



11<sup>th</sup> VERT Forum

# Technologies and Policies towards Zero-Impact Combustion Engines

March 25<sup>th</sup> 2021



## About the VERT Forum

The annual VERT Forum this years as e-conference is a one-day conference in cooperation with EMPA, the Swiss Federal Laboratories for Materials Science and Technology.

VERT and EMPA. Scientists and practitioners discuss the latest trends of Best Available Technology to minimize health- and climate-impact of combustion engine exhaust.

Cordially invited are members of

- environmental and municipal traffic authorities'
- manufacturers, owners, and operators of buses, HD and LD commercial vehicles, construction machinery
- manufacturers, owners, and operators of vessels, locomotives and airplanes
- public transport, harbor and airport management
- regulatory authorities and research institutes
- manufacturers of emission control technologies
- manufacturers of emission measurement equipment.

The new format of the conference will leave lots of opportunities for discussions, questions,

## Registration

Registration via email to [Kaethi.frenkel@bluewin.ch](mailto:Kaethi.frenkel@bluewin.ch)  
There is no participation fee  
The conference will start at 9 am and last until 6 pm including breaks, panel discussions , Q&A sessions with the speakers.

## e-conference venue

The conference will be together with EMPA on a professional and experienced e-conference platform including service and hotline for any technical problem.  
Registered participants can download the presentations two days before the conference and get the opportunity to contact speakers and participants.

## Technology presentations during break out sessions

For any **interest to become a sponsor** and present during the breakout sessions please contact [volker.hensel@aurigna.com](mailto:volker.hensel@aurigna.com).

Year by year about 150 experts will attend the VERT Participants come from all over the world, e. g., USA, UK, China, Israel, India, Iran, South Korea and China. Talks focus on

- best practice cases in cities and regions from all over the world on retrofit projects, e. g., for buses, construction machinery, heavy-duty and light-duty commercial vehicles, locomotives and vessels
- research projects and the latest scientific findings new regulations
- organizational approaches like low emission zones
- emission monitoring projects and technologies; health and global warming effects, trends and solutions for Small and large machinery. And the first-time virus filtration.

Please find presentations of former conferences and a video about the last event at [www.vert-dpf.eu](http://www.vert-dpf.eu) in the events section. Presentations will be published after the conference.

# VERT Forum e-conference program abstracts

## Dear VERT Members and others it may concern

Over the past decade the international VERT Association has consciously worked to increase awareness of verified emission reduction technologies with specific emphasis on best available technology for particulate filtration and NOx abatement for diesel engine applications. It is now widely accepted that particle emissions in all sizes do not apply for diesel engines alone but for combustion engines in general. VERT are therefore active in development projects highlighting problems and various solutions from small handheld equipment to large stationary & marine applications. VERT have successfully contributed to the introduction of a New Periodic Testing Inspection (NPTI) system to ensure that products and technologies do not only function efficiently during test & validation, but also during normal operation over time. NPTI has not just been developing a scheme checking In-Use compliance, but a validated system to ensure correct testing procedures, protocols and precise operational measuring equipment. This journey of traditional diesel retrofit will continue in close conjunction with other emissions related areas that can exploit the benefits of VERT's exceptional experience.



L. Larsen  
VERT President

## Synthetic renewable fuels – future contributions to and consequences for the global energy system

The de-carbonization of the Global Energy System within a few decades is indispensable in order to keep global warming at maximum 2 degrees Celsius. Renewable primary energy will be a key element of the energy carriers portfolio through both direct (battery electric vehicles) and indirect electrification based on hydrogen and synthetic hydrocarbons. We foresee that renewable fuels will in the long term dominate the sectors of long-haul transport, industry and seasonal storage (power-to-power). Such fuels can be produced by bioenergy (to a limited extent) and mainly through solar-thermochemical processes or electrolysis from solar and wind energy. For conversion to propulsion energy electro-and thermochemical (combustion) technologies will compete, most probably with varying outcome depending on the application. Specifically for combustion engines potentials for further minimization of pollutants are promising as the fuel structure can be designed "freely". Research on new combustion modes and exhaust after-treatment methods will be, however, necessary for near "zero"- environmental impacts.



K. Boulouchos  
ETHZ, Switzerland

## New fuels, new risks – the chemistry and toxicity of synthetic fuels

Atmospheric CO2 levels rise faster than ever, up to 2 ppm or 16 Gt per year. Thus, low- or no-carbon fuels, or synthetic fuels produced from CO2 are the only way to further use our large fleets of combustion engines in a sustainable way. But new fuels bring new risks. The chemistry of alternative fuels and fossil fuels can differ considerably. This requires adaptations of the engine and the converter technology. Oxygenated fuels might decompose to genotoxic and reactive carbonyl compounds like formaldehyde, affecting the overall toxicity of exhausts and their impact on men and the environment. Such risks should be assessed in advance.



N. Heeb EMPA,  
Switzerland

## Taking Cues from Nanoparticle Emission Control and Aerosol Nanotechnology for Antiviral Devices

Our past work with filters for emission control of nanoparticles from internal combustion engine exhaust (which are in the same size range as the coronavirus particles) and their in-situ elimination (by oxidation using functional catalytic coatings) in combination with the theory and practice of Aerosol Nanotechnology has given us inspiration to apply our more than 30-year experience from these areas to the effort against the coronavirus. Current status, applications and future potential of our technologies will be outlined, including among others re-usable, sterilizable filter media with anti-viral properties that can be manufactured locally or even in-house



A. G.  
Konstandopoulos  
APT Lab,  
CERTH, GR

## New evidence of soot particles affecting past and future clouds and climate

Aerosol catalyzed formation of cloud droplets and ice crystals in the atmosphere is of crucial importance to Earth's climate. Yet, these processes remain insufficiently understood. In particular, the contribution of anthropogenic aerosol particles such as soot for cloud formation and climate is largely unconstrained. During their atmospheric lifetime, soot particles undergo atmospheric aging processes, altering their cloud forming potential. Using global climate model simulations that encompass new laboratory findings of ozone-aged soot acting as cloud condensation nuclei and aqueous sulfuric acid-aged soot as ice nucleating particles reveal on the one hand a reduction in the shortwave cooling by anthropogenic aerosols, and on the other, an increased warming in response to a doubling of carbon dioxide.



Z.A. Kanji  
ETHZ, Switzerland

## Sub-23 nm particles – do we need to consider them?

The present number concentration limit with its 23 nm cutoff has been established in the framework of the PMP program for diesel powered vehicles and later extended to Gasoline Direct Injection (GDI) vehicles. Cutoff and the limitation to solid particles have been introduced to allow a stable and reliable measurement. The main goal was to enforce particle filters. In this sense this was very successful. Meanwhile most diesel-powered vehicles have very efficient particle filters. As most of the solid particles, emitted by diesel engines are larger anyways, the cutoff at 23 nm was not very problematic. However, GDI- as well as PFI engines and also CNG fueled engines emit much smaller particles. The size distribution peaks in the range of 10-60 nm. Usually, 20-50 % of total GDI particles are below 23nm, and these are not considered by the current regulation. This led to the discussion, if the 23 nm threshold should be decreased to 10 nm. In the framework of the HORIZON 2020 project 'SUREAL 23' this has been investigated. Results will be discussed.



H. Burtscher  
FHNW,  
Switzerland

# VERT Forum e-conference program abstracts



H.Noack  
UMICORE,  
Germany

## Robust aftertreatment systems for large engines and marine applications

Emission limits for diesel engines in the on-road sector have been tightened greatly since the 1990s. Hence, their relevance for harmful emissions could be significantly reduced using catalysts and filters. As a consequence the introduction of stricter emission limits also for Non Road Mobile Machinery has been pursuing globally during the last decade. Based on previsions, the number of NRMM is expected to see a constant long term growth. While land based applications in North America and Europe below 560 kW make use of well proven aftertreatment concepts from the automotive industry and can rely on the availability of ultra-low sulfur diesel fuels, the requirements and boundaries for Large Engines above 560 kW are somewhat different, in particular in the marine sector. In this presentation general challenges and potentials of aftertreatment systems in the Large Engine segment will be discussed. While focusing on the various system functions that are required under the relevant operation conditions, other aspects such as fuel type, fuel quality and pressure drop are also highlighted.

## Measurement of sub-23 nm exhaust emission particles

There is evidence that specific technologies like PFI and CNG engines can emit significant fractions of sub-23 nm particles. Further, the European Commission has expressed the intention to lower the present cut-off size of 23 nm in order to improve the control of tailpipe particle emission which is likely implemented in post EURO 6/VI regulation. Therefore measuring sub-23 nm particles accurately has become a focus of several current activities. TSI has further optimized how transient particle size distributions down to 5.6 nm can be measured with a fast time resolution of 10 Hz. By using a double stage porous tube thermos-diluter with real-time dilution control, and operating at 10 L/min total flow, losses for the smallest particles can be minimized thus enabling detailed studies for engine states and test cycles. Some of these results will be shown.



J. Spielvogel  
TSI

## Particle number measurements within periodic technical inspections: influence of size distribution and the fleet emission reduction

In this paper, particle number concentration measurements at idle speed for the identification of vehicles with malfunctioned particle filters have been studied. The results from a dedicated measurement campaign indicate that low cost equipment can be used for the identification of highly emitting diesel vehicles.

The effectiveness of under-discussion instrument specifications has been evaluated employing simulations based on measured particle size distributions.

Finally, an assessment of the potential impact of particle number measurements during periodic technical inspections on the fleet emission was performed.



M. Schriefl  
AVL

Finally, an assessment of the potential impact of particle number measurements during periodic technical inspections on the fleet emission was performed.

The corresponding results demonstrate that the enforcement of these measurements can reduce the overall particle emissions of the actual fleet by more than 80%

## High emitters dominate PN emissions of petrol LDV fleets – an urgent problem

In Mexico City, Nanoparticle (NP) emission measurements from Gasoline Light Duty Vehicles (LDV) have been implemented since 2018. These measurements have been carried out using 115 TESTO equipment's in 55 Emission Verification Centers, during the inspection and maintenance process. PN emissions were measured together with other air pollutants using a shaft dynamometer in a short cycle at 25 km/h /50% and 40km/h/ 25% of load. Every vehicle registered in Mexico City has to compliance this test twice a year (more than two million vehicles). The results showed that more than 15% of the vehicles measured presented PN emissions greater of one million P/cc. Therefore, this issue is an urgent problem for the assessment of air pollution in megacities.



C. Dominguez  
Manjarrez  
GESSPA, Mexico

## Emission Technology of non-road mobile machinery in EU and other markets

Since years the objectives of engine development are given by the regulations limiting pollutants emitted by diesel engines. Although it started later for non-road than for on-road, successive reductions of the limit-values did bring the non-road engines to the same level as HD on-road vehicles. This convergence of regulatory requirements logically leads to the convergence of applied technical solutions, where the non-road sector could benefit from synergies although on-road vehicles have the advantage of higher production volumes. This model, however, is unfortunately limited by the specifics of the globalized market for non-road mobile machinery. Increasingly stringent anti-pollution standards have shifted the complexity from the engine towards the exhaust after treatment system. Therefore, the new challenge will be to simplify and increase the reliability of these systems in the interest of the end user. As the engines themselves become simpler, the robustness and reliability of the entire exhaust aftertreatment system is the dominating challenge, since legal inducement can stop a machine working in case of simple failures like sensor damages.



F.Jaussi  
Liebherr;  
Switzerland

# VERT Forum e-conference program abstracts



J. Czerwinski  
AFHB/VERT,  
Switzerland

## Handheld Machines Network HaSMaNet - contributions to the occupational health protection

Handheld Machines Network (HaSMaNet) was established in 2011 as a knowledge exchange and a discussion group between authorities, industry and academia. Different useful inspirations and activities were performed since the foundation of HaSMaNet. The presentation explains the problems and challenges of HaSMa concerning emissions reduction, shows some technical results, gives perspectives of further activities and suggests including all small non-road machines in the scope of the activities.

## Regulatory limits for ocean vessels

While there are different ways to address the emission reduction targets within the maritime industry, there is no doubt that to meet those new targets; an introduction of new fuels to propel vessels in the future is required. The challenge that the introduction of new fuels brings, is one that needs a lot of attention and focus. Creating and testing new fuels and delivering a proof of concept, is challenging enough, getting the fuels that could be a viable alternative to be available at the volumes and at the multiple ports that would be required to replace traditional fossil fuels, is a more complicated task. As we are already experiencing with LNG, developing the logistics capabilities to deliver it on mass quantities and at multiple ports, is taking time and a significant investment, we should use this as a baseline to understand what lies ahead in terms of time and investment. Planning and engaging in this part of the challenge early on is very critical to achieving the emission reduction targets that, at the moment, seem very far into the future.



C.G. Torres Padilla  
BUNKER-Holding,  
DK

## First Global Regulatory Limits for Aircraft Engine PM and PN Emissions

Emissions from aircraft gas turbines are regulated with global standards. Presently regulated are emissions of oxides of nitrogen (NO and NO<sub>2</sub>), carbon monoxide, total unburned hydrocarbons and smoke (a non-visibility criteria for emission plumes). Substantial development work for new aviation particle emission standards has been done in Switzerland in collaboration with international partners and expert groups from SAE and ICAO. The international activities culminated in the first global measurement standard for non-volatile particle mass and number, published in ICAO Annex 16 Volume II, applicable to all in-production engines from 1.1.2020. Government bodies and engine manufacturers made huge efforts to establish a particle emissions performance database for many of the current and most recent engine types, which was key to develop regulatory limits. In February 2019, the ICAO Committee on Aviation Environmental Protection (CAEP) adopted the first global regulatory limits for non-volatile particle mass and number emissions, which will be applicable for new engines from 1.1.2023.



T. Rindlisbacher  
BAZL Bern,  
Switzerland

## The pros and cons of SCR&DPF retrofit in German Low Emission zones

Presentation of the German retrofitting project for public transport  
- The case for SCR retrofitting in in-use public transport  
- Successful case studies

The importance of backpressure and exhaust temperature. Furthermore presentation of governmental retrofit programs for cars, heavy duty vehicles and buses. Berlin has started the program to retrofit public transport with SCR systems and demonstrated reduction of NO<sub>x</sub>-emission under real life operation conditions by 75 % in public buses. In addition programs to retrofit SCR and particulate filter have been performed for passenger ship and refuse collection vehicles, which showed reliable results for vehicles of 3,5 to gross vehicle weight. Emission Technology of non-road mobile machinery in EU and other markets:

## Vehicle Upgrade Solutions for Clean Air in Emission Hot Spots

Retrofit is nowadays often considered as an old hat, as it has started more than 30 years ago to remove soot emissions from older equipment in operation. Retrofit, or more precisely, "upgrading" stands for the modernization of diesel vehicles in service, which can be upgraded to reach compliance with even highest ambient air quality standards. This presentation provides an overview and insight into some of the latest technical developments and best practice examples, certification schemes, investments and efficiencies. It is also an appeal and recommendation to all stakeholders, authorities and decision makers to implement upgrading as one of the best interim solutions in air quality plans, in particular in terms of implementation time and money.

## Introduction in the Netherlands of the PTI particle number test at low idle in 2021 to check DPFs

In November 2019 the regulations were published in the Netherlands to make it possible to check diesel particulates filters (DPF) with a particle counter. As a result of this, this test has become available for roadside inspections by the police and for inspection stations of the Dutch Road Vehicle Authority RDW starting from 1 January 2020. Next step is to make the particle test for DPF's mandatory for the PTI of diesel cars. The regulations for this are now being prepared. Various manufacturers are working on the development of a PTI particle counter. Instruments can now be offered at the Dutch Measuring Institute NMI for type approval. Target date for introduction of the PTI particle test in the Netherlands is 2021.



V. Schlickum  
UVK Berlin,  
Germany



H. Borgmeier  
HJS, Germany



L. Zuidgeest  
Ministry,  
The Netherlands

# VERT Forum e-conference program abstracts



J. Demuyck  
AECC, Belgium

## Low emissions measured on modern vehicles

European Union legislation on light-duty vehicle emissions has undergone major changes in the last years with the introduction of RDE and WLTP. The gap between diesel vehicle emissions in laboratory tests compared to those in use has been addressed and modern diesel technology demonstrates low emissions while driving on the road. The objective of the work presented is to further show low diesel NOx and particulate emissions capability across a wide range of operating conditions, from in the city up to on the motorway. To achieve the objective, a combination of deNOx technologies was implemented on a mild-hybrid diesel passenger car together with a Diesel Particulate Filter. Results on the road show consistent low emissions over the wide range of driving conditions. Tests on renewable fuels, e.g. HVO, to reduce the carbon footprint on a Well-to-Wheel or Lifecycle basis, show there is no negative impact on pollutant emissions.

## EU towards Post-Euro VI/6

The first European emission legislation appeared in the 1970's and since then many steps have been made in order to render vehicles cleaner. Euro 1 to 6 for light-duty vehicles and Euro I to VI for heavy-duty ones have brought a drastic reduction of pollutant emissions from road transport, accompanied by a significant increase in legislation complexity. However, the reported emission performance at the lab-based certification stage was not reflected in real driving conditions, leading to the introduction of the RDE test procedure. The post-Euro 6/VI legislation aims at ensuring that vehicles remain as clean as possible, in terms of a wider range of exhaust gas species, under all driving conditions and throughout their entire useful lifetime, tested and monitored within a less complex, but most effective, framework

## Requirements for Post EU VI/6 Emission – the DUH-perspective

In spite of more and more detailed emission regulations the gap between the emissions at the laboratory test and real world measurements grew in the past. The cost for the certification test went up. The focus should be in the future on enforcement, not to lower the emission limits. The question of durability should be more in the focus.

## CALAC+ in Latin America and the Nanoparticle Conference in Mexico City 2019

The Climate and Clean Air in Latin American Cities (CALAC+) Program has been working in Bogotá, Mexico City, Lima and Santiago, building the capacity of decision makers and stakeholders through knowledge transfer and exchange of successful experiences in introducing cleaner urban transport – in terms of soot and other air & climate pollutants – and addressing off-road machinery's decontamination. Among numerous virtual and face-to-face events that have been facilitated last year, one of the most relevant was the 1st Latin American Conference on Nanoparticle Emissions in Internal Combustion Engines, held in Mexico City in October 2019. This must be a top priority, considering that air pollution is the main environmental health risk in the Americas, with costs associated to externalities in the range of 2 - 4% of developing countries' GDP.



A. Dimaratos  
Aristotle  
Univerity, Greece



B. Lang  
Swisscontact,  
Switzerland

## DPF Retrofit for HDV in Low Emission Zones, for construction and railway in Israel

During the last five years Israel has initiated plans to reduce particle emissions from transportation. New regulations had made Israel a nationwide Low Emission Zone (LEZ) for diesel buses and trucks under emission standard Euro IV. Last year the city of Haifa started operating a LEZ, banning small trucks, and commercial vehicles under emission standard Euro 4. Jerusalem started operating a similar LEZ for the city center as of January 2020 that will be expanded to the entire city by mid-2020. The government is subsidizing filter retrofits and provides grants for early scrapping with more than 60 million Euros. During the last 3 years some 6,000 older buses and trucks were retrofitted with a DPF. The Israeli government is working towards additional particle emission reduction from diesel vehicles, construction machinery and trains.



A. Zalberg  
SVIVA, Israel

## New Approaches to Vehicle Emissions Inspections

This lecture covers the findings from the first month of vehicle emissions data collected using the parSYNC® iPEMS under the 3DATX sponsored PTI Trial supported by CITA. The data were collected by OPUS at their Borås, Sweden site. The current PTI test protocols and emissions checks, CO for petrol and smoke opacity for diesel, do not have the capability to measure particle number (PN) and oxides of nitrogen (NOx) emissions from current technology vehicles. As a consequence, the current PTI program is unable to identify PN and NOx high-emitters. It is therefore important to update the PTI test, and the use of integrated PEMS (iPEMS) solutions in a new PTI procedure (NPTI) to achieve this is an appealing solution. At the Borås site, an engine idle PN test and two different NOx tests (one dynamic acceleration test and one stationary high idle test) are being performed on a growing number of vehicles. Initial findings are promising, with high repeatability for individual vehicles and a wide range of results between vehicles, indicating good sensitivity of the equipment and protocol to vehicle emission levels. As the number of vehicles tested increases, 3DATX will further the investigation into the effectiveness of the protocol and be able to assess thresholds for pass/fail criteria.



G. S. Sandhu,  
3DATX, USA

## VERT-research projects and worldwide market support for air quality

Since

1993 VERT has been a pioneer in the field of emission elimination from internal combustion engines. The introduction of the particle limit value into EURO 6/VI, NRMM Stage V and the current introduction of vehicle testing with particle number measuring devices (NPTI) in the field are only examples of the global influence for best available technologies. The presentation will give an insight into the current worldwide activities that have been initiated on the basis of VERT criteria.



V. Hensel  
VERT, Germany

## Information for Attendees

The VERT Forum on March 25<sup>th</sup> this year again is organized in cooperation with EMPA, and this year as a **virtual conference**.

We already have over 200 registrations up to now (March 10<sup>th</sup>) and expect more to come.

The **technology** we will use is based on **Zoom Business** and limited to a certain number of participants.

**Therefore, please register as soon as possible.**

We recommend a **minimum internet bandwidth of 16 Mbit download** so that everything runs "smoothly" on your computer. You can check this at: <https://speedof.me>

We have decided that **all speakers at the VERT Forum will present their presentation live**.

We are convinced that this procedure supports the exchange character of the VERT Forum more than pre-recorded videos.

There is an opportunity for you to **actively participate in the discussions** and to **interact with the speakers**.

Please take advantage of this opportunity and be part of a lively and active event.

The event itself will **NOT be recorded**.

**Presentations are available 2 days in advance for registered attendees.**

A **telephone hotline** will be available on the VERT Forum day itself for the attendees in case of any problem.

**Registered attendees** will receive approximately **one week before the conference the web link**.

We offer an alternative dial-in number including the details of the conference.

In addition, attendees will receive a **detailed description of the process, how to join** and how to interact during the conference.

**For all technical questions in advance, please contact:**

[office@vert-dpf.eu](mailto:office@vert-dpf.eu)

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**Become a Sponsor, present your technologies and discuss with the attendees during the breakout sessions**

For more information, please contact [volker.hensel@aurigna.com](mailto:volker.hensel@aurigna.com).