motorway

Regulated pollutants – by vehicle

- Highly consistent results between vehicles
- Average 31% reduction in CO, but 21% increase in NO_x (small absolute increase)
- Both well below regulated limit on both fuels

	CO (mg/km)				NO_x (mg/km)			
	E0	E10	Δ	E10 EF*	E0	E10	Δ	E10 EF*
2020 Kia Sportage 1.6L	201	130	(35%)	0.13	4	5	25%	0.08
2022 Peugeot 2008 1.2L	333	205	(38%)	0.21	5	5	0%	0.08
2022 Citroen C3 1.2L	326	318	(2%)	0.32	3	4	33%	0.07
2022 Renault Clio 1.0L	153	79	(48%)	0.08	8	10	25%	0.17
Mean	**253**	**183**	**(31%)**	**0.18**	**5**	**6**	**21%**	**0.10**

* Exceedance Factor = real-world emissions / regulated limit

PEMS real-world emissions testing

Why unregulated pollutants matter

- Ozone formation potential of hydrocarbons
- Secondary organic aerosol formation potential of hydrocarbons

Pollutant	Human potential health effects	Other environmental effects
Formaldehyde (CH_2O)	Irritation of nose, mouth, throat; lung damage; carcinogenic	Biodegrades; not accumulative
Other aldehydes*	Damage organs; acute pain; inflammation; carcinogenic; heart disease	Can inhibit plant growth
Toluene ($C_6H_5CH_3$)	Irritation to skin, eyes, throat; liver, kidney damage; possible neuro and reproductive toxin	Moderately toxic to fish; damages plant leaves
Nitrous oxide (N_2O)	Dizziness, unconsciousness; long-term fertility effects	Powerful greenhouse gas; pollutant in upper atmosphere

* Benzaldehyde, butanal, heptanal, hexanal, propanal, pentanal

Unregulated pollutants – by vehicle

- Significant variances between vehicles at combined cycle level
- Lowered powered C3 (82 bhp) saw generally lower emissions compared to higher powered 2008 (129 bhp)

	Formaldehyde (CH_2O, mg/km)			Other aldehydes* (µg/km)			Toluene ($C_6H_5CH_3$, µg/km)			Nitrous oxide (N_2O, mg/km)		
	E0	E10	∆	E0	E10	∆	E0	E10	∆	E0	E10	∆
2020 Kia Sportage 1.6L	0.24	0.42	75%	18.0	5.7	(68%)	44.3	74.7	69%	5.6	5.1	(9%)
2022 Peugeot 2008 1.2L	0.32	0.36	13%	3.1	3.8	21%	43.9	64.9	48%	5.3	5.1	(3%)
2022 Citroen C3 1.2L	0.39	0.35	(12%)	3.0	1.7	(42%)	53.9	27.6	(49%)	5.9	7.2	21%
2022 Renault Clio 1.0L	0.29	0.27	(6%)	3.3	3.5	8%	39.1	152.7	290%	5.9	5.4	(8%)
Mean	**0.31**	**0.35**	**18%**	**6.9**	**3.7**	**(20%)**	**45.3**	**80.0**	**90%**	**5.7**	**5.7**	**0%**

* Benzaldehyde, butanal, heptanal, hexanal, propanal, pentanal

Unregulated pollutants – by cycle

- Consistent increases in all pollutants, especially in toluene
- Except in aldehydes under cold start

	Formaldehyde (CH_2O, mg/km)			Other aldehydes* (µg/km)			Toluene ($C_6H_5CH_3$, µg/km)			Nitrous oxide (N_2O, mg/km)		
	E0	E10	Δ	E0	E10	Δ	E0	E10	Δ	E0	E10	Δ
Cold start	1.00	1.27	27%	81.8	14.4	(82%)	295.9	433.5	47%	7.8	8.0	2%
Urban	0.39	0.43	10%	3.9	4.0	4%	47.1	82.0	74%	0.8	1.2	42%
Rural	0.38	0.41	8%	5.7	7.1	25%	52.3	119.4	128%	2.7	2.7	0%
Motorway	0.17	0.19	12%	1.7	2.3	32%	15.7	30.5	94%	1.0	1.2	18%
Mean	**0.49**	**0.58**	**14%**	**23.3**	**7.0**	**(5%)**	**102.8**	**166.4**	**86%**	**3.1**	**3.3**	**16%**

* Benzaldehyde, butanal, heptanal, hexanal, propanal, pentanal

Alternative gasoline blends

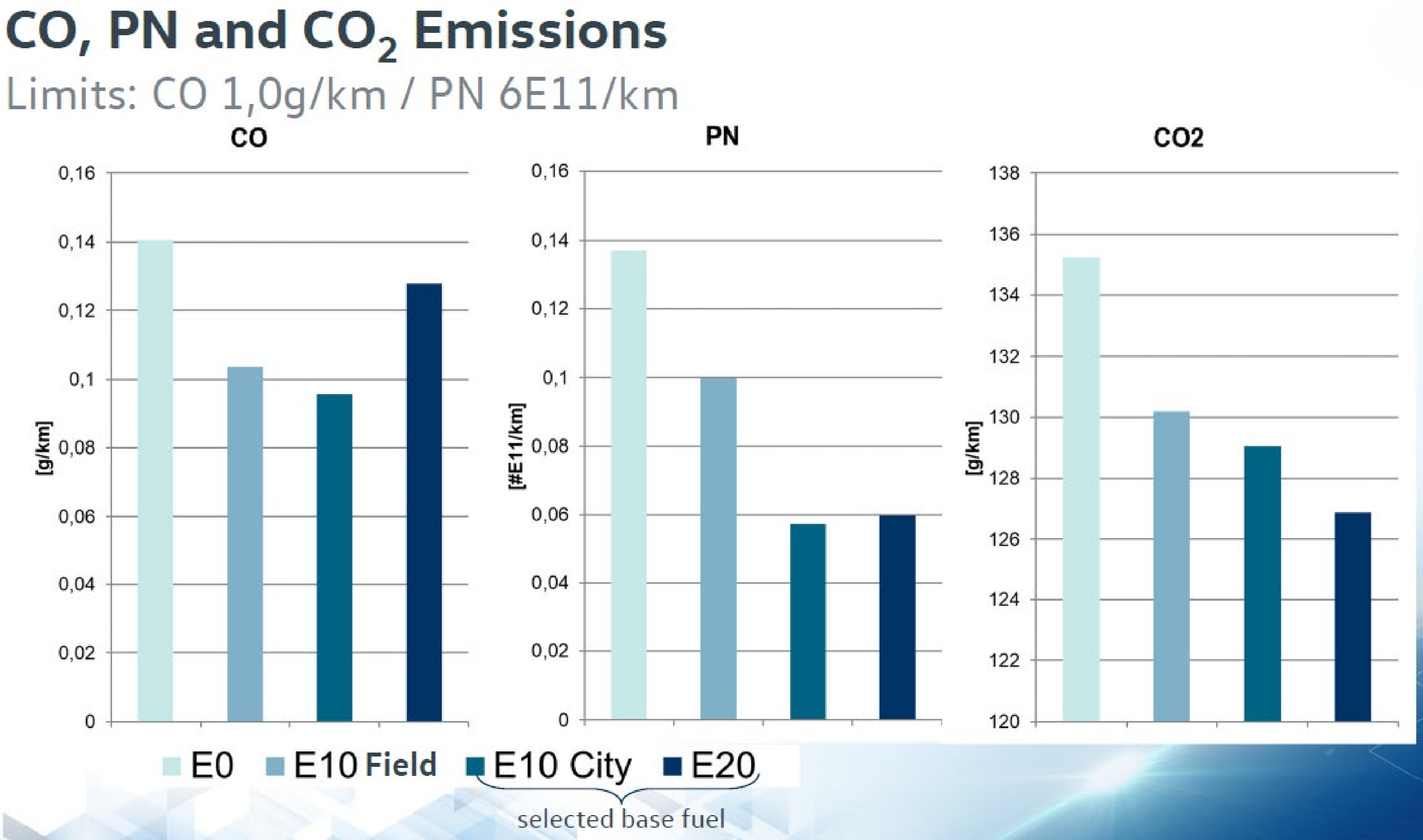
- Four types of gasoline tested
- With Volkswagen
- On-road route around Stuttgart, Germany
- Summer 2022
- Different proportions of ethanol and base fuels
- Testing for effect on CO_2, and regulated and unregulated pollutants

Vehicle Description:	2021 Volkswagen Nivus FULL
Euro Stage:	Euro 6d-TEMP-EVAP-ISC
Power	110 kW
Engine Size	1.5 L

E0	E10 field	E10 „City“	E20
„standard test fuel“	Taken from Gas station	Base fuel sufficient for proposed E20 standard	Fulfils DIN Proposal
Ethanol free	X% Ethanol	10% Ethanol	20% Ethanol

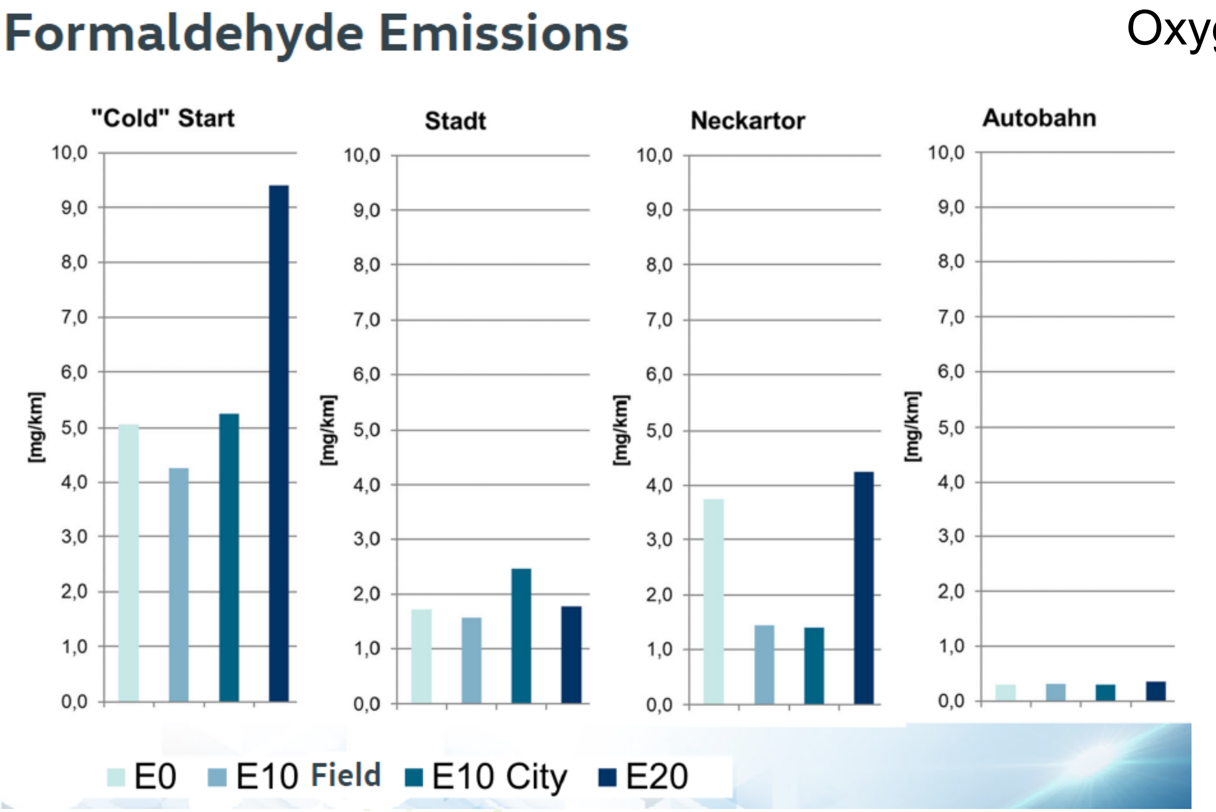
Regulated emissions – different ethanol levels

- Lower CO_2 and PN emissions as ethanol proportion increases
- CO emissions rise slightly with E20

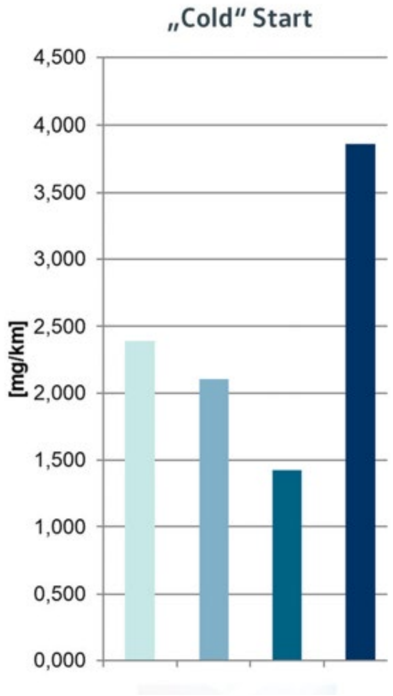


PEMS real-world emissions testi

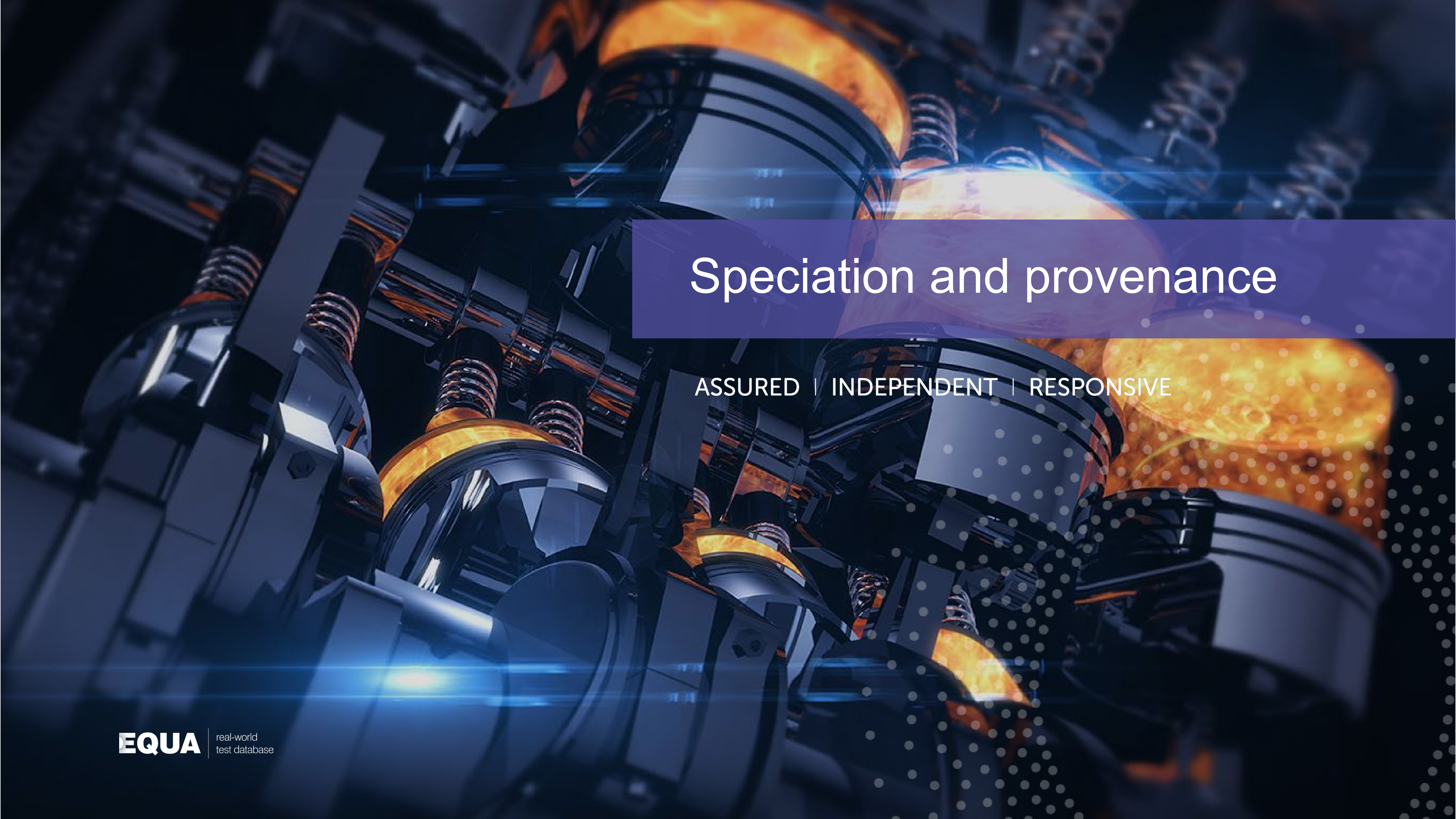
Unregulated emissions – different ethanol levels



Oxygenates (excluding formaldehyde)



- Formaldehyde tends to rise with higher ethanol blends



Speciation and provenance

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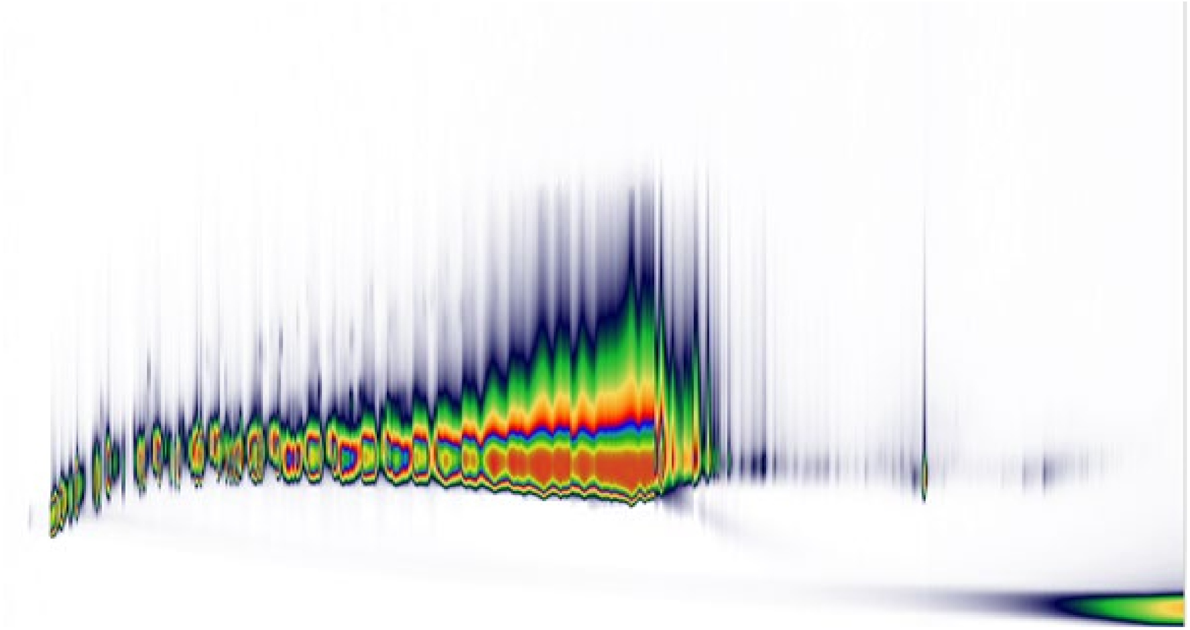
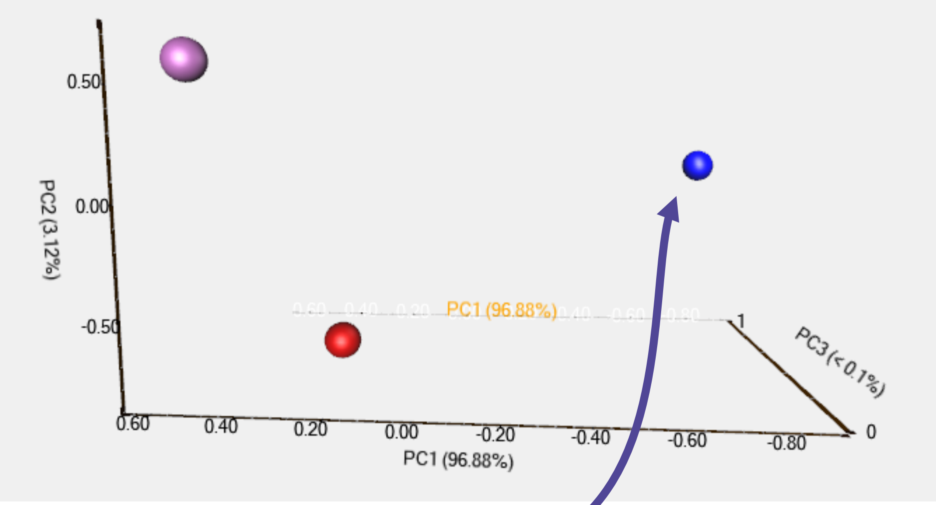
EQUA real-world test database

Carbon benefits of HVO

- Benefits are primarily upstream rather than at tailpipe
- Provenance is therefore vital
- Risk of fraud as demand exceeds supply
- Fuel analysis can help fingerprint



Provenance verification



- One HVO source is dissonant
- Much closer in composition to regular road diesel
- Cyclododecanol is differentiator – aquatic toxin

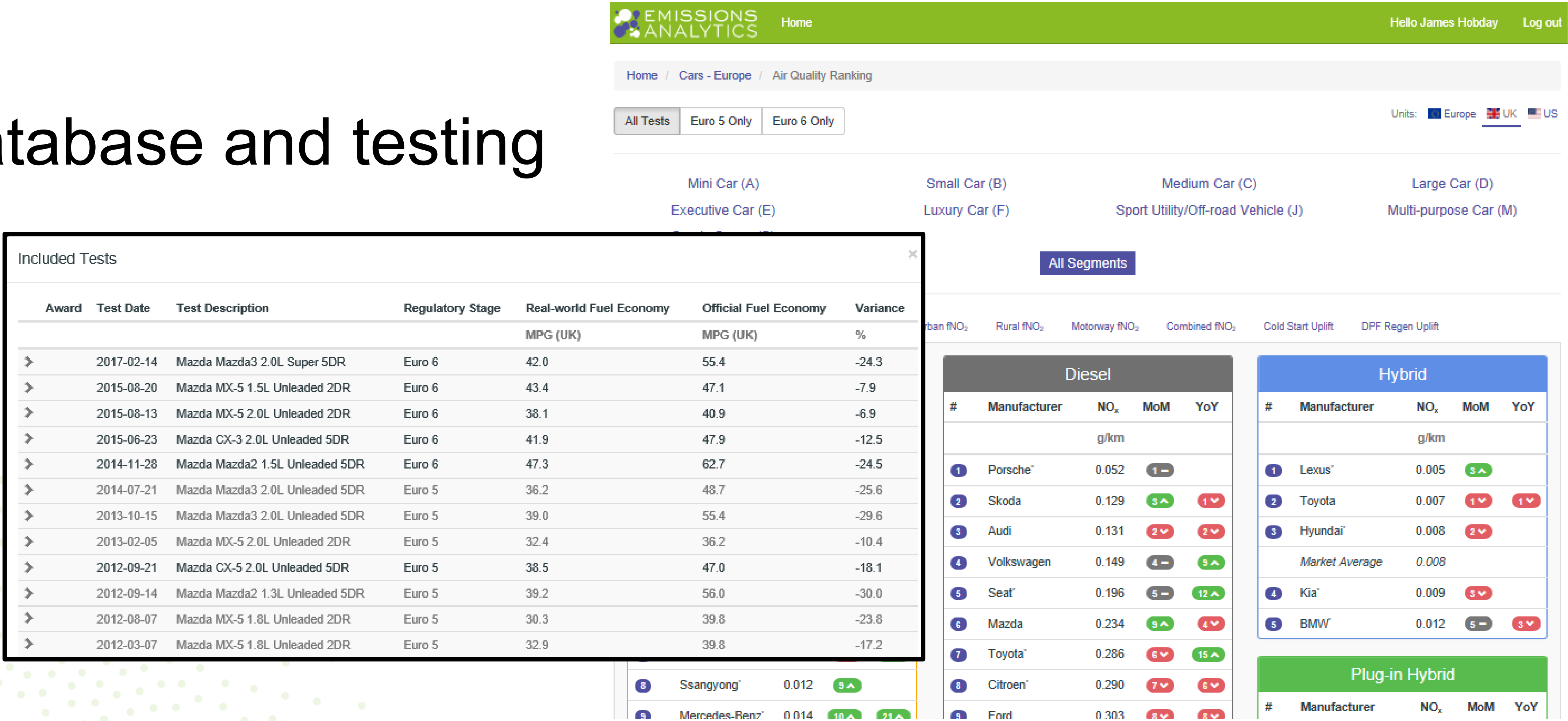
Peak area %	HVO 1	HVO 2	HVO 3	HVO 4	B7 diesel reference
Number of organic compounds	385	522	378	262	669
Aromatics/PAHs	0.14	13.23	0.09	0.04	0.04
Alkanes, alkenes, alkynes, alcohols, acids, cyclo	99.86	86.77	99.91	99.96	88.46
Oxygenated	0.30	13.97	1.30	0.73	43.31

Summary

- Combination of standard PEMS and two dimensional GC -MS is powerful in understanding fuel properties and tailpipe emissions
- Renewable fuels can make some reduction in regulated pollutants
- Ethanol in gasoline may lead to increases in certain aldehydes and hydrocarbons
- Supply pressures will create a fraud risk
- Fuel fingerprinting can be used to check CO_2 reduction credentials

➢ Renewable fuels must be shown to be genuinely low emissions to thrive

Database and testing



Included Tests

Award	Test Date	Test Description	Regulatory Stage	Real-world Fuel Economy	Official Fuel Economy	Variance
				MPG (UK)	MPG (UK)	%
›	2017-02-14	Mazda Mazda3 2.0L Super 5DR	Euro 6	42.0	55.4	-24.3
›	2015-08-20	Mazda MX-5 1.5L Unleaded 2DR	Euro 6	43.4	47.1	-7.9
›	2015-08-13	Mazda MX-5 2.0L Unleaded 2DR	Euro 6	38.1	40.9	-6.9
›	2015-06-23	Mazda CX-3 2.0L Unleaded 5DR	Euro 6	41.9	47.9	-12.5
›	2014-11-28	Mazda Mazda2 1.5L Unleaded 5DR	Euro 6	47.3	62.7	-24.5
›	2014-07-21	Mazda Mazda3 2.0L Unleaded 5DR	Euro 5	36.2	48.7	-25.6
›	2013-10-15	Mazda Mazda3 2.0L Unleaded 5DR	Euro 5	39.0	55.4	-29.6
›	2013-02-05	Mazda MX-5 2.0L Unleaded 2DR	Euro 5	32.4	36.2	-10.4
›	2012-09-21	Mazda CX-5 2.0L Unleaded 5DR	Euro 5	38.5	47.0	-18.1
›	2012-09-14	Mazda Mazda2 1.3L Unleaded 5DR	Euro 5	39.2	56.0	-30.0
›	2012-08-07	Mazda MX-5 1.8L Unleaded 2DR	Euro 5	30.3	39.8	-23.8
›	2012-03-07	Mazda MX-5 1.8L Unleaded 2DR	Euro 5	32.9	39.8	-17.2

- ➢ Vehicle and fuel fingerprinting database now available
- ➢ For performance benchmarking, provenance analysis, and R&D

Thank you.

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Emissions testing in real-world conditions brings challenges that experience anticipates and expertise overcomes. We deliver.

Independent
Objectivity and candour are the driving forces in all our work, so you know the facts.

Responsive
We're fast on our feet so we can conduct emissions testing when and where we're needed.

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