A View of Current and Future Trends in Automotive Emissions, Fuels, Lubricants and Test Methods (perspectives from the 3rd International Exhaust Emissions Symposium, 24-25 May 2012, Bielsko-Biala, Poland)

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Abstract

BOSMAL recently hosted the 3rd International Exhaust Emissions Symposium, entitled *Current and future trends in automotive emissions, fuels, lubricants and test methods - 2012*, which featured a total of twenty-five presentations from experts on automotive emissions and aftertreatment and the fuel and lubricant industries. The symposium's technical programme (presented in Appendix 1) consisted of one keynote address and four themed presentation sessions. The symposium formed part of a series of events to commemorate BOSMAL's 40th anniversary. The event built upon and the achievements of the previous two events and extended the format to cover new areas. Some of the most important trends mentioned during the symposium included: changes to test procedures to reflect the challenge of quantifying ever decreasing emission levels, accuracy and limits of detection and the role catalytic aftertreatment system and alternative fuel and oil concepts have to play in further reducing emissions from internal combustion engines.

Introduction

Concerns over the impact of the road transport sector on greenhouse gas (GHG) emissions and air quality remain high. Despite recent progress in fuel efficiency, road transport emissions are currently responsible for around twenty per cent of all greenhouse gas emissions in the European Union (EU).

Following the highly successful 1st and 2nd International Exhaust Emissions Symposia hosted in 2010 [1, 2] and 2011 [3, 4], BOSMAL Automotive Research and Development Institute Limited, (of Bielsko-Biala, Poland) recently hosted the 3rd International Exhaust Emissions Symposium, held over 24-25 May 2012. Symposium delegates hailed from a total of fourteen countries on three continents, testifying to the international, multi-disciplinary, strongly collaborative nature of the event. The 3rd symposium featured one keynote address from a specially selected expert, as well as a total of twenty-four presentations from both industry and academia, covering a broad range of automotive emission-related subjects: emissions legislation, real-world emissions and fuel economy, compounds which are potential candidates for emissions regulation, emissions test equipment and its limits of detection, emissions reduction technology, aftertreatment system and catalyst technology, particulate matter (PM) and particle number (PN) emissions, fuel development, alternative fuels, gaseous fuels (CNG, LPG), and engine oil development.

Aims, context and format of the symposium

This third symposium was hosted as a direct result of the successes of the previous emissions symposia hosted by BOSMAL: the 1st and 2nd International Exhaust Emissions Symposia [1-4]. As before, the aim of the event was to provide attendees with an opportunity to both share and obtain information, knowledge and contacts in fields relating to automotive emissions, fuel and lubricants. In common with the previous two events, the symposium also featured an integrated social programme and provided excellent opportunities for networking and informal discussions. A highly experienced individual with a background in both industry and academia was invited to deliver an extended presentations as a keynote lecturer. This keynote presentation commenced the first day of the symposium and set the tone for what was to follow. The remaining twenty-one oral presentations were divided into five themed sessions (see Appendix 1), each covering a particular aspect of automotive exhaust emissions: *'Emissions legislation and test method development', 'Powertrain Development, Test Method Development and Hybrids', 'Catalyst Technology and Emissions Reduction Methods CI and SI engines', 'Particle number and Particle Size Distribution Measurement Development' 'Fuel and engine oil development'.* Each presentation presented during these sessions lasted around twenty five minutes, with five minutes allocated for discussion at the end. These opportunities to ask questions were well used by attendees and generated a number of interesting discussions on points raised during the presentations.

BOSMAL President Dr. Antoni Swiatek formally commenced the symposium by delivering an opening address (Figure 1). After greeting the delegates and recognising that many had travelled great distances in order to attend, he mentioned how BOSMAL has been involved in automotive emissions testing activities (among others) for forty years. Dr. Swiatek also thanked the sponsors and media partners of the event. The rapid pace of change that currently exists within the industry requires ever more investment in equipment, test facilities and technical know-how. The first item of the technical programme (see Appendix 1) was the keynote lecture (Figure 2), followed by presentation session 1. This, in turn, was followed by a coffee break, during which a demonstration of AVL's Cameo software was given by BOSMAL staff. Two further technical sessions were held that day. That evening, delegates were welcomed to a formal dinner event held in Kotulinski Palace in Czechowice-Dziedzice (Figures 3 and 4). This event mirrored the social events organised as part of the previous symposia, but changed the context to a somewhat more formal and illustrious setting than in previous years.

Figure 1. BOSMAL President Dr. Antoni Swiatek opening the 3rd International Exhaust Emissions Symposium

Figure 2. Michael Walsh of the ICCT delivering his keynote address

Figure 3. BOSMAL's Dr. Piotr Bielaczyc welcoming symposium attendees to the formal dinner at Kotulinski Palace

Figure 4. Symposium attendees at the formal dinner at Kotulinski Palace

The following day featured the last two technical sessions. The second of these sessions was followed by a brief summary of the symposium, delivered by Professor Jerzy Merkisz (BOSMAL/Poznan University of Technology) that formed the closing ceremony of the conference proceedings. Additionally, attendees were offered guided tours of BOSMAL's various departments and testing facilities and time was available for further networking, bilateral meetings and discussions on current and future projects.

A further three presentations formed part of the Symposium Proceedings, but were not presented orally, due to time constraints. Each of these presentations was accompanied by a poster. These three posters were on display during the various coffee breaks. These presentations and their accompanying posters were authored by BOSMAL employees and represented BOSMAL's latest research efforts on automotive emissions themes.

Presentation abstracts and selected key slides

NB: the authors listed here are presenting authors only (i.e. one author per presentation). See Appendix 1 for the full listings of all co-authors of each presentation, where present.

1st day – Keynote lecture: Michael Walsh (The International Council on Clean Transportation) - Global Trends in Motor Vehicle Pollution Control - a 2012 Update

Growth in the vehicle population has been sustained and dramatic – there are now more vehicles on the roads than there were people on Earth two hundred years ago. This fleet of vehicles is a major source of urban/regional pollution and a global source of GHG. In response, for the last ten years, the International Council on Clean Transportation has monitored vehicular emissions and attempted to determine international best practice, with a focus on the ten largest global markets. There is a growing focus on $PM_{2.5}$ as a public health concern, largely due to its strong association with mortality; there may be no threshold (meaning any exposure at all is detrimental). There are no large urban conurbations on Earth where $PM_{2.5}$ levels are not high. Vehicles consistently contribute 20-35% of direct $PM_{2.5}$ emissions; the close link between health problems (asthma, etc) and proximity to vehicles may be mainly due to $PM_{2.5}$, rather than gaseous exhaust emissions. Depending on urban architecture, up to approximately half of a city's inhabitants may live close to (within 500 m of) a major road. A recently-introduced $PM_{2.5}$ standard introduced in China was found to be exceeded in every large city. City-wide emissions limits may not help much – heavy trucks from other areas "import" low quality fuel and engines meeting older emissions standards into the city, thereby affecting urban air quality. Additionally, efforts to improve air quality are being hampered by low quality fuel in certain markets. China would have made more progress if fuel quality had not caused so many problems. Similar issues have surfaced in Brazil, Mexico, India and Russia. The cost of improving fuel quality depends both on the fuel type (petrol/Diesel) and on the market in question, but an assessment conducted by the ICCT suggested that costs per litre of fuel produced are generally modest, notwithstanding the common perception that improving fuel quality is extremely expensive. California was the first jurisdiction to set automotive emissions limits and to this day automotive technological developments often flow from California to the rest of the USA, from there to the EU and then to the rest of the world. The latest trends in California are therefore of great interest. These include very stringent NMOG, NO_x and PM emissions limits and a durability requirement of 150 000 miles (241 000 km; around 15 years' usage). California remains without a particle number limit for any engine type. There has been much debate on an emissions limit, but it was decided that a mass-based limit would accomplish the same goal. (Doubts were also expressed over the test methodology for low levels of PN emission.) Regarding fuel economy, it is difficult to compare the US and the EU (due to the percentage of SUVs in the fleet, average vehicle weight, percentage of Diesel vehicles in the fleet, average engine displacement). California hopes and expects that by 2025 around 15% of vehicles sold will be powered by fuel cells and is taking steps to ensure the availability of hydrogen, as the density of current infrastructure is insufficient. California and the EU differ on their visions for usage of CNG and LPG; California expects these vehicle fleets to remain small and thinks that natural gas is better put to use generating electricity. California has a target of reducing GHG emissions (relative to 2000 levels) by 80% by 2050, with ICE-powered vehicles predicted to continue to dominate until at least 2025-2030. The additional cost to the consumer for a typical passenger car will be around \$2 000, equivalent to a payback period of 3 years (although this period could be considerably shorter with higher fuel prices). However, there remains no guarantee that people will buy these vehicles. However, it should be noted that California is not typical regarding fuel-cell vehicles and the state lies well ahead of the curve; the rest of the world is at least 10 years behind California on this issue. Life-cycle emissions vary by market: energy used in the production of vehicles in California is cleaner than in other markets, and figures calculated for California may not apply elsewhere. Globally, road vehicles dominate fuel consumed for transport (and therefore GHG emissions). While other sectors are important, LDV are the main target for improving efficiency. In this area, the EU is the leader. Roughly 3 out of every 4 cars produced in 2012 will be subject to fuel efficiency requirements, and this proportion will rise to 4 of every 5 cars before long (Figure 5). Currently, the emission of 1.6 Gt of CO_2 has been avoided via LDV efficiency standards; this value could become much larger, depending on future legislative moves. It would appear that the EU's 2020 target of 95 gCO_2/km can be met at a cost of around €900/vehicle. However, short-lived climate forcers are now coming under considerable scrutiny. Reducing emissions and GHG would have wide-ranging positive impacts, ranging from improved respiratory health to reduced crop damage (for example). As always, in-use emissions performance is what really counts. There is a large discrepancy between type approval fuel consumption/CO_2 emissions and real-world values (see, for example [5]), a topic involving both legal and technical issues, and this is a discrepancy that needs to be addressed, for example through the implementation of more realistic test cycles (e.g. the WLTC), randomized cycles and on-road testing, or indeed a combination of all three approaches.

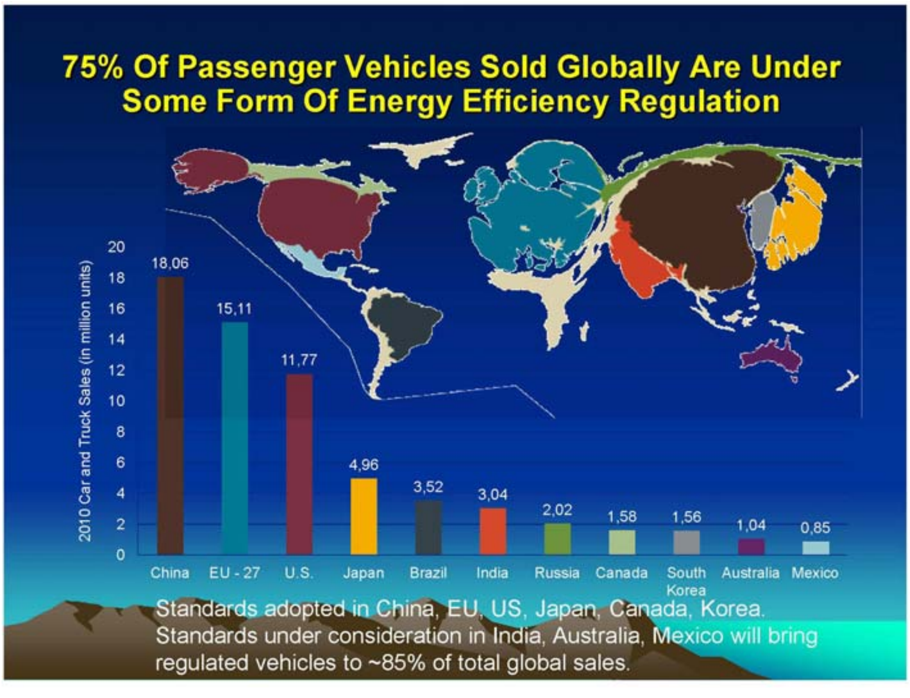

Figure 5 – The relative sizes of various global automotive markets, some of which regulate energy efficiency

Session 1 – Emissions legislation and test method development

Chairs: Michael Walsh (USA) and Dr. Piotr Bielaczyc (Poland)

Dr. Piotr Bielaczyc (BOSMAL, Poland) – Emissions Legislation/Test Method Development over the Last 40 Years and Predictions for the Next 40 Years

Emissions have a long history, but emissions regulation is much younger. The industrial revolution changed the game regarding emissions and humankind started to have an impact on the composition of the atmosphere. California experienced the effects of vehicular emissions and so set emissions standards to limit them. The balance of global energy supply and demand is evolving, but coal retains a huge share, particularly in developing countries. Since the 1960s, various legal jurisdictions have set emissions limits for light-duty vehicles, which have been reduced massively over time (Figure 6). In EU emissions legislation, the main recent change has been regarding the introduction of PN testing and limits. While US and EU legislation has generally moved in the same direction (lower limits, wider range of regulated components, cold start test requirements, etc), the US and EU markets and emissions landscapes remain difficult to compare. In the past, both emissions and fuel consumption were poor. Both parameters must be improved simultaneously and "diagonal" progress must be made, rather than only making progress regarding one parameter (Figure 6). Engine downsizing is a key weapon in the fight to reduce fuel consumption, but must be done in the right way. Also, reducing vehicle weight improves fuel consumption, emissions and performance. A growing focus on real-world emissions and fuel consumption leads to interest in emissions at low and sub-zero ambient temperatures. Fuel consumption at -7 °C has improved, probably mainly due to changes to the engine calibration. In the future, a greater number of exhaust gas components may be regulated (particle surface area, PN from DISI/PFI, NH_3, NO_2, N_2O, GPF regeneration, SCR performance) and greater emphasis will be placed on obtaining results that are representative and realistic. Political (rather than technical) legislation relating to transport, sources of energy, etc, will have the greatest impact on the personal transportation sector. The demand for R&D work to meet these requirements has never been greater. BOSMAL has 40 years' experience working with engines, vehicles and emissions, and recent investments mean it is well placed to provide for the needs of the future, ready to play a role in the development on cleaner solutions for personal mobility.

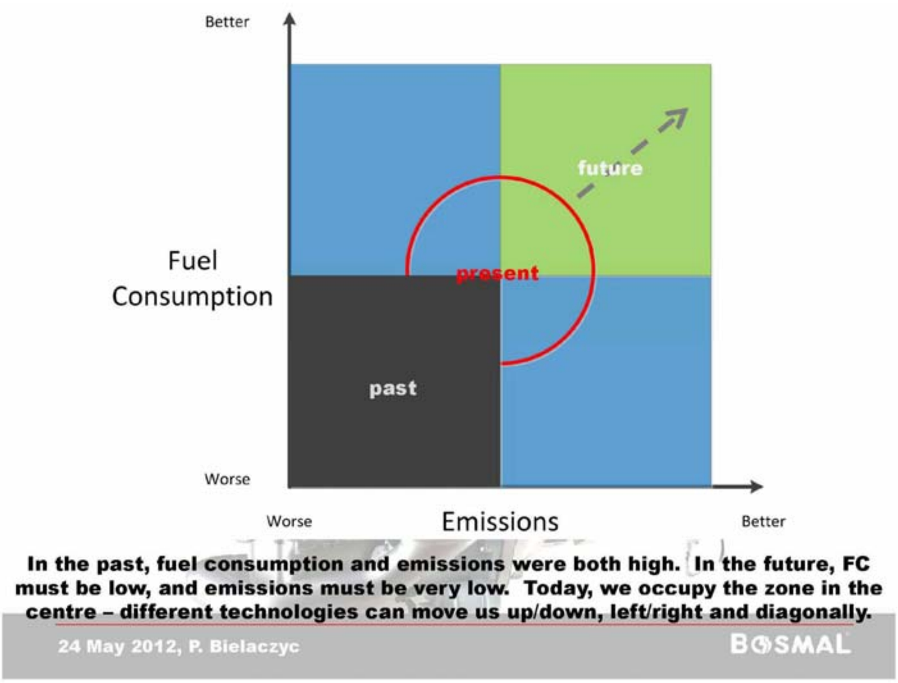

Figure 6 – Light-duty vehicle development megatrends presented as perpendicular goals

Les Hill (Horiba Europe, UK) – Recent Development and Trends in Exhaust Emissions Control

The present situation is an exciting time regarding automotive emissions legislation – as substantial changes are being made to emissions limits, emissions test procedures, equipment, etc. Changes are underway to make emission testing conditions more realistic. Pressure to use alternative fuels and biofuels, all the while ensuring full compatibility and drivability are also added to this mix. This combination of changes and additional requirements conspire to produce what could be described as "the perfect storm" for vehicle and engine manufacturers. Regarding the upcoming European emissions standards (Euro 6), the main issues are: particle number emissions from direction injection petrol engines and NO_x emissions from Diesel engines. An overriding trend in Europe is that of gradual changes to engines and powertrains, with multiple goals, including the capability to use multiple fuels. In the EU, concern over emissions centres around NO_x and PM. The emissions limits for these pollutants are now very low, but air quality problems remain. The proportion of NO_x which occurs as NO_2 is also a cause for concern (this proportion is much higher for Diesel vehicles, related aftertreatment systems). In the USA, California's legislation will eventually intermesh with Federal US legislation, homogenizing the emissions landscape in that country. Current US limits are stringent, particularly for PM. The current limit of 3 mg/mile (to be replaced by a limit of 1 mg/mile) are problematic – there is considerable doubt over the accuracy of measurement of such low emission levels. Questions have been raised over whether emission from the vehicle is really being measured, or whether other factors, such as cleanliness of the dilution air, weighing balance drift, etc are the factors which really control the result. The forthcoming 1066 procedure for testing light-duty vehicles is still being drafted, but the procedure for PM measurement should be in place by 2017, with other components following in 2022. The method used to provide fuel consumption data to consumers in the US has changed, with a composite result from five test cycles now used to determine "real-life" fuel consumption for the US market. The forthcoming EU CO_2 emissions limits would be extremely punishing to large-volume manufacturers who exceed the limit – a cost of around €100 million per gram of CO_2 might be incurred. Such high financial stakes mean manufacturers will insist on very reliable, highly repeatable emissions measurements. There has been much debate over how to test HD vehicles: testing on a chassis dynamometer creates practical problems; testing on-road would have to be defined ab initio; the remaining possibility – namely simulation and modelling – is not acceptable to the EPA. For light-duty vehicles, potential issues have come to light regarding testing of cars with hybrid powertrains. (If the IC engine starts for the first time during the last 10 s of the cycle, the quantity of gas collected is insufficient to provide an accurate measurement.) Interest is growing in measuring emissions of a range of "additional" compounds (Figure 7). Recent tests have confirmed that manufacturers' CO_2 emission values are almost impossible to replicate – repeat measurements always return higher results. The development of a harmonized global light-duty vehicle emissions test procedure (the WLTP) is a significant development. The idea is to have a universal test procedure and drive cycle, but with local emissions limits. The aim is to produce a drive cycle that is representative of real conditions on the road, including periods of severe acceleration, microaccelerations and a higher top speed than current legislative cycles. Testing will also be performed with onboard accessories (A/C, electronic navigation aids, etc) both on and off. Additionally, in order to measure real emissions performance, testing will be required on-road (using PEMS) or in the laboratory, but using randomized cycles (details of which are not known to the manufacturer before the test). It is even possible that both approaches could be used; a decision on this is due in the near future.

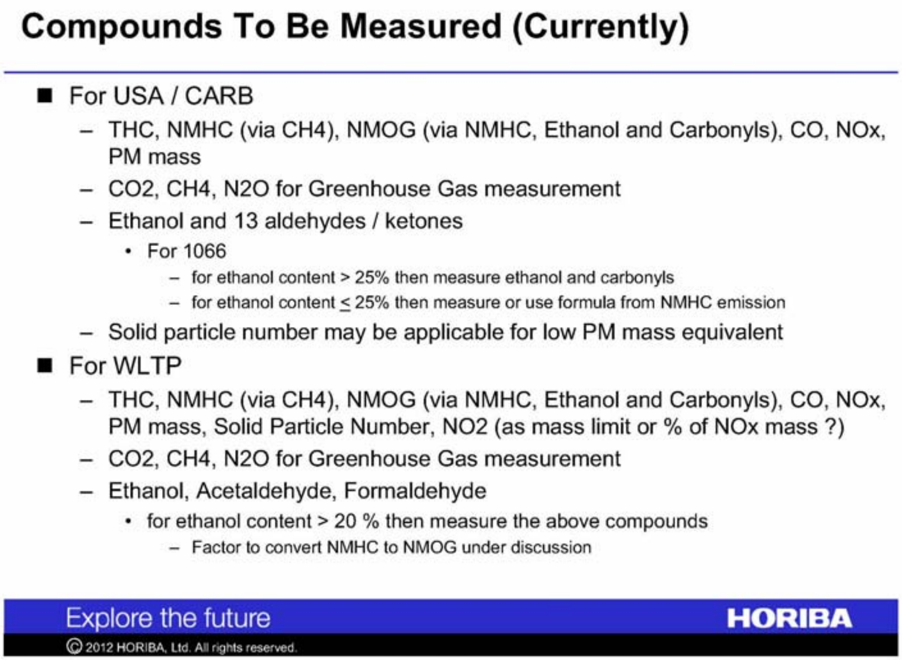

Figure 7 – "Traditional" and "additional" pollutant species measured currently (EPA/CARB) and in the near future (WLTP)

Wolfgang Thiel (Technical University Munich, Germany) **– Measuring near-zero automotive emissions – a big challenge**

Unfortunately, Mr. Thiel was unable to deliver this presentation in person, so it was delivered by Les Hill of Horiba Europe. While zero emissions from vehicles would be very welcome for a variety of reasons, it is impossible and impractical to measure zero emissions. "Zero" as a concept represents a very small number, but also a very precise number. Depending on the context, some emissions can be so low that they are indistinguishable from zero; as the emission factor approaches zero, the worse such problems become. As the sample and the ambient sample concentrations approach numerical equivalence, the accuracy of the measurement begins to be determined entirely by the accuracy of the dilution factor, which is itself at the mercy of a number of other parameters. For low emission levels, a huge range of interfering factors become significant; practically everything can change the results, but a few factors are particularly important. The presence of very low levels of contaminants in span gases can create errors in the calibration process, leading to an offset in the concentration value returned by the analyser (the current specified purity tolerances for span gases are relatively lax). Pollutant compounds can change the viscosity of the sample gas and cause phantom readings (flame ionization detectors can even show a response to water molecules). Quantification of hydrocarbons as very low levels is difficult, and many corrections have to be made; even the geometry of the flame itself has to be considered. Similarly, there is some evidence that CO_2 analyzers may show a phantom response to water in the sample gas. Even where a zero-carbon fuel is used (i.e. H_2), CO_2 emissions of around 1.5 g/mile (0.93 g/km) will be recorded, simply from the flow of air ambient air through the powertrain. The hydrogen content of the fuel can affect the CVS, and thereby skew all emissions results. For low PM and PN measurements, background levels become significant. Some PM filters trap certain gases (including hydrocarbons) to produce artefacts and produce an apparent mass increase, to such an extent that emissions limits can even sometimes be exceeded without the engine running at all. The result of this interference is that using the current method, the lowest viable limit has been calculated to be 7.3 mg/mile (4.54 g/km); current legislative limits are very close to the limits of accuracy and reproducibility (Figure 8). The topic of PN measurement has not yet been concluded; current testing requirements will inform the final decision on a robust methodology. For measurement of all pollutant types, technical progress has meant that emissions limits approach the limits of detection – thereby creating a need to know which emissions values which are statistically equivalent to zero.

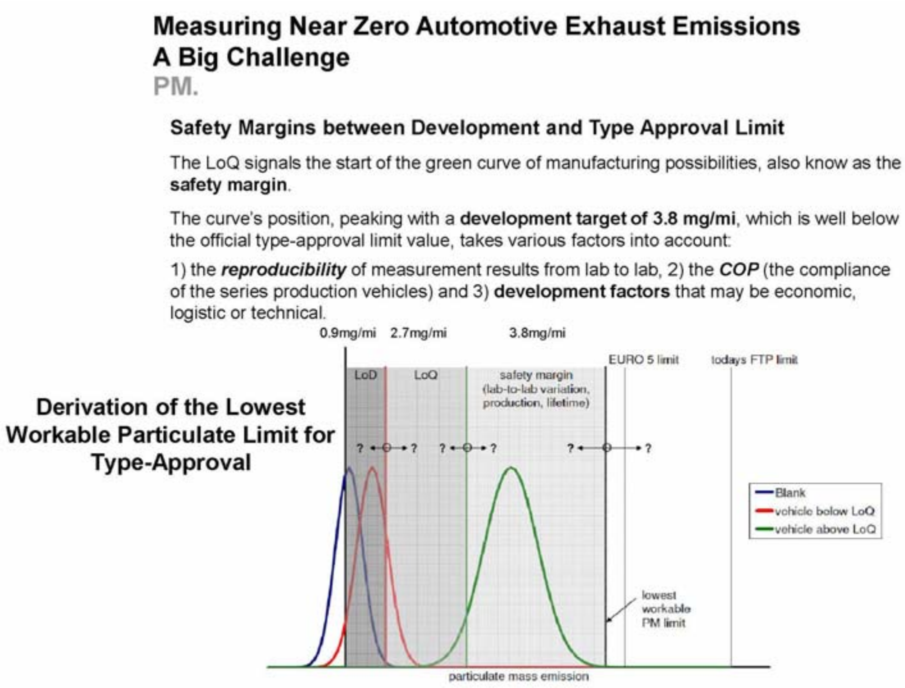

Figure 8 – Quantitative considerations of the lower limit of accuracy regarding gravimetric PM measurements

Dr. Christos Dardiotis (European Commission Joint Research Centre, Italy) – JRC's Contribution to the Revision of the European Type Approval Procedure for Light Duty Vehicles

European Union legislation specifies a number of different tests relating to emissions from passenger cars. Revisions to multiple test types are currently being planned. These revisions are deemed necessary due to a range of factors, from increased use of biofuels to political targets for reduced CO_2 emissions. The test procedure for evaporative emissions (the Type IV test) will have to be modified, due to wider use of biofuels (namely ethanol). Durability is also a potential issue in this area and the three new test scenarios currently under consideration attempt to address this. In future, a mixture of type-approval and self-certification could be used. The canisters themselves will also have to change – to become somewhat larger, more resistant to ethanol, etc. The main change to the emissions testing procedure (the Type I test) will be the driving cycle, but supplemental requirements for real driving emissions will also be introduced. PEMS monitoring has revealed that emissions of virtually every automotive pollutant are exceeded during real-world usage of vehicles which meet the limits under laboratory conditions. One option is to perform on-road testing using PEMS to ensure compliance, or mandate laboratory testing using randomized cycles. Both options are under consideration and in fact future legislation may require both types of testing to be carried out. The low temperature cold start test, in which the first phase of the legislative test cycle is performed at an ambient temperature of -7 °C (the Type VI test) may have its limits reviewed. The current limits were carried over from Euro 3 legislation at the time of the introduction of the Type VI test and these limits for emission of HC and CO need updating, as passenger cars meeting the Euro 5 and 6 standards easily meet the Type VI test HC and CO limits (by a very large margin in most cases – see Figure 9). Regarding diesel operation at -7 °C, emissions of NO_x are of greatest concern. For SCR-equipped vehicles, emission of NOx is generally only an issue during the UDC, after this the system has reached its operating temperature and deals with NO_x in the exhaust gas effectively. The possibility of extending the Type VI test to include NO_x emissions from all light-duty vehicles with CI engines is currently under consideration.

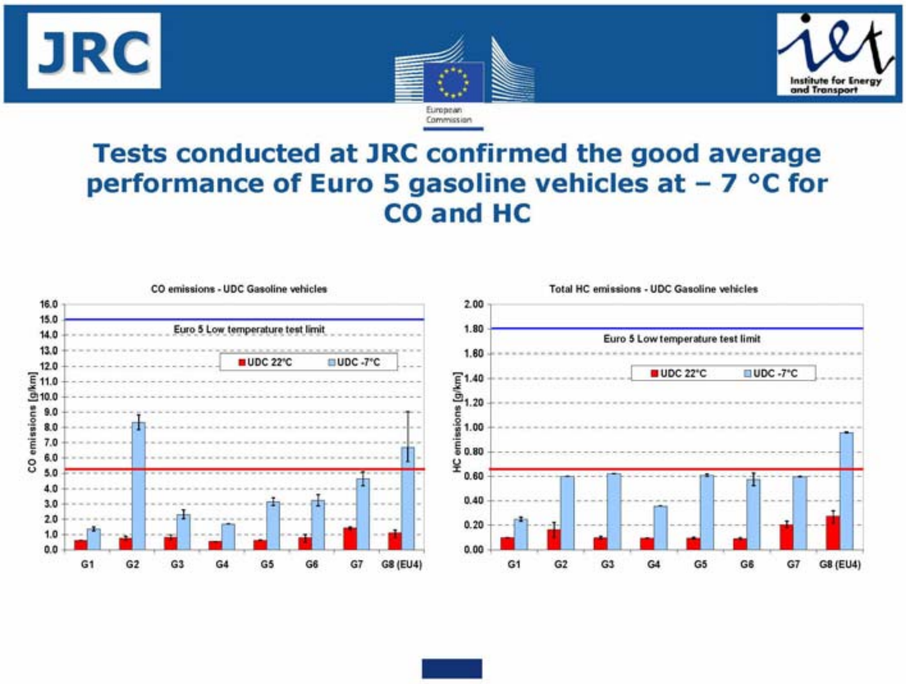

Figure 9 – CO and HC emissions results obtained at -7 °C, presented in comparison to the legislative limit

Kurt Engeljehringer (AVL, Austria) – Hybrid vehicles – Emission test and measurement challenges

Growth, both in the general population and in the number of vehicles in use, means we have no option other than to become more efficient. Hybrids were developed as an attempt to increase efficiency and make better use of limited natural resources (i.e. fossil fuels, clean air). A conventional vehicular powertrain does not reclaim any mechanical energy, and so no recovery of energy is possible. The potential benefits that hybrid powertrains can provide need to be quantified for legal, technical and commercial reasons and so there is a requirement for the execution of substantial numbers of tests. In general, this testing should be realistic (but the NEDC is normally used; depending on the test setup, simulation of turns, etc can also be possible). Conceptually, the test procedure is the same as for vehicles featuring conventional drivetrains. One major deviation is the concept of the total energy balance at the end of the test cycle – generally the calibration is such that over the NEDC, the battery's state of charge returns to its original value. When the vehicle makes only limited use of the IC engine, emissions of HC, CO and NO_x can be as much as 84-90% lower than the relevant Euro 6 emissions limits. After the initial start up, hybrid systems improve the emissions performance during subsequent starts of the engine – in fact such a system shows advantages over a Stop&Start system (no CO or HC peaks, apart from the initial start-up when the engine and its fluids are at the ambient temperature – see Figure 10). Off vehicle charging complicates matters – cycles have to be run while monitoring the state of charge. Some vehicles can even run the whole NEDC without resorting to the ICE at all. Running "best case" and "worst case" tests provide data for a weighted calculation. The availability of off-vehicle charging and the frequency with which it is performed affect the real-world emissions performance of a vehicle. It is assumed that the vehicle can be charged every 25 km. Running the majority of the test without the ICE running results in over-dilution of the (limited) exhaust gas that has been generated. One possibility would be to turn off bag sampling for periods where the IC engine is shut off, but this is currently prohibited in all relevant legislation and the sampling volume must also be great enough to permit analysis. For R&D testing, sampling of the raw exhaust (Figure 10) avoids these problems, but for legislative testing, it is clear that the 40-year-old test procedure is inappropriate. The test stand's constant volume sampler can pull air through the powertrain, cooling components including the catalytic aftertreatment system, changing emissions results and filling the TWC with NO_x. (A potential solution to this problem would be a temperature-controlled valve which prevents the CVS from sucking air though the powertrain when the engine is not running. However, such a solution has yet to be agreed upon, still less approved in automotive emissions legislation.) Technology moves much too fast for legislation to follow. To avoid protracted discussions and road-blocks in the future, it is important to agree on a robust procedure now. The drive cycle used for testing is perhaps more important for CO_2 than emissions and this aspect is particularly important for testing of hybrids. The current driving cycles are all extremely well known and even cycles slated to be introduced in the future are widely available online. To ensure that exhaust emission limits for all vehicle types (including hybrids) translate into concrete air quality benefits, off-cycle emissions must be addressed.

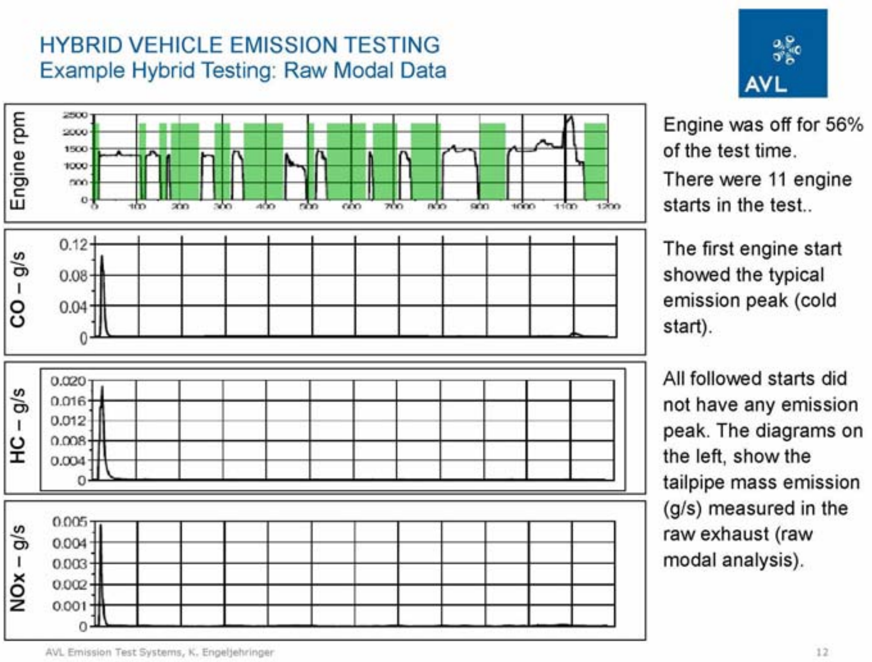

Figure 10 – Raw (undiluted) CO, HC and NO_x emissions from a hybrid vehicle, showing peaks only for the initial cold start

Session 2 - Powertrain Development/Test Method Development/Hybrids

Chair: Professor Giovanni Cipolla (Italy)

Professor Giovanni Cipolla (Politecnico di Torino, Italy) – Euro 7 Emissions Challenge for IC Engine

In the past, emissions limits were set and the positive impact of these measures on ambient air was assumed by default. The automotive industry finds itself a major target in a wide-ranging drive to improve sustainability, reduce pollution and improve ambient air quality. Regarding the well-known and widely reported differences between type approval values and on-road values, the user (driver) has no way of telling what real world regulated emissions are, but can tell very easily what the real-world fuel consumption is. Under certain conditions, a trade-off is observed between regulated emissions and fuel consumption – and it should be kept in mind that one is of far greater concern to the user than the other. Despite the difficult current climate and legislative and technical pressure, the internal combustion engine is far from dead – and there remains much work to do on it. Further development and refinement of ICEs is the first step in a long-term programme to improving the environmental performance of vehicular powertrain solutions (the next step is more widespread adoption of alternative fuels). The next round of emissions legislation (the Euro 7 standard) has not been confirmed and any comments on this subject are mere speculation. However, it has been clear for some time that the test procedure (particularly the driving cycle) may well change. Changing the driving cycle changes the engine operating parameters (Figure 11), with multiple impacts on the calibration, ATS, etc. It will almost certainly become harder for manufacturers to engage in "cycle beating". However, current technology will probably be sufficient to meet the next round of emission limits, but will require adaptations and improvements in certain cases. Completely new technologies will likely not be required. Rather than putting all the emphasis on ATS, we can reduce the engine out emissions, but ATS will always be required for ICE. ATS can help us to overcome the trade-off between fuel consumption and emissions. Longer driving cycles will make things easier for manufacturers (cold start a smaller proportion of the total cycle). Downsizing and downspeeding are also in this area, but have opposing effects on HC and NOx emissions. Driving cycle construction is highly complex – whatever is chosen, it will be unrepresentative of driving conditions in many areas. For ultra-realistic considerations of fuel consumption, turning, bumps in the road, chassis/suspension resonance and abrupt swerving will all have an impact. The current situation, where requirements to reduce emissions and GHG emissions are the main drivers of development of vehicles, engines, ATS, etc looks set to remain unchanged for the foreseeable future.

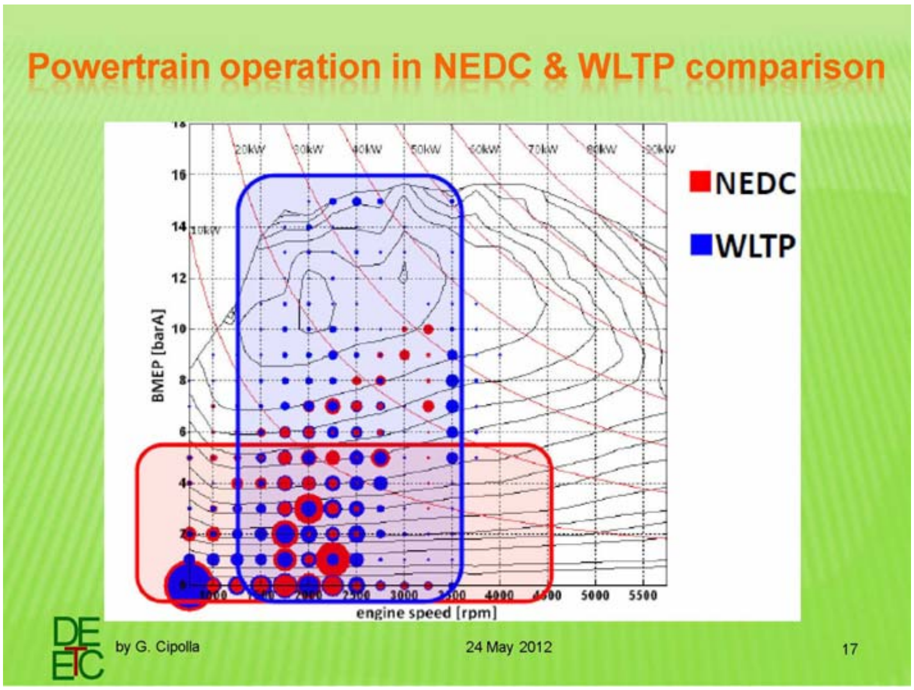

Figure 11 – Typical engine operating parameters over the NEDC and the proposed WLTP cycle

Ignazio Gentile (Fiat Powertrain, Italy) – Cylinder Head Integrated Manifold on Gasoline Turbo Engines

Across Europe (and elsewhere) a feature of urban living is the presence of heavy traffic. This has a large impact on urban air quality. Fiat recognises that "the next big thing" is for green vehicles. In response to this, Fiat developed the TwinAir engine family, which remains the most recent addition to Fiat's engine options. The engine comes in several versions, both turbocharged and naturally-aspirated, for two different fuel types (petrol and CNG). The design criterion was to simultaneously increase driving fun and reduce fuel consumption. Since the benefit derived from modifying existing technologies follows an asymptotic curve (i.e. increasing effort in needed to deliver smaller and smaller returns), a simple yet new idea can make a large difference for relatively little cost/effort. With this fact firmly in mind, the cylinder head and intake manifold were designed especially for this application. Additionally, for turbocharged versions, a new turbocharger configuration was devised. It was not possible to implement such innovations on an existing engine, and so the new engine was designed from the ground up. Thermal management in the engine system avoids excessive catalyst temperatures, while allowing very high in-cylinder temperatures. Such a strategy permits excellent oxidation of the fuel, while avoiding long-term damage to the ATS. Benchmarking with an engine produced by a well-known competitor yielded favourable results. One of the main standout features of the new engine type is the integration of the manifold into the cylinder head (cylinder head integrated manifold, "CHIM"). The main benefit of this innovative strategy is reduced fuel consumption. Over the NEDC, no real reduction in fuel consumption is visible, but for "real world" driving behaviours (and over more aggressive drive cycles, such as the US06), enrichment can be avoided at high injection pressures (Figure 12), thereby reducing fuel consumption. Great attention is paid to the casting process, in order to produce a high-quality surface finish suitable for use in high-pressure environments. Following casting using the lost foam method, hot isostatic pressing is employed to produce a surface suitable for use in high-pressure environments. The HIP process results in the elimination of pores and the creation of a higher-quality surface finish. The integrated manifold is an excellent example of how simple ideas and modest refinements can help in the continuing drive to reduce emissions and fuel consumption of modern IC engines.

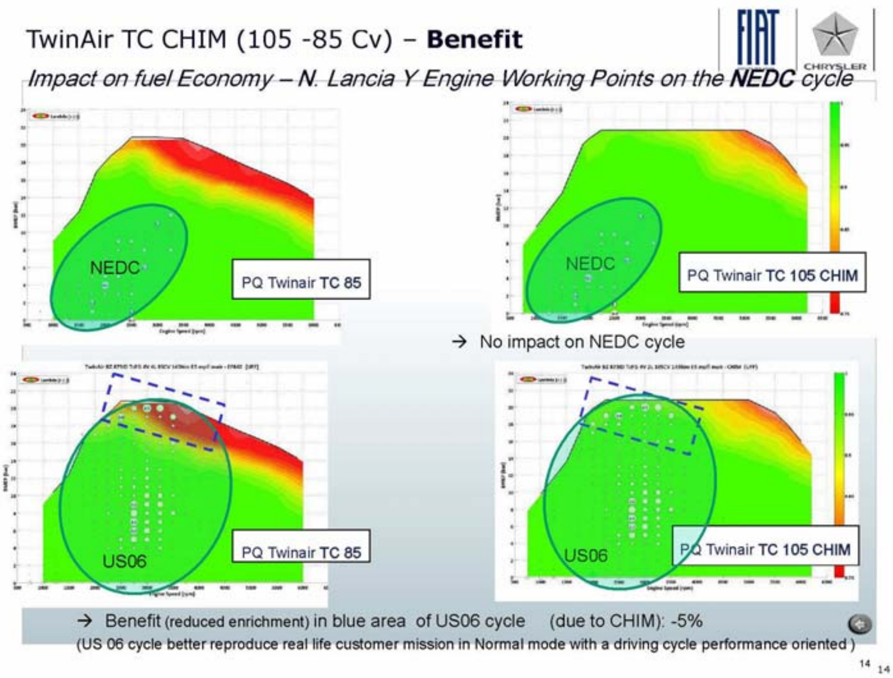

Figure 12 – Fuel enrichment maps for non-CHIM (left) and CHIM (right) Fiat Twinair engines over the NEDC and US06 cycles

Eike Martini (AVL, Austria) – Emission Calibration Yesterday, Today and Tomorrow

In the past, emissions control was all done via hardware, with no computer control and limited possibilities for re-calibration. Emissions standards were lax and could be met in other ways. Any re-calibration had to be performed by taking the car off the road and altering settings – there was simply no possibility of updating/changing calibration settings on the fly. There was no on-board diagnosis system. This situation has changed dramatically, such that currently full on-line access to many parameters is possible, effectively giving a vehicle more than one calibration. Today's OBD systems have access to more than 50 % of all functions. Currently, the road environment is the most important for calibration – and simulation environments the least important, but this will change somewhat in the future. Long term goals include eliminating transient peaks and improving real world fuel consumption, with an increasing emphasis on transient operation and the resulting emissions (Figure 13). Interactions between systems which are separate must be considered, as the emissions, fuel consumption and drivability result from the combined efforts of these individual systems. Multiparameter trade-offs regarding emissions, fuel consumption, performance, etc need to be analysed and compromises found. This can be done by humans, but is much more rapidly and efficiently achieved by computers. Data handling can occupy up to 51% of the time of employees involved in tasks such as refining and optimising calibrations. Different file formats, data array sizes, etc can cause problems and waste time. While there are robust procedures and control protocols for changing any mechanical component in a vehicle, calibration parameters are often changed ad-hoc, with little record kept of the evolution of the calibration through time. This is an anachronism which needs to be urgently addressed. In certain situations, the calibration can be the weakest link in the chain, thereby frustrating efforts regarding the system as a whole (i.e. the vehicle). In order to assess the suitability and viability of a particular calibration, integrated testing must be performed – involving measurement of emissions, fuel consumption and driveability under variable conditions. Trends for the future include increased use of in-vehicle measuring equipment and an even greater level of automation and computerization for the entire calibration process.

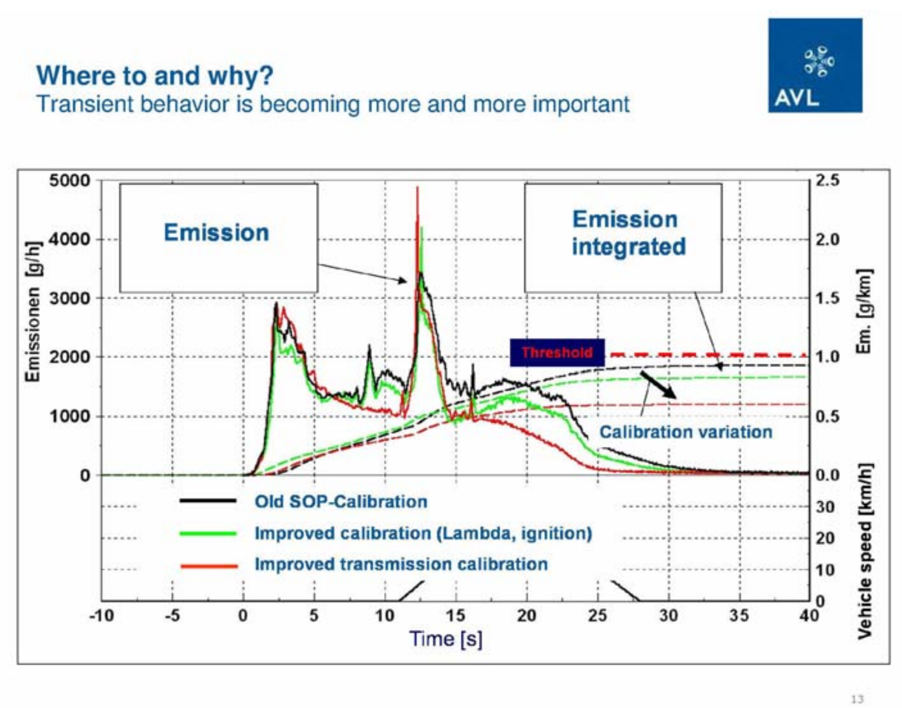

Figure 13 – The impact of calibration refinements on emissions behaviour during transient powertrain operation

David Mauke (EMPA Swiss Federal Laboratories for Materials Science and Technology, Switzerland) – CNG and CNG Hybrid Vehicles: A Potential Concept to Reduce CO_2 Emissions?

Carbon dioxide emissions limits set to be introduced in the EU in the near future will implement an ambitious trendline for the correlation between vehicle weight and CO2 emissions (Figure 14). When subjected to such an analysis, CNG-powered vehicles perform well (Figure 14). The operating parameters (i.e. typical drive cycle) are crucial for determination of the relative performance of vehicles with different engine/fuel types. A series of tests revealed a CNG-powered vehicle to outperform hybrid, petrol and Diesel powertrain concepts under rural and motorway conditions (in terms of CO_2 emissions); under urban conditions the CNG concept came second only to the hybrid vehicle. When subjected to well-to-wheel life-cycle GHG analyses, CH_4 seems like a very attractive fuel. However, as a great deal of driving (particularly urban driving) involves regular braking, coupling hybrid systems with CNG powertrains can improve the GHG performance still further – using a clean, low C fuel, and recovering energy via an electrical generator. The various options regarding fuel types fit differently to different applications. A diversification approach is required, whereby fuel consumption is reducing where it can be reduced and drivetrains and fuels are replaced where appropriate. CNG is chemically different from petrol and CNG applications require specialised ATS, as methane oxidation is difficult to achieve. The high octane number of methane would permit much higher engine compression ratios, thereby increasing thermal efficiency. The flame temperature is lower, leading to lower NO_x emissions, if the system is generally well-designed. Manifold and direct injection CNG delivery strategies have been assessed; both are functional, but research continues into the impact on emissions and fuel consumption. CH_4 and H_2 could be good options for storing energy from solar/wind, i.e. when conditions are favourable (sunny/windy), the energy is used to make fuel, and fuel production is halted when conditions become unfavourable. Usage of mixtures of CH_4 and H_2 is also possible, with substantial CO_2 emissions reductions observed at lighter loads. Many ultra-clean vehicles are presented at trade shows, described in journals, etc, but very few ever complete the journey to vehicle showrooms. CNG vehicles could be the first to start to seriously break this trend. CNG tanks and hybrid systems (with their batteries) add weight and to the vehicle and require space onboard, but experimental data suggests that the FC benefits they provide outcompensate these effects, particularly as hybrid systems permit the use of smaller, lighter fuel tanks.

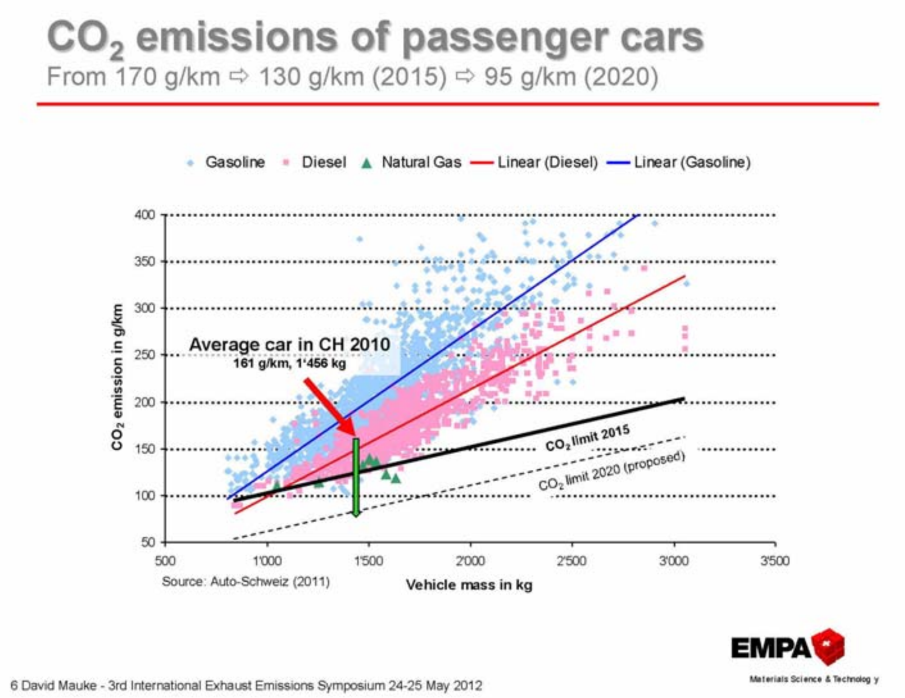

Figure 14 – CO_2 emissions as a function of vehicle mass for natural gas powered vehicles alongside other vehicle types

Session 3 - Catalyst Technology & Emission Reduction Methods for CI & SI Engines

Chair: Dr. Andre R.R. Silva (Portugal)

Dr. Gerardo Carelli (Umicore, Italy/Germany) – Efficient NO_x Aftertreatment Technologies for Clean Diesel

Pessimism regarding a "perfect storm"-type situation for the automotive industry (as described above, in Session 1) may in fact be overstated. In the past, there was much pessimism within the industry surrounding the introduction of PM/PN limits and the total demise of the Diesel engine was even forecast. Quite evidently, this never occurred. Current emissions standards for Diesel engines are stringent and demanding, but can be met with the use of various aftertreatment technologies acting in concert. One of the overwhelming difficulties regarding meeting European Diesel emissions limits is the low engine out temperatures encountered during the UDC. There are three configurations options for Diesel aftertreatment systems to meet stringent emissions limits: DOC+cDPF, NSC+cDPF, DOC+cDPF+SCR – this last one allows maximum elimination of NO_x, but is the most costly option. NSC was originally devised for medium- and heavy-duty applications, but changes and refinements now mean it can be applied to passenger cars. For CI engines, NO_x is the pollutant of greatest concern. NO_x itself is regulated via emissions standards, NO_2 is regulated in air quality standards, regional limits and emissions standards. NO_2 is as big an engineering problem as NO_x. A NO_x storage catalyst (NSC) is like a sponge – it fills up and requires regeneration before too long. Sulphur competes for active sites on the catalyst, so the effectiveness of the system depends somewhat on fuel sulphur content. (A target for the future is the development of systems which exhibit a greater tolerance to sulphur.) New technology can drastically improve the performance of NO_x conversion at lower temperatures, as well as the sulphur tolerance and HC and CO conversion light-off points. Technological improvements such as these can make systems more practical and ease implementation. Urban driving conditions present difficult conditions for performing any kind of regeneration. Since 75% of NO_2 is emitted in urban environments, NSC+cDPF systems are of interest and will be the main weapon with which to fight NO_2 in urban areas. Tests of a new type of system under urban driving conditions revealed substantial reductions in NOx emissions, without any increase in the PGM loading (Figure 15). With this new technology, where use of a DOC is avoided, excellent fuel economy can be achieved. Testing revealed the durability characteristics to be good and the deterioration to be limited. Various combinations were tried regarding metals, coating types and coating processes. This solution was designed for conventional Diesel engine types, but could perhaps be gainfully employed for alternative combustion strategies.

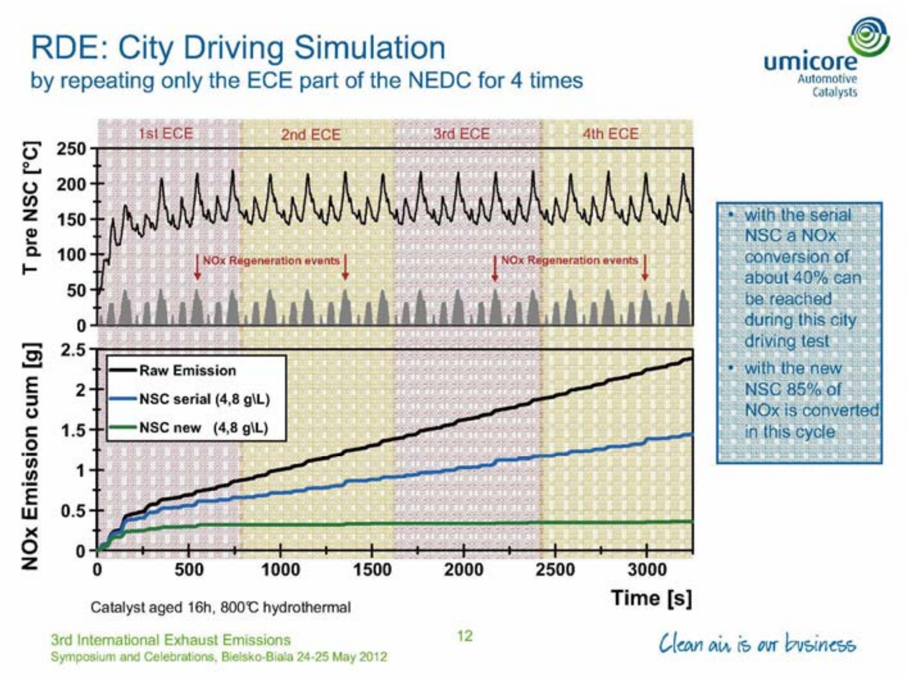

Figure 15 – NO_x emission from two NSC systems under simulated urban driving conditions

Dr. Toni Kinnunen (Ecocat Finland) – Emission Techniques and Related SCR Systems by Ecocat and Albonair

There are many options available for Diesel applications – the best strategy is to chose the right systems for a given application and put them in combination. No application currently requires all available solutions. The SCR system seems promising, and has been the subject of much research. The 'fast SCR' reaction is the target. Changes to the substrate enable reasonable control of ammonia slip. Even at high space velocities, through the entire range of normal engine operation, NO_x conversion performance of an Ecocat system was shown to be good. Achievement of acceptable conversion at low temperatures is a development target. Limiting the ammonia slip to 10 ppm by reducing α had a limited effect on the NO_x conversion efficiency. The effectiveness of SCR systems for Diesel applications depends strongly on the cell density. A Vanadium-SCR (V-SCR) system was approved by the EPA and CARB for off-road applications (the first such approval of this type), with the durability judged to be good enough to obtain the aforementioned approval. Regarding the control of ammonia slip, a good development strategy is to set an ammonia slip limit and explore options which meet this limit. By using an ammonia slip catalyst, higher dosing can be used, thereby keeping performance high. During a DPF generation, the temperature of the exhaust gas is much higher, and so V-SCR systems must exhibit high thermal durability. (In fact, they must be able not only to withstand high temperatures; they also need to function well at high temperatures.) A special thermally stable solution showed much better behaviour than less advanced designs, especially following long-term ageing. The SCR system necessitates complicated electronics; the system requires its own controller and many connections. A relatively large amount of information must be exchanged between components and systems (Figure 16). Somewhat surprisingly, air is a critical component for SCR mixture formation and air consumption demands must be taken into consideration. Urea dosing is also important and must be closely controlled – if done incorrectly, the efficiency of the system can be dramatically reduced. Multiple concepts exist for injecting AdBlue; the concept which was decided upon exhibits low air consumption and no crystallizing and depositions of the AdBlue liquid in the system. This system improves the size distribution of the droplets and consequently the evaporation profile, which is important as uniform urea distribution and decomposition must be achieved before entering the SCR catalyst if the system is to function effectively. The entire SCR system does produce some backpressure, but the value is within acceptable limits.

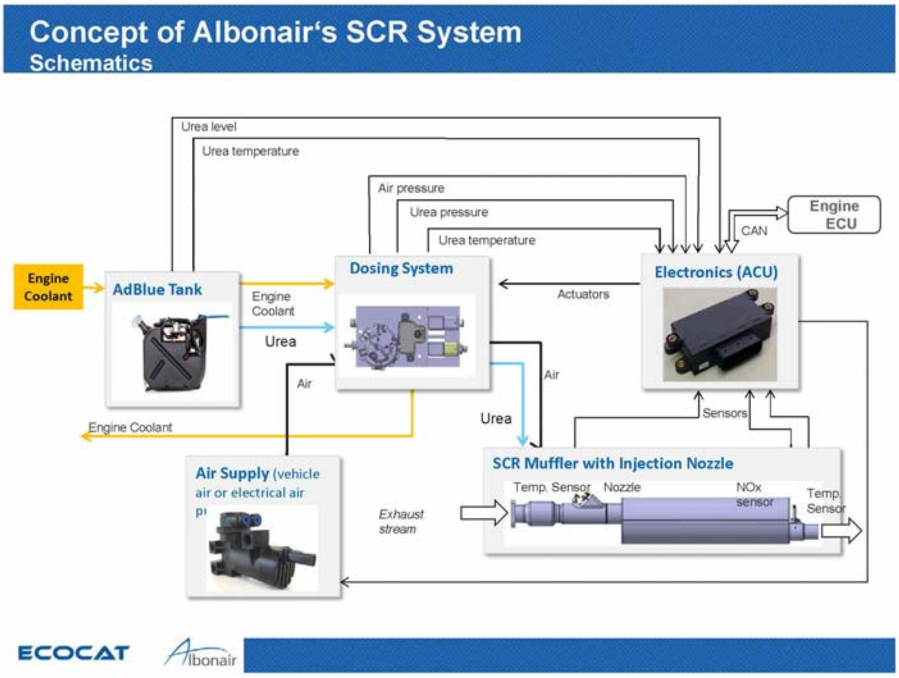

Figure 16 – A concept of Albonair's SCR system, showing the key elements, mass flows and associated control parameters

Chris Whelan (WDL, UK) – Design and Development of a Turbo-Expander for Charge Air Cooling

Downsizing has usually been accompanied by charging of engines, in order to maintain drivability and performance characteristics. However, despite the obvious conceptual link between turbocharging and performance, turbochargers can play a role in reducing emissions and even fuel consumption. Aftertreatment systems eliminate pollutants following their formation within the cylinder; certain solutions could be described as 'pretreatment systems' as they prevent the formation of pollutants in the first place. Refrigerated turbocharging is not a new idea, but it was only recently that it became possible (at least theoretically) to apply to automotive applications. (It can also be used off-road on machinery and similar applications.) The turbo expander's role is to cool the charge air drawn into the intake system. The turbo cooling system consists of a turbo-expander and an additional charge air cooler. The specific requirements are that it increase (or at least maintain) the density of the intake air, but substantially reduce the temperature of the air. The two-step charge air cooling system permits these goals to be achieved (Figure 17). The effect of the resulting temperature drop can be to improve various combustion and emission parameters at high load, which can mitigate some of the negative side-effects of downsizing. To facilitate the development of a charge air cooling system, a one-dimensional modelling was used; experimental results were found to agree well. From a realistic starting model, the new system was added, and full load power curves simulated. Next, a 3-D model was employed to further investigate the effect on combustion and in-cylinder processes. A limited time range was considered – from the closing of the intake valve to the opening of the outlet valve. Fuel spray and temperature distribution was modelled separately to complement the first models. Operation of the system is self-sustaining, simple and effective – the intake air enters the cylinder at a low temperature and a managed pressure. Heat obtained by reducing the temperature of the charge air provides up to 18 kW of power to drive the compressor. The benefits are less pronounced at lower loads, as the energy available is proportional to the square of the mass flow. The system uses an air bypass with a sensor and closed loop control to maintain the desired temperature; temperatures drops of up to 60 degrees are achievable. The size, weight and heat rejection of the system are all unproblematic. The main result is reduced NO_x formation – up to around 15%, depending on the engine operating point. A 20% reduction in the soot was also observed, despite the fact that there is normally a trade-off between formation of these two pollutants. This device could be of benefit for future low temperature combustion concepts (HCCI and others). Very highly boosted engines suffer detonation through a process which is not yet well understood, but this system controls the process and keeps operation stable. Other benefits can also be obtained: reduced fuel enrichment (20-30% less at high load), with benefits for fuel consumption and emissions. Testing performed under real-world conditions agreed with simulation studies which had been carried out previously and showed good performance under a range of conditions.

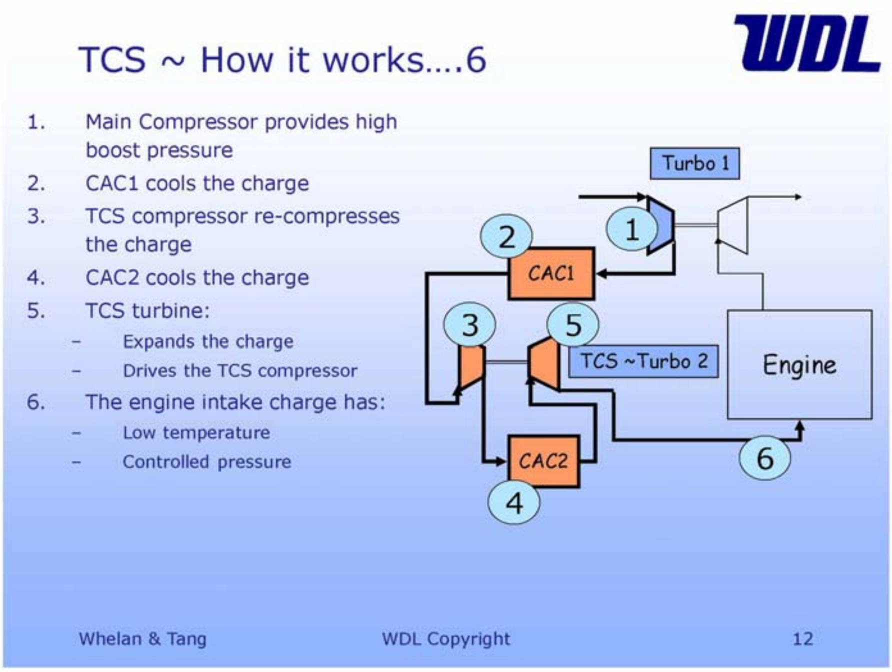

Figure 17 – A concept of WDL's turbo-expander charge air cooling system

2nd day – Session 4 – Particle Number & Particle Size Distribution Measurement Development

Chair: Dr. Bianca Maria Vaglieco (Italy)

Dr. Thomas Krinke (TSI, Germany) – Transient Measurements of Particle Size Distributions from Engine Exhaust

A number of factors affect the formation and properties of particles in automotive exhaust, including fuel, lubricants, engine type, engine management, aftertreatment systems, etc. Monitoring of particle emissions under transient operating conditions (for example: over the NEDC) can provide information on a range of topics relating to emission of particles from engines. Particle size distributions are qualitatively and quantitatively different depending on which metric is used to weight the curve (number, surface area of mass). The UN-ECE PMP particle number counting procedure in fact excludes most particles in terms of number. The measurement process is sensitive to external effects and the sample can change substantially between being sampled and being analysed. Size-selective losses, coagulation, condensation and nucleation can all affect the particle size distributions when the sample is transported; Teflon tubes can even act as particle filters. Dilution and thermal conditioning can reduce these problems, if performed correctly. Particles often behave unpredictably and do not follow the streamlines of the gas in most cases. The particle size-number distribution is a strong function of the temperature at which the thermodilution process is performed. Size distributions also vary by sampling point – the in-cylinder distribution is markedly different from the distribution at the tailpipe (Figure 18). Significantly smaller particles are found in the cylinder. Typical profiles have changed with engine and ATS technology – specific size distributions used to be visible during the NEDC (Euro 3); but these are no longer visible. Various measurement systems are available, for performing steady-state or transient measurements. An EPS system measures everything present in the sample, from tiny aerosols of volatile hydrocarbons to heavy soot agglomerates. Microsoot sensor results can be compared with these results, although the metric measured by the two instruments classes is not the same. Experiments on engines burning hydrogen reveal the contribution of lubricating oil to particle formation, which is of considerable interest in particle formation studies. A nanoparticle surface area monitor can be used to measure surface area via use of a diffusion charger which reports a current proportional to particle surface area. While not called for by the legislation, measurement of particles <23 nm diameter is achievable: current technology permits measurement down as far as 2 nm. In fact, measurement can be performed on “particles” so small that their status as a particle could be questioned, leading to doubts over the accuracy of the “particle” count where very small particles are concerned.

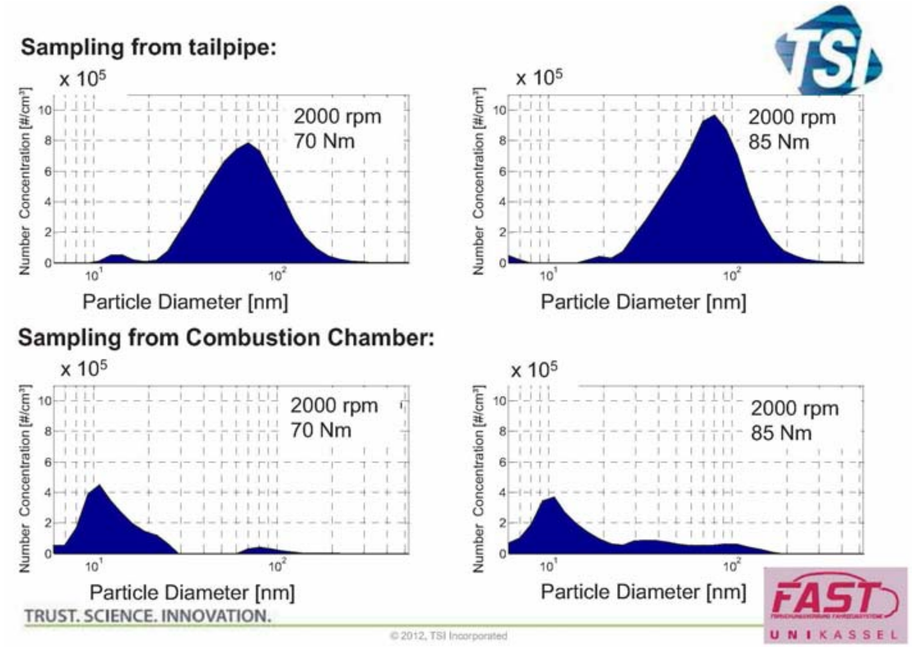

Figure 18 – particle size distributions measured in the cylinder and at the tailpipe

Panu Karjalainen (Tampere University of Technology, Finland) – Vehicle Technologies and Nucleation Mode Particles

Particles present in urban environments come from several key sources. Nucleation mode particles are not legislated directly, but contribute to PM and PN emissions, which are regulated for some engine types. Under real world driving conditions, nucleation mode particles dominate particle number concentrations and their formation is a function of a wide range of variables and parameters (Figure 19). The size profile of the nucleation mode and accumulation mode vary considerably. Controlled experiments can be performed to assess the impact of fuel, lubricant, ATS, driving conditions, engine operating point on particle formation. Alternatively, vehicles can be “chased” on the road to obtain data on their particle emissions. A thermodenuder is the best way to obtain a sample containing no volatiles. Dilution parameters can be fixed such that they replicate the real-world dilution process which occurs in the atmosphere. Interactions between sulphuric acid and water form semi-volatile nucleation mode particles. Different types of particles have different charge profiles. Differences in the profile of particle emissions are observed between Diesel and GDI engines, as well as between engines of different engine size. Reduced emissions have meant that the contribution of the lubricating oil to particle emissions has become greater and greater. Reducing the amount of idling can reduce emissions of certain types of particles, since for light-duty engines non-volatile nucleation mode particles are emitted at low load and idle. Precursors to particle formation can be stored in ATS, and then released, causing a wave of particles to pass through the exhaust system. Metals from the powertrain, oil and fuel supply systems may be at the heart of the cores of non-volatile particles. Many particle types which are known to exist in real-world exhaust emissions are not captured for quantification in the PMP PN measurement procedure. Multiple questions and areas of investigation regarding nucleation mode particles and their formation, including the origin of non-volatile cores, the impact of SCR systems, direct injection petrol vs Diesel and atmospheric processes and the ultimate fate of the particles. It is difficult to say if any kind of particle poses no threat to human health – very small particles are generally viewed as not particularly damaging, but exhibit very high penetrating ability.

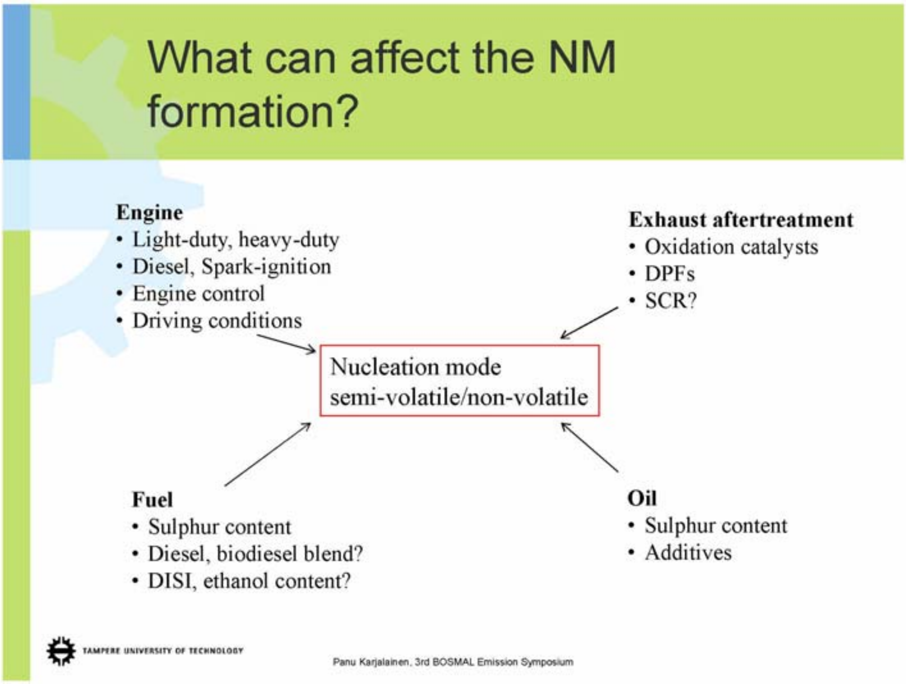

Figure 19 – Factors affecting nucleation mode particle formation

Dr. Bianca M. Vaglieco (Istituto Motori-CNR, Italy) – Particle Size Distribution in Internal Combustion Engine Fuelled with Different Biofuels

The particulate pollution emitted by internal combustion engines consists of a mixture of different types of material, depending on various factors (fuel, engine type, temperature, etc). Different types of combustion (low temperature, standard Diesel, HCCI) generate particles of different size profiles. While particles are generally non-spherical, they are treated as perfect spheres to simplify analysis and make it possible to speak of a particle diameter. Fuel pyrolysis products undergo a range of processes to grow in size from the size of a single organic molecule to coagulated soot particles 20-30 nm in diameter (Figure 20). Comparisons between different measurement systems and different sampling points provide information on particle formation, characteristics, etc. A series of tests was conducted to investigate particle formation in engines using conventional and alternative fuels. Both in-cylinder and exhaust studies were carried out. The presence of a DPF and the injection pressure and timing all significantly impacted the particle size distribution. SI engines are generally considered to be clean, but their particle emissions have been studied. A TWC changes the size profile in the range <30 nm. A bimodal distribution was observed in one study. The first peak is transparent to some types of light; the second peak corresponds to soot. The first peak appears to be made of organic nanoparticles; recent work has shed some light on their formation and characteristics. It is sometimes stated that using ethanol in SI engines is good regarding particle emissions, but this may be in doubt. Pure ethanol was tested and found to produce lower numbers of particles overall, but greater number of smaller particles. Regarding petrol-ethanol blends, there are benefits and penalties, and some evidence of a trade-off. Engine warm-up also has an effect – the evolution of the temperature of the engine coolant is reflected in particle emission trends. Biofuels age very quickly compared to fossil fuels, and this too is reflected in the particle emissions. From the particle point of view, the impact of biofuels (ethanol blends, biodiesel, ethanol in Diesel) remains to be fully evaluated. Another topic of interest and considerable relevance for the near future is the development of PM aftertreatment system for direct injection petrol engines – practical, effective solutions will have to be developed, thanks to the demands of forthcoming legislation.

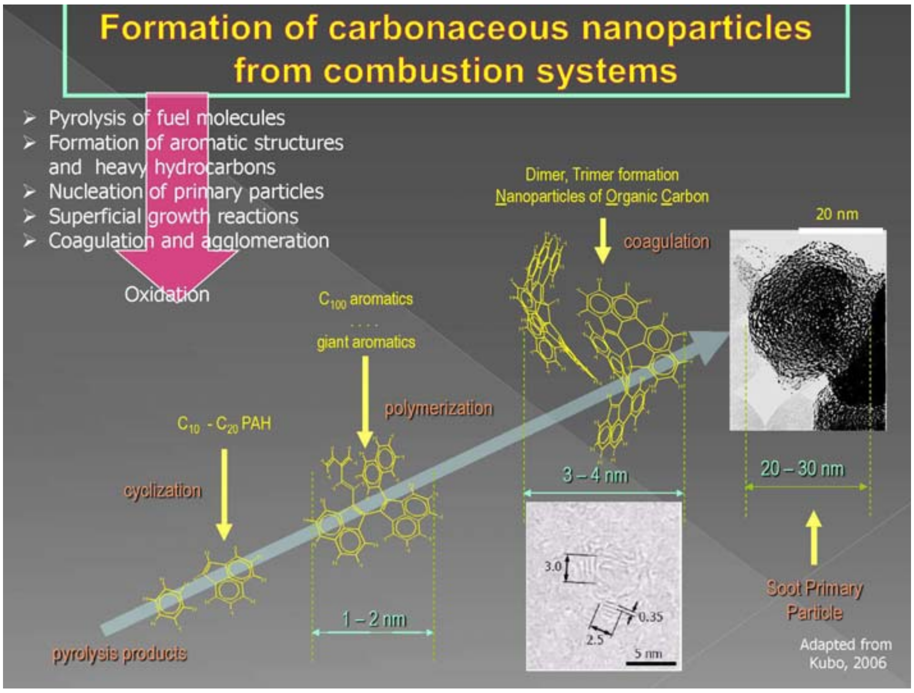

Figure 20 – The chemical and structural evolution of a primary soot particle in an ICE

Session 5 – Fuel and Engine Oil Development

Chairs: Professor Jerzy Merkisz (Poland) & Professor Miroslaw Wyszynski (UK)

Roberto Peirano (Petronas Lubricants, Italy) – Racing Fuels Pre-Screening Test Bench Methodology

While most fuel development work has focussed on reducing emissions and complying with fuel quality regulations, work also continues on development of fuels for motorsport applications. For such projects, the aims are to maximise power output, while maintaining fuel consumption at reasonable levels. (Reducing fuel consumption eventually leads to a positive impact on vehicle weight.) Pre-screening using modelling and testing is necessary to identify viable candidates. The process is required to be quick and cost-effective. A base ECU calibration was used, and later optimised for the racing application (very high load), with testing conducted on both calibrations using a methodology developed in-house for this very purpose. A motorcycle engine was selected due to its high rotational speed and high piston speed. A fuel matrix was constructed and populated with fuels with different physicochemical characteristics (density, oxygen content, octane rating, etc), in order to assess the impact of these properties on power output and fuel consumption. While some evidence of trade-offs was observed, a number of candidate fuels showed power increases approaching 2 kW and appreciable reductions in fuel consumption (Figure 21). Comparing the reference fuel and various candidate fuels, some evidence of trade-offs was observed. A range of combustion parameters obtained from a combustion indication system were also used to assess the performance of the candidate fuels. It was determined that the test methodology and the motorcycle engine selected for the prescreening study were appropriate tool s for rapidly determining the suitability of various candidate fuels. Thanks to the data collected during the prescreening study, a limited-number of high-performance fuels can be selected and subjected to further testing.

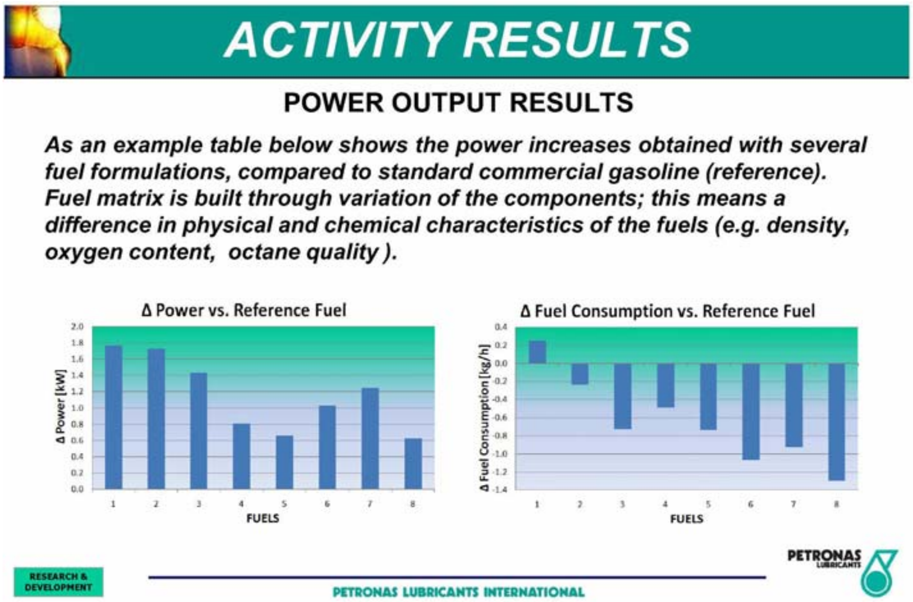

Figure 21 – Power output and fuel consumption results, presented in comparison to the pre-screening programme reference fuel

Knut Skårdalsmo (Statoil Fuel & Retail, Norway) – Evaluation of a Premium Diesel Deposit Control Additive

Since deposits have an adverse affect on the operation of Diesel engines, there is considerable interest in the use of additives in Diesel fuel which remove such deposits and prevent further formation. However, as with the addition of any additive to the fuel, testing must be performed to determine what the deposit control additive do to the engine, its emissions and its fuel economy. Common rail Diesel engines are very sensitive to deposits in the injectors and standardised tests exist to measure the impact of additives on power output. A test programme was designed by Statoil and exceuted at BOSMAL Automotive Research and Devleopment Institute Ltd. The aim was to perform the test on European vehicles, measuring emissions and fuel consumption as well as power. The NEDC drive cycle was used to have meaningful emissions results and the road phases testing used a variety of driving cycles to give data on the mid- to long-term fuel consumption benefits and any possible drivability penalties. There was evidence that the additive was effective – reduced emissions were observed (Figure 22). However, once the engine has been cleaned, it cannot be cleaned any further, and no further changes will be observed due to the effect of the deposit control additive. Deposit debris combusts, and this increases soot emissions, but eventually all of it is removed and soot returns to normal levels. The overall fuel consumption reduction observed was on the order of 1% - a significant achievement, and a finding of interest, particularly for fleet operators, but also for individual consumers (albeit on longer timescales). Most of the test cars showed higher power and torque results, with the exception of one vehicle. This is concordant with the action of the additive in removing deposits and improving the injection process and overall engine efficiency. The increases in power and torque were judged to be detectable by the average driver. The fuel consumption benefits were similar for both base fuels tested. The full-load power and torque curves also showed visible differences. Power loss (dirty up and clean up) tests were also performed (using the well-known DW10 procedure). After 32 hours, the power loss approached 4%; the additives returned power output to close to its original value within around 8 hours, and the power value finally stabilised at a power loss value of around 0.5% (not detectable by the driver). The DW10 test appears to be a good test procedure for evaluation of this additive type, and the additive was shown to be effective at preventing the zinc in the doped fuel from forming deposits. It was shown that removing engine deposits improves emissions, fuel consumption, power and torque (at least once the system has stabilised); however, the relatively low statistical significance of the results must be considered, given that changes are on the order of 0.5-3%.

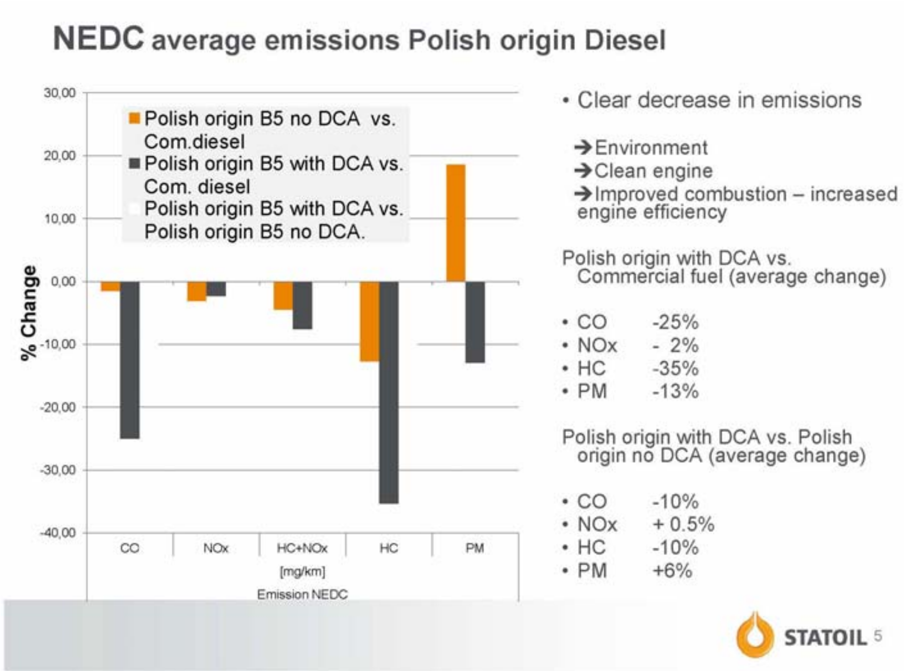

Figure 22 – Emissions benefits gain through use of the deposit control additive

Professor Miroslaw Wyszynski (University of Birmingham, UK) – Speciation of Gaseous Emissions, Solid Particulates and Deposits using GC-MS and TGA-GC-MS

Speciation is important to gain data on the emission of individual hydrocarbons, as their toxicity and status as carcinogens varies from compound to compound. Other compounds (such as toluene) are not carcinogenic, but are of interest due to their propensity to participate in reactions which produce other hydrocarbons. A single-cylinder engine was set up to perform measurements, with a gas chromatography/mass spectrometry unit employed to provide hydrocarbon speciation data. This setup revealed a range of hydrocarbons in the exhaust, including simple alkanes, iso-alkanes, aromatic compounds and some larger molecules. Repeat measurements performed with mixtures of various biofuels revealed substantial changes in the exhaust gas hydrocarbon speciation. Concentrations varied significantly according to the fuel used. The higher of the two injection pressures tested also lead to reduced emissions of every hydrocarbon species. Interestingly, significant amounts of toluene were detected for a fuel with zero toluene content, raising questions over the origin of heavier hydrocarbons. An isooctane-toluene blend was tested; the range of detectable species in the exhaust was very limited for this fuel type. Petrol-ethanol blends up to E30 were also tested, and the results were judged to be favourable, with reductions in the concentrations of all species identified, particularly toluene, although the magnitude of these reductions depend strongly on load. Higher ethanol blends cause emissions of certain hydrocarbons to almost disappear. A speciation analysis conducted on standard petrol, a petrol blend containing 10 % ethanol and a blend containing 10 % dimethylformamide revealed the blended fuels caused somewhat lower emissions of a wide range of hydrocarbons (Figure 23). Thermogravimetric analysis can be used to perform a analogous procedure for PM collected on filters. Different weight loss profiles were obtained for PM produced by a CI engine tested using RME and ULSD fuels. A sample of the stained filter is heated in an inert atmosphere and then exposed to an oxidising atmosphere, all the while being monitored for mass loss, leading to the creation of a characteristic thermal mass loss profile. Very different profiles were obtained for tallow-based biodiesel and standard Diesel, suggestive of markedly different hydrocarbon speciation on the filter. However, the methodology is still under development, and there remains room for improvement. One of the main problems is dealing with very small samples – a few mg, nothing more – although the method appears to generate meaningful results. The NIST database was used to identify individual hydrocarbons in the PM material. PAH were also detected in the PM material and this is an important area for future investigations.

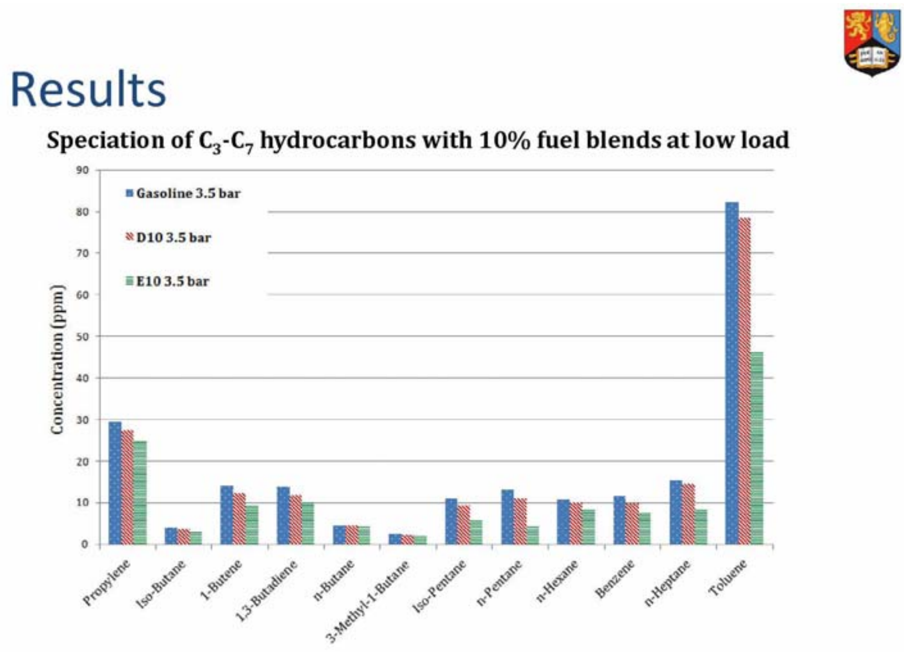

Figure 23 – Hydrocarbon speciation for three fuel types tested at a single load point

Zdzislaw Cieslikowski (Orlen, Poland) – Is LPG really Competitive to Petrol?

LPG is currently the most widely-used alternative fuel for ICE. In 2010, some 2.5 million vehicles in Poland were equipped to use LPG, serviced by around 6000 LPG filling stations – 2.4 stations per thousand vehicles, although this ratio has dropped rapidly as many smaller station which offered LPG have had to close. Still, the fuel remains widely available in Poland (and in many other countries). LPG is generally recognised as presenting a range of advantages and disadvantages regarding usage in modern ICE. The advantages range from a high fuel octane rating and improved mixture formation to a broad ignition range; the disadvantages include increased temperatures, reduced power output and reduced energy density. A project was performed to determine the impact of LPG on emissions, durability, performance and long-term cost implications, using third generation LPG supply systems. After accumulating 60 00 km of mileage, inlet valve deposits were some 16 times greater (by mass) for the vehicle running on LPG than the vehicle running on standard petrol. Commercial gasoline contains a range of additives for inhibition of corrosion, deposit formation, etc, but these are completely absent from LPG. When using LPG, heavy deposits must generally form from the lubricating oil. (However, low-quality imported LPG may contain impurities including hydrocarbons from pumps, etc.) Volumetric consumption of LPG was found to be higher – as much as 40% higher at high speeds. Emission of HC was found to be lower at low mileage, but by the time the vehicle had accumulated more miles, this situation had reversed (Figure 24), (due to reduced performance of the vehicle's TWC). Regarding emissions of CO and NOx, emissions were appreciably higher when running on LPG through the mileage accumulation programme. Long-term operation on LPG reduced the effectiveness of the TWC for all of HC, CO and NOx, although it should be noted that the TWC fitted to the test vehicle was not produced for LPG-specific applications. Slightly reduced power and acceleration results were obtained; the power loss measured would be easy to feel when overtaking under highway conditions. The cost of LPG has been consistently lower than that of petrol, with the ratio of the costs of the two fuels remaining relatively constant for the last few years. However, increased costs are incurred related to engine servicing and replacement parts resulting from usage of LPG. It should be remembered that the engine starts on petrol, and only switches to LPG when a certain temperature has been achieved. Fuel economy, savings and engine wear will vary as a function of journey length and the number of times the engine is started each year. Future distribution of LPG as an automotive fuel depends on cost as the main factor.

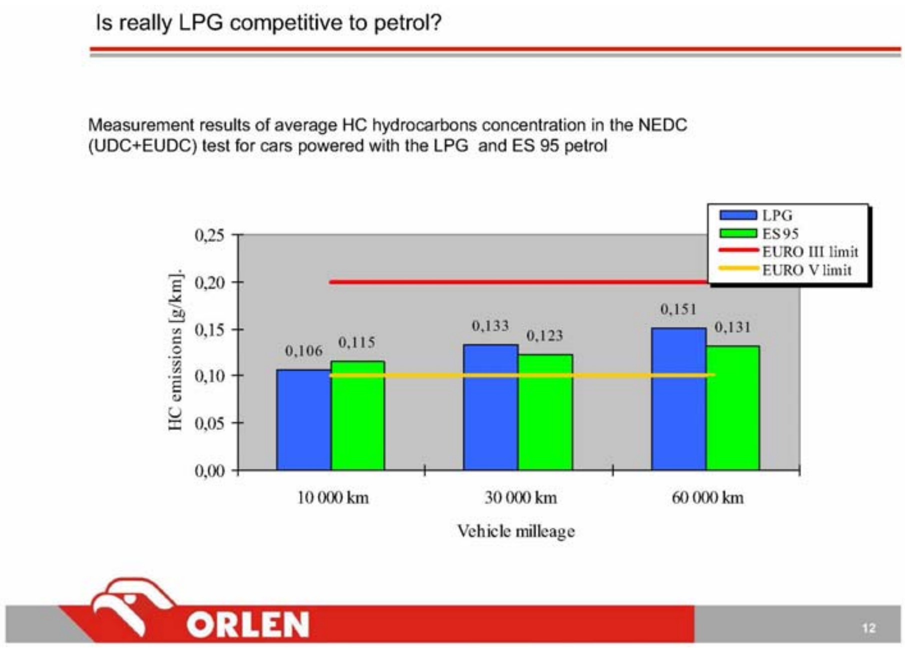

Figure 24 – The evolution of HC emissions from a vehicle running on petrol and LPG over the mileage range 10 000 - 60 000 km

Dr. Mathias Woydt (BAM, Germany) – DOW PAG Engine Oil - Fuel Economy through Engine Oils Based on Polyalkylene Glycols

Demands placed on engine oils have increased significantly, and will be more so in the future. Efforts to reduce fuel consumption and CO2 emissions rely to a certain extent on the ability of advanced lubricants to reduce friction. Poly-alkaline glycol (PAG) was first used in fighter-planes some 60 years ago, as it was found to prevent clogging of the oil pump with soot. In contrast to hydrocarbons, polyglycols contain significant amounts of oxygen. The presence of these oxygen atoms makes the molecule polar, thereby increasing lubricity. One disadvantage is that PAG are miscible with oil, but this can generally be overcome with the use of additives. Depending on the blend and the particular molecules chosen, a wide range of properties can be obtained in the synthetic oils. Combustion of PAGs is ash free (of considerable interest for vehicles featuring DPF systems). The synthetic oil's low temperature viscosity is determined by the backbone of the molecule. Engine bench testing revealed noticeable reductions in entrained friction across the engine map, and further benchmarking tests revealed fuel consumption benefits at 5 of the 6 operating points tested. Road testing in a passenger car revealed that over the entire lifetime of the oil, 0.73-1.48% less fuel would be consumed, depending on the base oil used for comparison. Road testing on a fleet of heavy-duty vehicles revealed a variety of changes: fuel economy increases as high as 5.2 %, very low concentrations of wear metals, power increases and lower operating temperatures (some 8-9 K). Reduced wear was measured for some components. Stribeck curves showed the differences to be substantial. The non-zero shear of the oil surface using PAG is a major difference, and this explains the improved performance at high tribological velocities. Under high shear conditions (where the potential for metal contact and wear is greatest), the dynamic viscosity of the PAG oil was shown to be significantly greater than for other oil types (Figure 25). Other benefits include higher thermal conductivity and better overall heat transfer. Using low friction oils can be a much more cost-effective CO2 reduction measure than reducing vehicle weight – or both could be performed simultaneously to achieve a substantial drop in CO2 emissions. Where polyglycols are present in fuel they can even reduce soot formation, and so any oil burned in the engine does not cause emissions problems. Despite the fact that the current lubricating oil specifications were written for hydrocarbon-based oils, the new PAG oils meet all relevant SAE standards and have the potential to deliver a wide range of harmonious effects. There are various production methods and feedstocks from which to produce PAG, and this innovative synthetic oil type will certainly be of great interest in the near future.

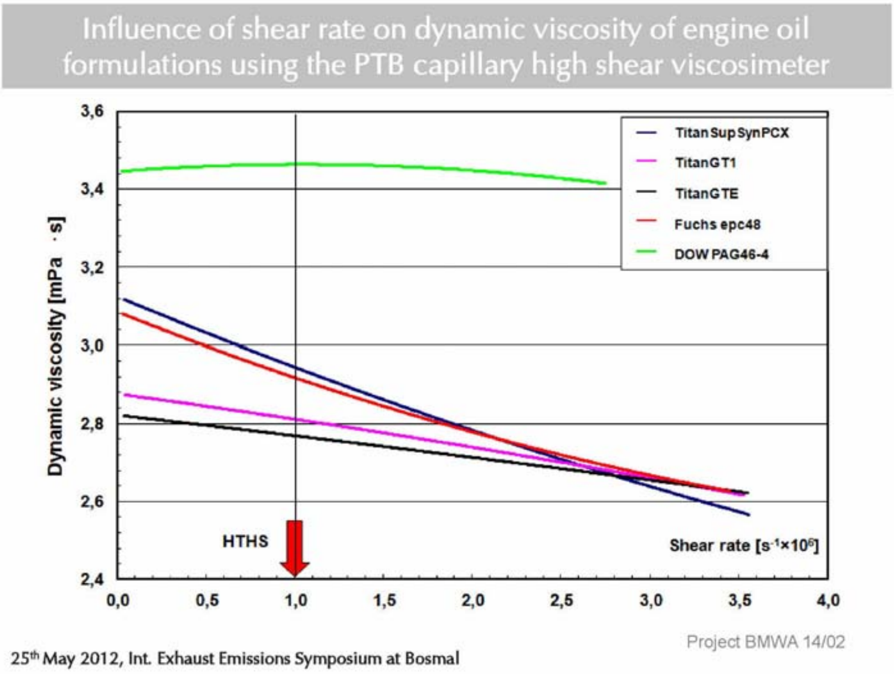

Figure 25 – Dynamic viscosities of a range of oil types under high temperature/high shear conditions

Dr. Massimo Manni (Eni, Italy) – An Environment-Oriented Approach in the Development of Passenger Car Engine Oils

The automotive community today finds itself facing three general goals: achieving high fuel economy, high after-treatment device efficiency and high performance. Engine oil has a part to play in all three of these areas. Some of these goals are in conflict with each other. For example, the use of components that guarantee high performance in terms of wear protection and good engine cleanliness must be reduced to preserve the duration and efficiency of ATS; in addition the use of sulphur containing components (molybdenum dithiocarbamates or dithiophosphates) in the oil helps keep fuel consumption low but must be limited for the same reason. The oil SAPS content (Sulphated Ash, Phosphorus, Sulphur) is important in this area, and reducing the value of this parameter is a necessity to preserve ATS, but requires the study of a new oil technology to maintain high performances in terms of wear protection and engine cleanliness.

OEM interest in revised oils is increasing, with Ford interested in SAE 5W-20 oils as an original fill option for their 3/4-cylinder EcoBoost gasoline engines. Low and ultra low viscosity oils are one of the main solutions regarding the achievement of lower fuel consumption. In vehicles featuring S&S and full hybrid systems the number of engine start-up events is much greater and a low viscosity oil ready to lubricate during re-starts is required. Additives have an important part to play, but they must be chosen with all goals in mind, and some level of compromise has to be reached between requirements which are in conflict. The potential conflict between fuel economy and wear protection deserves close examination (Figure 26). Many existing cars have to use traditional oils. However, the ecological credentials and environmental sustainability of established oil types can be improved, for example: no PCB content, compatibility with ATS, etc. The current limit for oil viscosity is 2.6 cP, according to SAE J300 standards: Updates will be required for the future with new oil categories characterized by lower viscosities. In addition, oil characteristics also have an impact on oil consumption (although it is not the only controlling parameter): the reduction of oil viscosity and the consequent increase of oil volatility could be detrimental for oil consumption. So the oil basestocks must be carefully selected to control the rate of oil consumption. The use of recycled components and molecules of biogenic origin are options for improving the sustainability of lubricating oils are other important issues for future lubricant development: preliminary engine tests have demonstrated good performances in terms of engine cleanliness and oil oxidation stability. Further research will come to focus on individual components in the continuing drive to develop ultra low viscosity oils able to assure good fuel economy and high compatibility with current and future engine-ATS combinations.

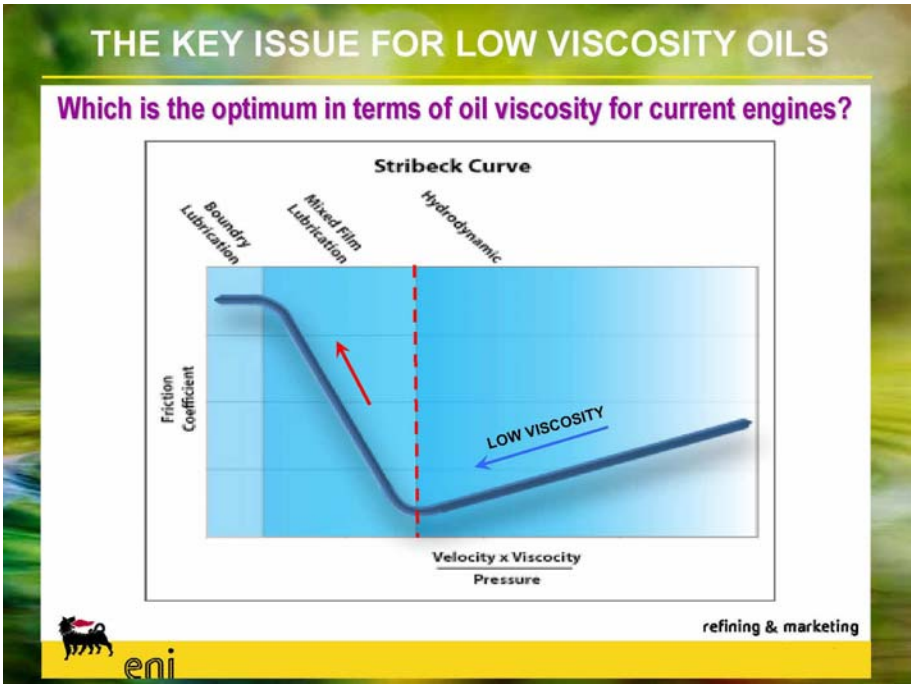

Figure 26 – A qualitative Stribeck curve showing the theoretical optimum viscosity for an engine oil

Written papers (no oral presentation)

Dr. Piotr Bielaczyc, Dr. Antoni Swiatek, Dr. Andrzej Szczotka, Joseph Woodburn (BOSMAL, Poland) – An Analysis of Ammonia Emissions from Light-Duty Vehicles Operating on Gasoline, Liquefied Petroleum Gas (LPG) and Compressed Natural Gas (CNG)

Vehicular ammonia emissions are currently unregulated, even though ammonia is harmful for a variety of reasons, and the gas is classed as toxic. Ammonia emissions represent a serious threat to air quality, particularly in urban settings; an ammonia emissions limit may be introduced in future legislation. Production of ammonia within the cylinder has long been known to be very limited. However, having reached its light-off temperature, a three-way catalyst can potentially produce substantial quantities of ammonia (Figure 27) through various reaction pathways. Production of ammonia is symptomatic of overly reducing conditions within the three-way catalyst (TWC), and depends somewhat upon the particular precious metals used. Emission is markedly higher during periods where demand for engine power is higher, when the engine will be operating under open-loop conditions. The air-to-fuel ratio, cylinder temperature and rate of availability of carbon monoxide and nitrogen monoxide all correlate to varying degrees with ammonia production. A series of tests was performed to study ammonia emissions data from three European passenger cars, using three different fuels, with varying physicochemical characteristics and carbon:hydrogen ratios, namely gasoline, LPG and CNG. All vehicles were tested on BOSMAL's chassis dynamometer over the New European Driving Cycle, with undiluted ammonia quantified directly at tailpipe. Both cycle mean emission factors and second-by-second data were considered. The results indicated a degree of correlation between ammonia emission and demand for engine power, for example upon commencing acceleration and following gear shifts. Emission over the entire driving cycle was found to vary depending on the fuel used, and between the three test vehicles. One vehicle emitted 93 % more ammonia when operating on gasoline than on CNG; the other vehicle emitted 2 % more ammonia when running on LPG than on gasoline. A simple numerical correction implied that the lower carbon:hydrogen ratio was at least partially responsible for the minimal ammonia emissions observed when running on that fuel.

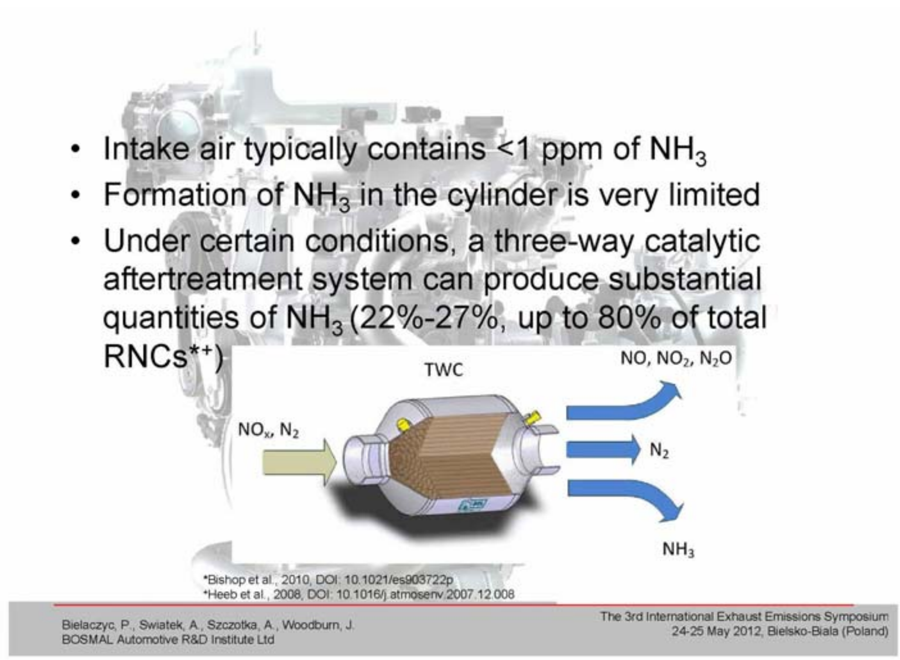

Figure 27 – The flow of nitrogen atoms and NO_x through a TWC, resulting in the formation of compounds including ammonia

Dr. Piotr Bielaczyc, Dr. Andrzej Szczotka, Joseph Woodburn (BOSMAL, Poland) – An Investigation of Different Gasoline-Ethanol Blends' Influence on Performance and Exhaust Emissions from a Light-Duty Gasoline Vehicle

The possibility of using bioethanol blends (mixtures of gasoline fuel and ethanol derived from biomass) of varying strengths in unmodified vehicles featuring gasoline engines is a topic of great interest in efforts to make furl consumption more sustainable and reduce emissions. A series of tests was carried out using different proportions of bioethanol in the fuel (E5, E10, E25, E50 and E85) on the emission of gaseous pollutants, such as: carbon monoxide, hydrocarbons, oxides of nitrogen and carbon dioxide, with testing performed at normal (22 °C) and low (-7 °C) ambient temperatures. All emissions testing was performed on a chassis dynamometer over the NEDC; engine performance metrics were also tested. Tailpipe emission data suggested that modest improvements in air quality could result from usage of low-to-mid ethanol blends in the vehicle tested. In general, blends up to and including E50 were relatively unproblematic; emissions of regulated compounds and CO2 were in some cases substantially lower for ethanol blends higher than E5 (standard European gasoline). This finding has potentially significant implications for air quality scenarios regarding potential greater usage of ethanol blends. However, the usage of two ambient temperatures in this study confirmed previous findings that such emissions reductions are in some cases strongly temperature dependent, and further testing is required in this area. The relative deterioration of emissions performance at low temperature varied from blend to blend (Figure 28), but interestingly the fuel consumption increase was very similar for all four test blends (Figure 28). Overall, no single blend emerged as a clear best or worst performer at either test temperature. Although maximum engine power and torque values for all blends were very similar, it was observed that for the E5 blend, engine power and torque were the highest, whereas for the blend E10 they were the lowest. The maximum power for the blend E10 was some 2% lower (significant at the 95% confidence level) in comparison to results obtained for the E5 blend.

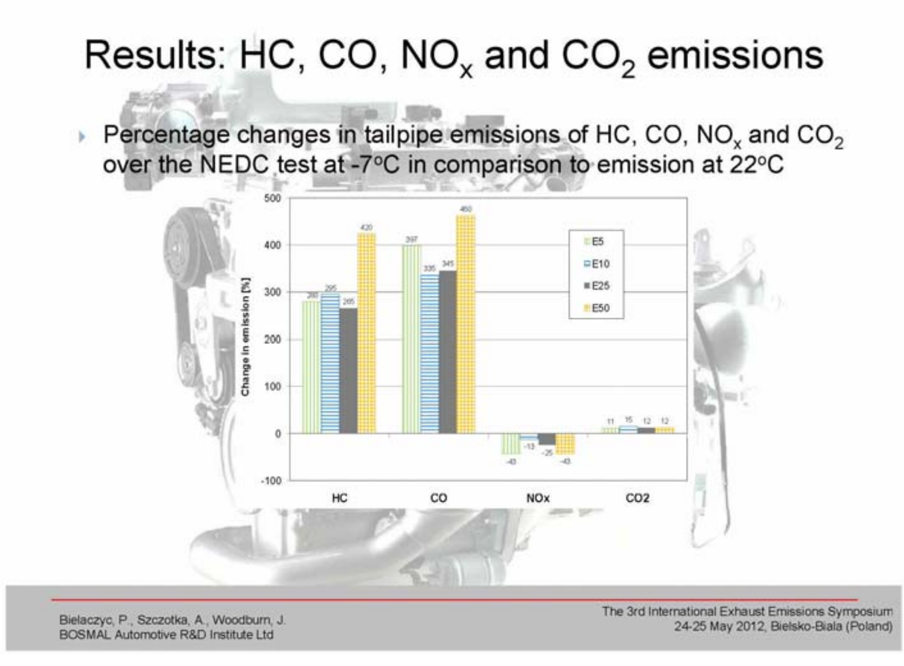

Figure 28 – The flow of nitrogen atoms and NO_x through a TWC, resulting in the formation of compounds including ammonia

Dr. Piotr Bielaczyc, Dr. Andrzej Szczotka, Joseph Woodburn, BOSMAL, Poland - An Analysis of Low Ambient Temperature Conditions' Influence on Excess Emissions and Fuel Consumption from Modern Spark Ignition Passenger Cars

Cold starts are demanding events for spark-ignition (SI) internal combustion engines. Indeed, start-up events are the most fundamental transient events experienced by automotive engines as the numerical values of engine speed and fuel consumption change from zero to non-zero values in a very short space of time. When the temperatures of the engine oil, coolant and the engine block are close to the ambient temperature, start-up can be difficult to achieve without fuel enrichment, which results in significant excesses in exhaust emissions and fuel consumption. In general, the lower the ambient temperature, the more substantial these problems are. Many nations frequently experience sub-zero ambient temperatures, and the European Union (among others) has specified an emissions test at low ambient temperature (-7°C). Passenger cars typically experience one to two cold start events per day, and so both cold starts and the warm up period that follows are significant in terms of exhaust emissions. A series of tests were performed a pool of 19 European passenger cars on a chassis dynamometer within an advanced climate-controlled test laboratory at BOSMAL Automotive Research and Development Institute, Poland. Emissions data obtained over the Urban Driving Cycle by testing at 24°C and at -7°C, are presented for a selection of modern Euro 5 gasoline vehicles representative of the European passenger car fleet. A full modal emissions analysis was also conducted at 24°C and at -7°C over the New European Driving Cycle. Emissions and fuel consumption were substantially higher at -7°C than at 24°C. The results indicated substantial deteriorations in emission performance at the lower test temperature, however, all test vehicle easily me the relevant legislative limits by a wide margin, particularly for emissions of CO (Figure 29). Emissions responses from direct and indirectly injected petrol engines were found to be different. A finding of significant interest was that the CO2 emissions increase at -7°C was relatively modest and significantly smaller than other values reported for research performed on slightly older vehicles.

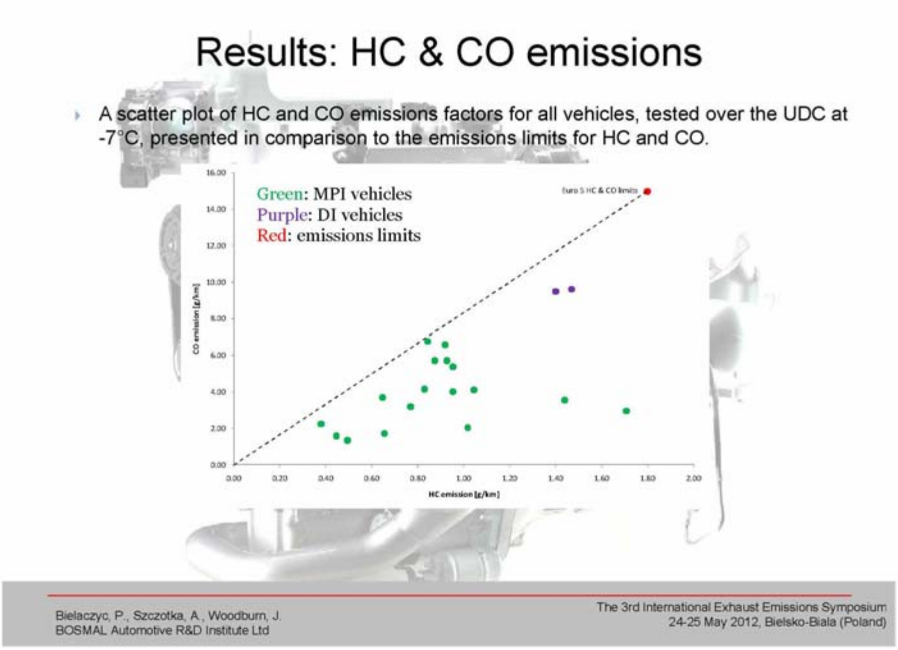

Figure 29 – A comparison of HC and CO emissions results obtained at -7 °C, presented in comparison to the relevant legislative limits

Symposium summary

Professor Jerzy Merkisz (BOSMAL/Poznan University of Technology, Poland)

Professor Jerzy Merkisz, the current chairman of BOSMAL's Advisory & Scientific Boards, concluded the symposium by mentioning certain key themes which had surfaced in the proceeding presentation sessions and offering his own comments on the overall technical message of the 3rd International Exhaust Emissions Symposium. Internal combustion engines have been, are and will be the main solution for transportation for the foreseeable future. However, the ICE concept has certain key existential challenges to overcome; powertrain development is moving the direction of reduced levels of emissions of harmful compounds and CO_2 emissions. Various tools, as described during the symposium, are available to meet these goals. Refinement, improvement and implementation of these devices and techniques for emissions reduction and fuel economy is the current task facing engineers working in the automotive industry.

Conclusions

Presentations delivered at this year's event covered topics of interest to the automotive audience from a variety of standpoints. A theme which surfaced repeatedly was the need to consider systems (engine, fuel, lubricants and vehicle characteristics (e.g. weight)) in context, as integral components of the supersystem (the complete vehicle, the environment and which it operates and its range of operating duties). Events such as the symposia hosted by BOSMAL facilitate and foment inter-disciplinary dialogue between engineers and scientists working in related but distinct fields, which is essential if the aforementioned vision of integrated research, development and technical progress is to be realised. The sheer numbers of passenger cars on the roads globally mean that they have a relatively large impact on the environment, but over time the impact per vehicle has been reduced massively. Current and future legislation will insist on further reductions and there remains a great deal of work to be done in terms of finding, testing, developing, certifying and implementing viable solutions. Emissions of regulated compounds from light-duty vehicles are now so low that in some cases accurate measurement is difficult to achieve. There is now a focus on unregulated compounds and also on emissions during real-world driving conditions. Both these areas of interest have extensive test requirements and represent worthy research directions, which are sure to occupy those working in the emissions world for the foreseeable future.

While operation of surface vehicles is in fact only one aspect of a range of human activities that degrade air quality and emit GHGs, the automotive industry is subject to strict controls and this status is unlikely ever to change. Increasing interest is being shown in air quality issues by politicians, lawmakers and even the general public.

Once again, the annual automotive emissions symposium organised by BOSMAL has proven to be a great success. The social programme organized as an integral part of the conference was once again a highlight of the event and positive feedback regarding the technical and social programmes was forthcoming from participants, both those who had participated in the previous two symposia and those who were participating (and indeed visiting Poland) for the first time.

The proceedings from the 3rd International Exhaust Emissions Symposium have been archived on a CD entitled 'Current and Future Trends in Automotive Emissions, Fuels, lubricants and Test Methods -2012', ISBN: 978-83-931383-2-6. As with the previous two emissions symposia hosted at BOSMAL, a DVD containing video reportage of the event accompanies the proceedings CDROM.

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[1] Bielaczyc, P., Woodburn, J. Global trends in emissions regulation and reduction. Combustion Engines, 3/2010 (142), 3-27, 2010.

[2] Bielaczyc, P. (editor) and 13 co-authors. Global trends in emissions regulation and reduction from the perspective of powertrain and fuel development, Proceedings of the 1st

International Exhaust Emissions Symposium, ISBN 978-83-931383-0-2.

[3] Bielaczyc, P., Woodburn, J. Analysis of current and future trends in automotive emissions, fuels lubricants and test methods, Combustion Engines, 4/2011 (147), 104-118, 2011.

[4] Bielaczyc, P. (editor) and 17 co-authors. Global trends in emissions regulation and reduction from the perspective of powertrain and fuel development, Proceedings of the 2nd International Exhaust Emissions Symposium, ISBN 978-83-931383-1-9.

[5] Mock, P., German, J., Bandivadekar, A., Riemersma, I. Discrepancies between type-approval and "real-world" fuel-consumption and CO_2 values. ICCT working paper 2012–02, 2012. Available online: www.theicct.org

Abbreviations and definitions

ATS	Aftertreatment system
CI	Compression Ignition
CNG	Compression Natural Gas
GTL	Gas-to-liquid
CO	Carbon monoxide
CO_2	Carbon Dioxide
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
EGR	Exhaust gas recirculation
EPA	Environmental protection agency
EU	European Union
FAME	Fatty-acid methyl ester
GDI	Gasoline Direct Injection
GHG	Greenhouse gas
GPF	Gasoline particulate filter
HC	Hydrocarbons
HCCI	Homogenous charge compression ignition
ICCT	International Council on Clean Transportation
LNT	Lean NO_x Trap
NEDC	New European Driving Cycle
NH_3	Ammonia
NO_x	Oxides of nitrogen
PGM	Platinum group metals
PM	Particulate matter
PMP	UN-ECE Particulate matter programme
PN	Particle Number
POC	Particulate Oxidation Catalyst
SCR	Selective catalytic reduction
SI	Spark ignition
UN-ECE	United Nations Economic Commission for Europe
WLTC	World Harmonised Light Duty Vehicle Test Cycle
WLTP	World Harmonised Light Duty Vehicle Test Procedure

Appendix 1 – the Technical Programme of the Third International Exhaust Emissions Symposium

BOSMAL® Bielsko-Biała, Poland

3rd International Exhaust Emissions Symposium and Celebrations to mark BOSMAL's 40th anniversary

The Symposium Programme

Thursday, 24th May 2012

Symposium Opening

- Antoni Swiatek, President, BOSMAL Automotive R&D Institute

Keynote speaker

- Michael P. Walsh, Board Chairman, International Council on Clean Transportation, USA - **Global Trends in Motor Vehicle Pollution Control - A 2012 Update**

Session 1 - Emissions Legislation/Test Methods Development

Chair: Michael Walsh, USA & Piotr Bielaczyc, Poland

- Piotr Bielaczyc, BOSMAL, Poland - **Automotive Emissions Legislation/Test Method Development Over the Last 40 Years and Future Predictions for the Next 40 Years**
- Les Hill, HORIBA, UK - **Recent Developments and Trends in Exhaust Emissions Legislation**
- Wolfgang Thiel, Technical University Munich, Germany - **Measuring Near Zero Automotive Exhaust Emissions - a Big Challenge**
- Christos Dardiotis, Alessandro Marotta, Giorgio Martini, Pierre Bonnel, Monica Tutuianu, Martin Weiss, European Commission, JRC Energy Institute, Italy - **JRC's Contribution to the Revision of the European Type Approval Procedure for Light Duty Vehicles**
- Kurt Engeljehringer, AVL, Austria - **Emission Test and Measurement Challenges on Hybrid Vehicle**

Session 2 - Powertrain Development/Test Method Development/Hybrids

Chair: Giovanni Cipolla, Italy

- Giovanni Cipolla, Politecnico di Torino, Italy - **Euro 7 Emissions Challenge for IC Engine**
- Ignazio Gentile, FIAT/CHRYSLER, FIAT Powertrain, Italy - **Cylinder Head Integrated Manifold on Gasoline Turbo Engines**
- Eike Martini, AVL, Austria - **Emission Calibration Yesterday, Today and Tomorrow**
- David Mauke, EMPA Swiss Federal Laboratories for Materials Science and Technology, Switzerland - **CNG and CNG Hybrid Vehicles: A Potential Concept to Reduce CO2 Emissions?**

Session 3 - Catalyst Technology & Emission Reduction Methods for CI&SI Engines

Chair: Jorge Barata, Portugal & Andre R R Silva, Portugal

- Gerardo Carelli, S. Eckhoff, S. Franoschek, W. Müller, Umicore, Italy/Germany - **Efficient NOx Aftertreatment Technologies for Clean Diesel**
- Silke Jürgens, Albonair, Germany; Toni Kinnunen, Teuvo Maunula, Ecocat, Finland - **Emission Techniques and Related SCR Systems by Ecocat and Albonair**
- Chris Whelan, Wai Chun Tang, WDL, UK - **Design and Development of a Turbo- Expander for Charge Air Cooling**

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BOSMAL

Bielsko-Biała, Poland

3rd International Exhaust Emissions Symposium and Celebrations to mark BOSMAL's 40th anniversary

The Symposium Programme

Friday, 25th May 2012

Session 4 -Particle Number & Particle Size Distribution Measurement Development

Chair: Bianca Maria Vaglieco, Italy

- Thomas Krinke, TSI, Germany - **Transient Measurements of Particle Size Distributions from Engine Exhaust**
- Panu Karjalainen, Topi Rönkkö, Jorma Keskinen, Tampere University of Technology, Finland - **Vehicle Technologies and Nucleation Mode Particles**
- Silvana Di Iorio & Bianca M.Vaglieco, Istituto Motori - CNR, Italy - **Particle Size Distribution in Internal Combustion Engine Fuelled with Different Biofuels**

Session 5 - Fuel and Engine Oil Development

Chair: Jerzy Merkisz, Poland & Miroslaw Wyszynski, UK

- Roberto Peirano, Fausto Alberici, Alberto Colombo, Petronas Lubricants, Italy - **Racing Fuels Pre-Screening Test Bench Methodology**
- Knut Skårdalsmo, Bob Seymour, Åsa Håkansson, Statoil Fuel & Retail, Norway - **Evaluation of a Premium Diesel Deposit Control Additive**
- Miroslaw Wyszynski, Farshad Eslami, Jakub Piaszyk, Tahee Park, University of Birmingham, UK - **Speciation of Gaseous Emissions, Solid Particulates and Deposits using GC-MS and TGA-GC-MS**
- Zdzislaw Cieslikowski, Orlen, Poland - **Is LPG really Competitive to Petrol?**
- Stephen Merryweather, Daniel Zweifel, DOW Europe, USA/Switzerland, Mathias Woydt, BAM, Germany - **DOW PAG Engine Oil - Fuel Economy through Engine Oils Based on Polyalkylene Glycols**
- Massimo Manni, Eni, Italy - **An Environment-Oriented Approach in the Development of Passenger Car Engine Oils**

Symposium summary & closing ceremony

Jerzy Merkisz, Poznan University of Technology/BOSMAL, Poland

Written papers, with poster presentation (no oral presentation)

- Piotr Bielaczyc, Antoni Swiatek, Andrzej Szczotka, Joseph Woodburn, BOSMAL, Poland - **An Analysis of Ammonia Emissions from Light-Duty Vehicles Operating on Gasoline, Liquefied Petroleum Gas (LPG) and Compressed Natural Gas (CNG) - written only**
- Piotr Bielaczyc, Andrzej Szczotka, Joseph Woodburn, BOSMAL, Poland - **An Investigation of Different Gasoline-Ethanol Blends' Influence on Performance and Exhaust Emissions from a Light-Duty Gasoline Vehicle - written only**
- Piotr Bielaczyc, Andrzej Szczotka, Joseph Woodburn, BOSMAL, Poland - **An Analysis of Low Ambient Temperature Conditions' Influence on Excess Emissions and Fuel Consumption from Modern Spark Ignition Passenger Cars - written only**

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