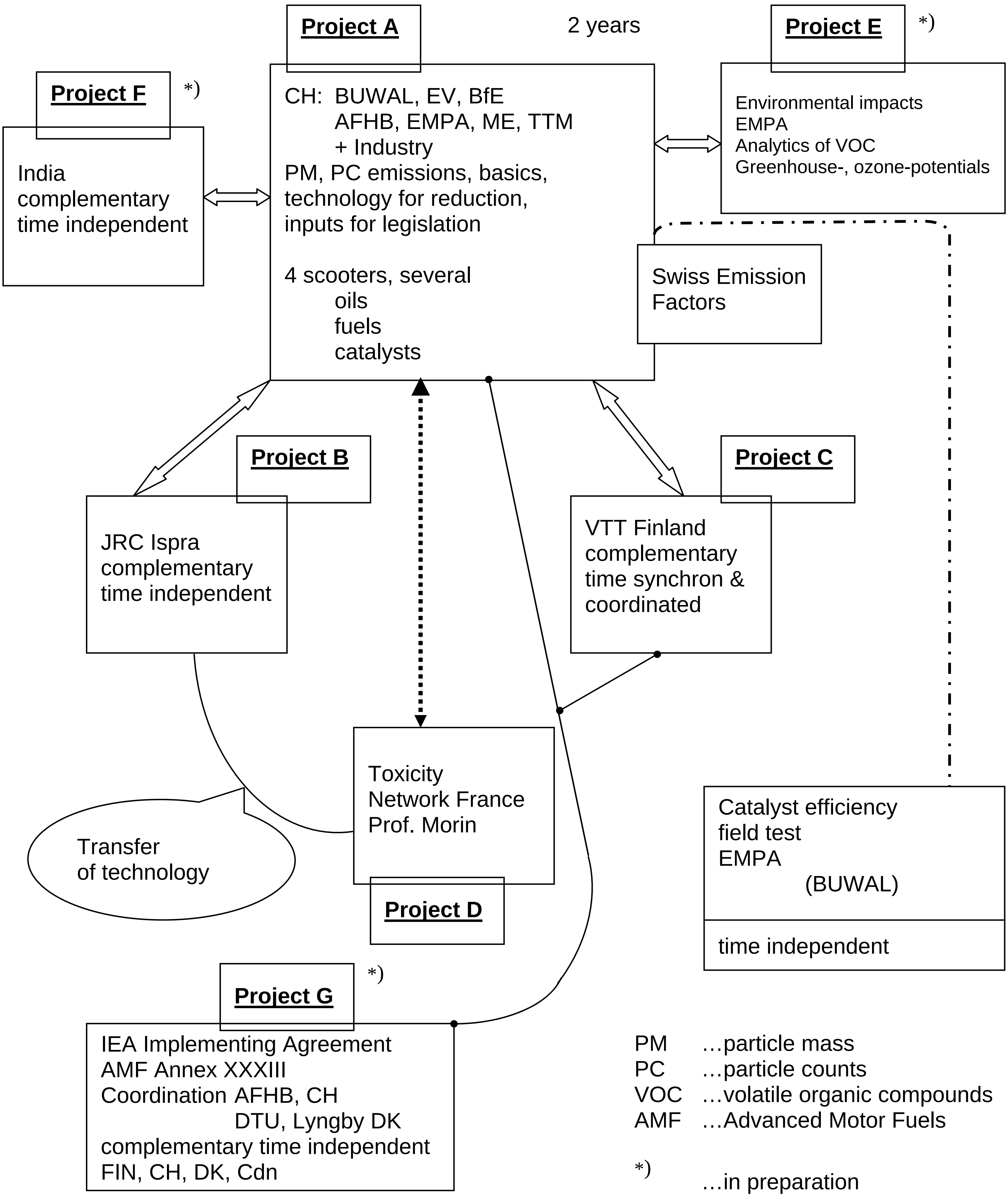
# 2-S Scooters International Projects Network: Particle emissions, toxicology & environmental impacts

November 2004



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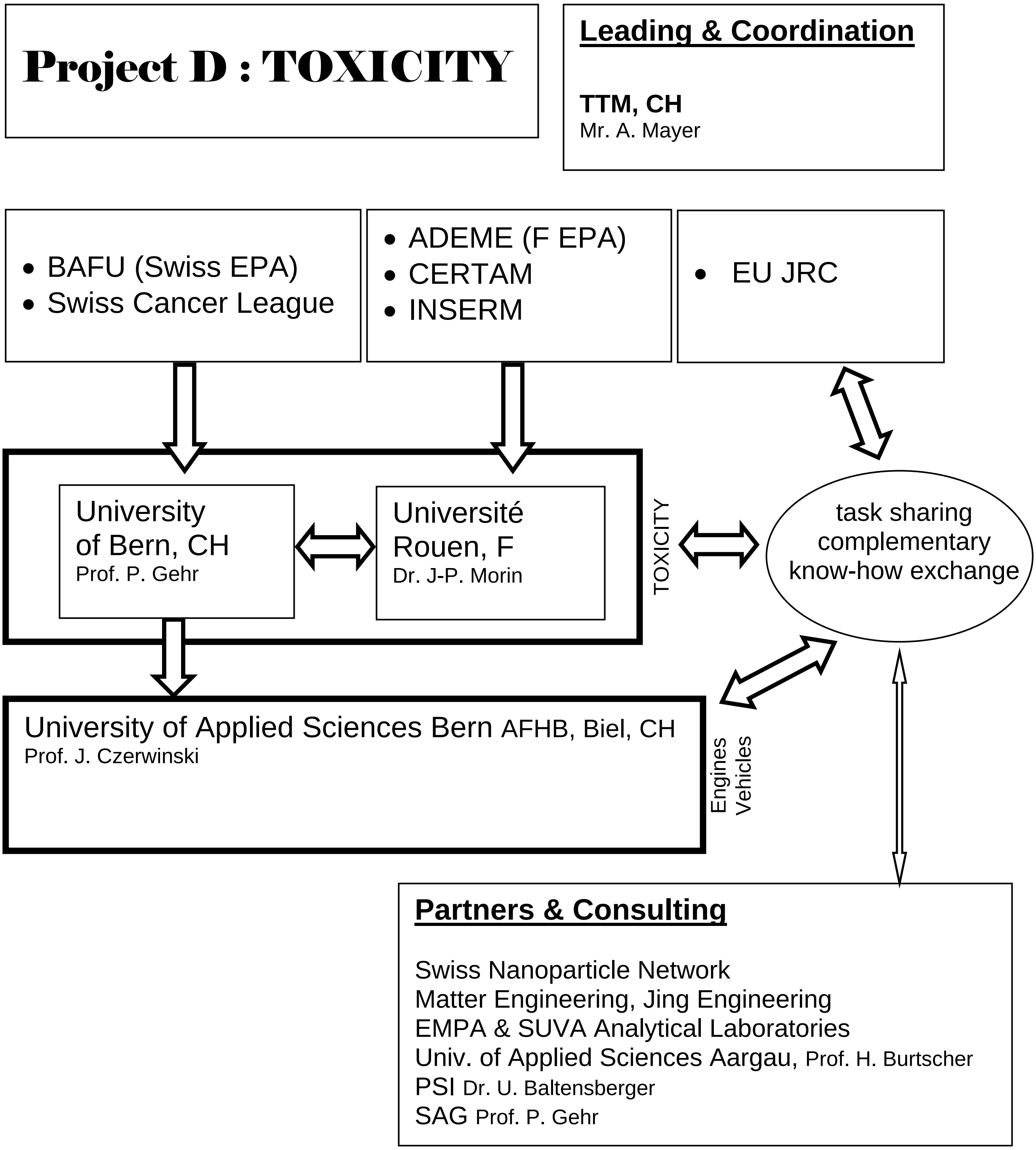


BAFU … Bundesamt für Umwelt
ADEME … Agence de l'Environnement et de la Maîtrise de l'Energie
CERTAM … Centre D' Etudes et de Recherche Technologique en Aérothermique et Moteur
INSERM … Institut National de la Santé et de la Recherche Médicale
JRC … Joint Reserch Center
AFHB … University of Applied Sciences Bern, Abgasprüfstelle FH Biel
TTM ... Technik Thermische Maschinen
EMPA ... Matrials Science and Technology
SUVA ... Schweizerischer Unfall Versicherungsanstalt
PSI ... Paul Scherrer Institut
SAG ... Swiss Aerosol Group (medical)

# A New Exposure System to Evaluate the Toxicity of Scooter Emission in Lung Cells *In Vitro*

**Loretta L. Müller[1], Barbara Rothen-Rutishauser[1], Pierre Comte[2], Jan Czerwinski[2], Markus Kasper[3], Andreas C.R. Mayer[4], Jean-Paul Morin[5], Peter Gehr[1]**

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It is known that diesel exhaust particles (DEP) have the potential to induce adverse health effects associated with pulmonary and cardiovascular diseases (Brunekreef et al, 2002) by inducing oxidative stress (Xiao et al, 2003), inflammatory reactions (Becker et al, 2005), and there is a link between exposure to diesel soot and lung cancer (Donaldson et al, 2005). The toxicity of DEP was studied by using an epithelial airway model (Rothen-Rutishauser et al, 2005). We have shown that DEP in suspension resulted in an increase of both of reactive oxygen species and of the pro-inflammatory chemokine, the tumor-necrosis factor alpha (TNFα, figure 1).

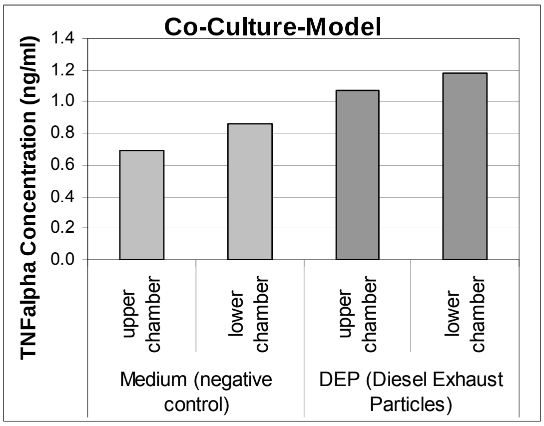


**Figure 1.** Increased TNFα concentration in co-cultures after DEP exposition in suspension.

**Figure 2.** Scooter Avalanche in Taipeh.

The number of registered scooters in Switzerland and in other countries is increasing every year. In some countries scooters are already the main mean of transport in cities (figure 2). Because of their simple technology they produce an exhaust with a lot of fine and ultrafine particles which have a potential to cause adverse health effects (Peters et al, 1997).

For a realistic exposure of cell cultures, a system was developed in which these cultures can be exposed at air-liquid interface directly to exhaust emissions of scooters (figure 3). The exhaust is discharged and directed to a mass regulator, where it is diluted 1:100 with absolute clean air. Before passing the cell cultures in a round exposure chamber which was developed especially for exhaust exposure (Morin et al, 1999; Papaioannou et al, 2006), the diluted exhaust emission is heated to 37°C, enriched with $CO_2$ to an end concentration of 5% $CO_2$ and humidified to a relative humidity of 80% (figure 4).

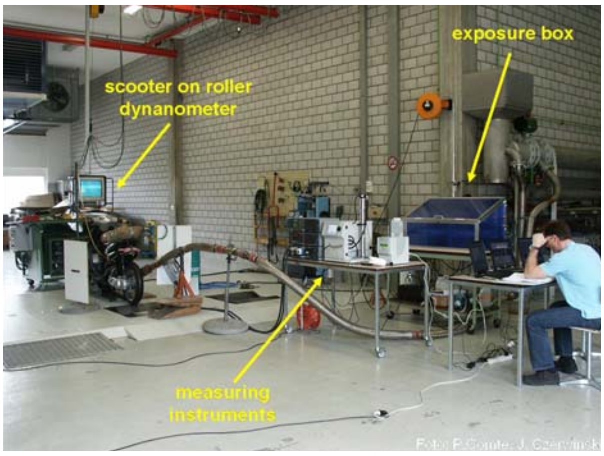


**Figure 3.** Scooter exposure system.

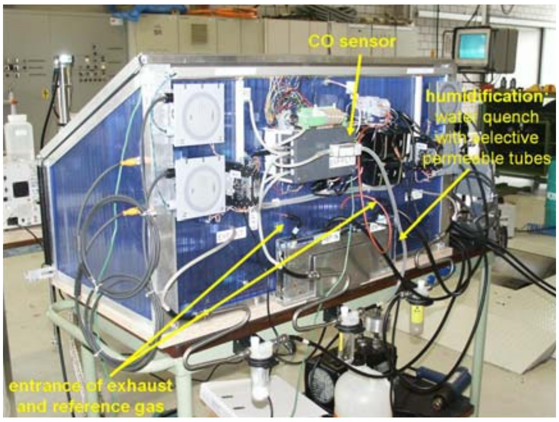


**Figure 4.** Air/Exhaust preparation system.

Directly before the entering to the exposure chamber control measurements (CO and $CO_2$ concentration, temperature, pressure, relative humidity) are conducted. On the top of the round exposure chamber, which is located in the isolated and heated box (37°C), the scooter exhaust enters with a flow of 2 l/min and is spread evenly over the four exposed 6-well plates. The air is sucked at the bottom of the exposure chamber and again $CO_2$ concentration, temperature, pressure and relative humidity are measured. Parallel to the exhaust exposure experiments control experiments are conducted in a reference exposure chamber, where cell cultures are exposed to absolute clean air enriched with $CO_2$, humidified and heated. The conditions in the exposure chamber during the exposure are stable with 80-85% of humidity, 36.5-37.5°C and about 5% $CO_2$ (figure 5).

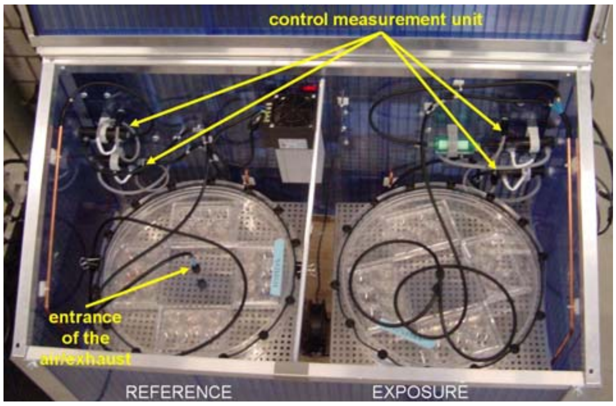


**Figure 5.** Exposure chambers with control measurement units.

Parallel to the exposure of the cells, the exhaust is analyzed by measuring the elementar carbon mass with a photoelectric aerosol sensor (PAS), the total particles surface with a diffusion charging particle sensor (DC), the number of particles and the distribution of particles between 10-400nm with an electrostatic classifier with differential mobility analyser (DMA) in combination with a condensation particle counter. First measures and calculation showed that about 20% of the total particle number passing the exposure chamber stay in the chamber.

We exposed monocultures of 16HBE human bronchial epithelial cells and triple cell co-cultures (monolayer of 16HBE epithelial cells with dendritic cells and macrophages (Rothen-Rutishauser et al, 2005)) to a Peugeot two stroke direct injection scooter. We investigated two different cases: best case (oxi cat and wire-mesh filter catalyst, best lube oil with a ratio of 50% and Aspen fuel) and worst case (dummy muffler, worst oil with a ratio of 100%, unleaded fuel). After a warm-up phase of 90 minutes for the exposure system and 45 minutes for the scooter the cells were exposed during 2 hours with a dilution of 1:100 and a flow of 2 litres/min. After the exposure we incubated the cell cultures for 4h in a $CO_2$ incubator before we removed the medium and fixed the cells for toxicity analysis.

Two independent preliminary experiments give the following results:

- The LDH cytotoxicity test show higher cytotoxicity in triple cell co-cultures than in monocultures. The tendency of higher cytotoxicity in best case conditions than in worst case condition is too small to make a conclusion.
- We see a tendency for more oxidative damage in the DNA of mono-cultures than of triple cell co-cultures and a tendency for more oxidative damage in worst case conditions than in best case conditions (results of only one experiment).

- The evaluation of inflammation markers shows higher TNFα concentrations in co-cultures than in mono-cultures and more TNFα in worst case than in best case conditions. The IL-8 concentrations are higher in co-cultures than in mono-cultures and the IL-8 levels of co-cultures are higher for best case than for worst case conditions.

We can summary that mostly the co-cultures show higher reactions than mono-cultures. The only exception is oxidative damage. The results concerning the two cases are contrary: some parameters are higher in best case conditions (IL-8) and some in worst case conditions (oxidative damage, TNFα). The reasons therefore have still to be found. One possible reason could be the amount of ultrafine particles (diameter < 100nm) in the exhaust, as we have more ultrafine particles in best case conditions than in worst case conditions (figure 6). This factor we have to study further.

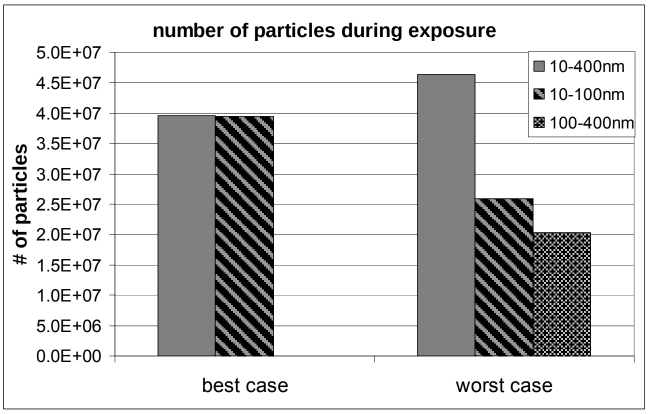


**Figure 6.** Fractions of particle numbers during exposure.

To complete this study and to finish the evaluation of the exposure system we need to do a third repetition of the experiments, we need to check the particle number in the reference chamber and we have to test other scooter types and other improvements.

## References

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Peters, A. et al (1997). Am.J.Respir.Crit Care Med.

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Xiao, G. G. et al (2003). J Biol Chem.

Conference Announcement

# SAE – EC JRC Joint Conference

# (Particle)Emissions of 2-stroke Scooters – science, problems, solutions & perspectives

Autodromo Nazionale Monza / Milano / Italy June 11th – 12th, 2009

1,5 day technical sessions accompanied by social, technical and cultural events in the traditional place of motor sport and historical environment.

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- Legislation & Inventories
- Research and Reduction of Emissions
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  - research on nanoparticles and measuring techniques
  - developments aftertreatment devises
  - comparison 2-S → 4-S
  - lube oils & fuels
  - emission reduction potentials
- Toxicity & Health Effects
- Alternative Powertrains (EV, HEV)
- Panel discussion with representatives of: Authorities, Industry, Health Protection and Research

Further information and registration see at www.sae.org, or http://ies.jrc.ec.europa.eu/ (starting February 2009)
Program of the event see: www.afhb.bfh.ch → SAE –EC JRC Joint Conference

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Chair of Scientific Committee

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Dip. Ing. Andreas Mayer, TTM
Dr. Paul Richards, Innospec
Dipl. Ing. Felix Reutimann, BAFU

# SAE – EC JRC Joint International Conference

# (Particle)Emissions of 2-stroke Scooters – science, problems, solutions & perspectives

Version 2

Autodromo Nazionale Monza / Milano / Italy June 11th – 12th, 2009

## Technical Program

## Wednesday, June 10th 2009

Arrival. Welcome aperitif and registration in Grand Hotel Baron di Sassj 19:00.

## Thursday, June 11th, 2009

08:00 – 08:30 opening of registration "Autodromo di Monza"
08:30 – 09:00 NN opening & welcome address: IES Director and/or EC-IE Director, Air Quality Regione Lombardia / Milano

### General Projects on Emissions [Chairman: G. De Santi]

09:00 – 09:30 **Physical & Chemical Characterization of emissions from 2-Stroke motorcycles**
T. Adam, C. Astorga, G. Martini, A. Farfaletti, U. Manfredi, L. Montero, A. Krasenbrink, B. Larsen and G. De Santi.
*EC-JRC, Transport and Air Quality Unit*
*Phone: +39 0322 78 35 64, Fax +39 0332 78 66 71, Thomas.adam@jrc.it*

09:30 – 10:00 **Study on possible new measures concerning motorcycle emissions**
Savas Geivanidis, Leonidas Ntziachristos, Zissis Samaras[1]*, Anastasios Xanthopoulos[2], Heinz Steven[3], Bernd Bugsel[4]
*[1]Laboratory of Applied Thermodynamics, Aristotle University of Thessaloniki,*
*[2]Laboratory of Quantitative Analysis, Logistics and Supply Chain Management, Aristotle University of Thessaloniki, [3]TÜV Nord Mobilität GmbH & Co.KG,*
*[4] BAST Federal Highway Research Institute of Germany,*
** corresponding author: zisis@auth.gr*

10:00 – 10:30 **Emission performance and evolution over mileage of modern low- displacement two-stroke scooters in statutory and real-world cycles**
Robert Alvarez, Christian Bach, Martin Weilenmann
*Empa, Swiss Federal Laboratories for Materials Testing and Research, Laboratory for Internal Combustion Engines; Ueberlandstrasse 129,8600 Duebendorf,Switzerland.*
*Phone: +41 44 823 48 69, Fax: +41 44 823 40 44, robert.alvarez@empa.ch*

10:30 – 11:00 **Coffee break and poster session**

### Research & Reduction of Emissions [Chairman: Z. Samaras]

11:00 – 11:30 **The Solid-Volatile Challenge of Nanoparticle Emissions from 2-Stroke Scooters**
[1]Kasper, M., [1]Mosimann, T., [2]Comte, P.
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*[2] AFHB, University of Applied Sciences, Biel-Bienne, Switzerland*
*Phone: +41 32 321 66 90, Fax: +41 32 321 66 81, pierre.comte@bfh.ch*

11:30 – 12:00 **Low pressure fuel injection strategies for low emission two-stroke scooter engines**
Franz Winkler, Roland Kirchberger
*Graz University of Technology Institute for Internal Combustion Engines and Thermodynamics Engine Research*
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*Phone:+43/316 873 4596, Fax:+43/316 873 8099,winkler@vkmc.tugraz.at*

12:00 – 12:30 **Regulated and unregulated emissions of mopeds**
M.V. Prati[1], A. Unich[2], M.A. Costagliola[3]
[1]*Istituto Motori of National Research Council, Naples*
[2]*Second University of Naples*
[3]*University of Naples "Federico II*
*Phone: +39 081 71 77 210, Fax: +39 081 23 96 097, m.v.prati@im.cnr.it*

12:30 – 13:00 **Recent research activities on particle emissions from two-stroke mopeds performed at ENEA.**
P. Spezzano, P. Picini, D. Cataldi, F. Messale, C. Manni, E. Donato
*ENEA- ACS PROTANT- Via Enrico Fermi, 45 – 00040 Frascati, Rome, Italy.*
*Municipality of Rome, Department of Environmental Policies, Air Quality and Environmental Noise.*
*Phone: +39 06 6710 5445, e.donato@comune.roma.it*
*Phone: +39 06 3048 6211, picini@casaccia.enea.it*

13:00 – 15:00 **Lunch break and poster session**
**Lunch speech about knowledge transfer & networking**

## Reduction potentials [Chairman: J. Czerwinski]
(by oils, fuels, catalysts)

15:00 – 15:30 **Combinations of Technical Measures for Reduction of Particle Emissions & Toxicity of 2-S Scooters.**
Jan Czerwinski[1], Pierre Comte[1], Maria C. Astorga[2], Thomas Adam[2], Andreas Mayer[3], Felix Reutimann[4]
[1]*University of Applied Sciences, Biel-Bienne, Switzerland (AFHB)*
[2]*EU Joint Research Center, Ispra, Italy (EC JRC)*
[3]*Technik Thermische Maschinen, Switzerland (TTM)*
[4]*Federal Office of Environment, Switzerland (BAFU)*
*Phone: +41 32 321 66 80, Fax: +41 32 321 66 81, jan.czerwinski@bfh.ch*

15:30 – 16:00 **The effect of (hydrous) ethanol on the emission and performances of 2- and 4-stroke scooters**
Michiel Makkee[1], Jan Czerwinski[2] and Pierre Comte[2]
[1] *Catalysis Engineering, Faculty Applied Sciences, Technical University Delft, Julianalaan 136, NL 2628 BL Delft, The Netherlands (m.makkee@tudelft.nl)*
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*Phone: +31 15 278 1391, Fax: +31 15 278 5006, m.makkee@tudelft.nl*

16:00 – 16:30 **Coffee break and poster session**

16:30 – 17:00 **Effects of ethanol-gasoline blends on exhaust emissions for a two- stroke motorcycle**
Jiun-Horng Tsai, Yung-Chen Yao, Wei-Ting Chang, Ting-Hsien Yan
*Department of Environmental Engineering, National Cheng Kung University, Tainan, 701, Taiwan, R.O.C.*
*jhtsai@mail.ncku.edu.tw*

## Alternative Propulsion [Chairman: G. Martini]

17:00 – 17:30 **Electric Scooters: Technologies and Markets**
Urs Schwegler, NewRide, CH-8376 Fischingen
*Tel +41 (0)71 931 60 20; urs.schwegler@newride.ch; www.newride.ch*

## Regional Inventory Lombardy [Chairman: G. Martini]

17:30 – 18:00 **Emissions from 2-wheels vehicles in Lombardy: results and uncertainties in the regional emission inventory**
Stefano Caserini, ARPA Lombardia, Regional Agency for Environment Protection
tel. +39.02.69666.262 - 252 +39.02.6765.4961; s.caserini@arpalombardia.it

20:00 **Social Dinner**
**Transportation to hotels**

# Friday, June 12th, 2009

## Health Effects [Chairman: A. Krasenbrink]

08:30 – 09:00 **Prevalidation of in vitro continuous flow exposure systems as alternatives to in vivo inhalation engine emission safety evaluation experimentations.**
Outcome from MAAPHRI-PCRD5 research program.
Jean-Paul Morin[1], Virginie Hasson[1-2], Mamadou Fall[1], Eleni Papaioanou[3], David Preterre[2], Frantz Gouriou[2], Veronika Keravec[2], Athanasios Konstandopoulos[3] and Frédéric Dionnet[2]
*[1]INSERM U644 – Université de Rouen – France, [2]CERTAM , 76800 Saint Etienne du Rouvray – France, [3]APTL – CERTH, Thessaloniki – Greece*
*Phone : +33 2 3514 8538, Fax : +33 2 3514 8365, jp.morin@univ-rouen.fr*

09:00 – 09:30 **Cytotoxicity and inflammatory potential of two stroke scooter exhaust in lung cells *in vitro***
Loretta Müller[1], Peter Gehr[1], Pierre Comte[2], Jan Czerwinski[2], Markus Kasper[3], Andreas C.R. Mayer[4] and Barbara Rothen-Rutishauser[1]
*[1] Institute of Anatomy, University of Bern, Switzerland*
*[2] AFHB, University of Applied Sciences, Biel-Bienne, Switzerland*
*[3] Matter Engineering AG, Nanoparticle Measurement, Wohlen,Switzerland*
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*Phone: +41 31 631 84 46, Fax: +41 31 631 38 07, loretta.mueller@ana.unibe.ch*

09:30 – 10:00 **Analysis of exposure levels to particle mater of cyclists and car drivers in 11 Dutch cities**
Borgman, Frank *(Dutch Cyclists Union,* van Bree, Miriam *(Dutch Cyclists Union)*
Fietsersbond *(Dutch Cyclists Union)*
*P.O. Box 2828, 3500 GV Utrecht, The Netherlands*
*Phone: +31(0)30 2918168 / 69, vanbree@fietsersbond.nl, borgman@fietsersbond.nl*

10:00 – 10:30 **Characterization of submicron particles in scooter parking garage**
Jie-Ming Shih, Dai-Hua Tsai, Chang-Chuan Chan*
*Institute of Occupational Medicine and Industrial Hygiene, College of Public Health, National Taiwan University, Taipei, Taiwan*
* Corresponding Author: Prof. Chang-Chuan Chan
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*Phone: 886-2-33228082, Fax : 886-2-23222362, ccchan@ntu.edu.tw*

10:30 – 11:00 **Coffee break and poster session**

11:00 – 12:00 **Panel discussion (Legislation EC-JRC / Industry / New Technologies / Authorities / Environment- & Health / others)**

12:00- 12:15 **Closing remarks & goodby**

12:15- 13:30 **Lunch**

## Visiting Autodromo Monza" and "Aria Nuova"

a) Guided tour around historical and Formula 1 tracks
b) Visit to racing control room, F1 winner podium, etc.
c) Eco-driving school
d) Mopeds emissions tests and visit to boxes

# Physical & Chemical Characterization of emissions from 2-Stroke motorcycles

T. Adam, C. Astorga, G. Martini, A. Farfaletti, U. Manfredi, L. Montero,
A. Krasenbrink, B. Larsen and G. De Santi.

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## ABSTRACT

Due to the significant emission reduction from light and heavy duty vehicles in the past few years, it came out that two-stroke engines are a considerably strong source of pollution in the urban areas where congested traffic made of these vehicles an appropriate alternative to increase mobility. After the entry into force of additional measures on light-duty vehicles (Euro 5/6) and on heavy duty vehicles (Euro VI), the share of two- and three-wheelers in total emissions should increase, in particular they may become higher contributors to gaseous emissions. In this context, the Commission wishes to prepare a recast of the legislation on the type-approval of two- and three-wheelers as well new measures on safety and pollutant emissions to be proposed by mid 2009.

In view of this new legislative process and the preparation of an amendment to the European directives 97/24/EC and 2002/51/EC5 on “characteristics of two or three-wheel motor vehicles”, Transport and Air Quality Unit has worked on the characterization of emissions from motorcycles with the aim of obtaining estimates of the impact of these emission sources on air quality.

In this research program, we have taken into consideration some measures that can be adopted to reduce emissions from the existing mopeds, considering that the next stricter emission standards for mopeds will bring important benefits only in the mid/long-term, when a significant fraction of the fleet will have been replaced by newer vehicles. Indeed, new available after-treatment technologies may reduce emissions from Euro 1, two-Stroke motorcycles by a factor of 10 compared to previous emissions standard. Some of these new technologies for emission reduction are still under development and they are expected to be ready to allow new emission limits in the next legislative proposal.

Another output of this project shows the influence of the engine technology and running conditions on the emissions for regulated pollutants as well as for some non-regulated ones (ie. PM, $CO_2$, PAHs, VOCs, Carbonyls). Throughout the testing programme on mopeds, engine settings and maintenance resulted to affect emissions to a large extent. This means that an inspection and maintenance programme for mopeds can be very effective in reducing emissions. Anti-tampering measures should put in place in order to prevent people from this practice.

## Study on possible new measures concerning motorcycle emissions

Savas Geivanidis, Leonidas Ntziachristos, Zissis Samaras[1]
Anastasios Xanthopoulos[2], Heinz Steven[3], Bernd Bugsel[4]

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### ABSTRACT

This paper presents work that have been carried on the behalf of the European Commission for the evaluation of alternative measures to be included in future legislation aiming to reduce emissions and fuel consumption from powered two wheelers (PTW). The assessment covers the period from 2008 up to 2020 and has been performed using new experimental information on emissions from modern PTW as well as up to date fleet and cost data. In order to consider the impact of different policy options, the current legislative status as defined by directives 2002/51/EC and 2006/72/EC was compared against the introduction of three alternative measure policy categories: the introduction of the bundle of measures proposed by the European Commission on their preliminary draft proposal (Moto_105), the introduction of emission standards for motorcycles that would be equivalent to passenger car Euro 5 and the introduction of measures that are today considered as best-available technology for PTWs. A number of specific objectives were assessed as regards the emission benefit achieved and the cost-effectiveness of the application of the respective measures: durability of anti-pollution devices, in-use conformity, $CO_2$ emissions and fuel consumption, new set of pollutant emission limit values for tricycles and quadricycles, new set of pollutant emission limit values for mopeds, OBD systems on two and three-wheel motor vehicles, evaporative emissions on two and three-wheel motor vehicles as well as the impact of the mandatory use of the new WMTC were studied. The paper concludes with the evaluation of the current status and future evolution of PTW emissions as well as the presentation and discussion of the outcome of the alternative measures assessment.

# Emission performance and evolution over mileage of modern low-displacement two-stroke scooters in statutory and real-world cycles

Robert Alvarez, Christian Bach, Martin Weilenmann

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## ABSTRACT

Low-displacement two-stroke scooters represent a common transportation system for individual mobility in present and in future, especially in urban areas. Stringent emission limit legislation aiming to meet the desired air quality standards nowadays implicates the use of catalytic converters in such vehicles. In this regard, its evolution of emission performance over mileage is of great relevance considering the fact that many countries do not include an in-use compliance test for vehicle certification. Therefore, an experimental investigation on a roller test bench was executed with six brand new two-stroke scooters equipped with oxidation catalytic converters, whereas four of them carry out air fuel mixture preparation via a mechanical carburetor and two via an electronic fuel injection system. Emissions of gaseous pollutants were periodically recorded at different mileages up to 1000 km before and after the catalytic converter to determine its evolution of conversion performance in the statutory test cycle, the urban section of the Worldwide Motorcycle Test Cycle (WMTC) and at constant speeds. In between, the scooters were normally operated in the streets.
The test results reveal that 4 out of the 6 scooters do not meet the given emission limits already in brand new state. Conversion efficiencies of 10% to 90% for HC and -90% to 90% for CO were recorded at different constant speeds. Part-oxidation of unburnt fuel in the hot oxidation catalytic converter is most likely to be the reason for the latter observation. Only a minor deterioration of the performance of the oxidation catalytic converter over mileage can be stated. However, the pollutant emission levels of the scooters tested are considerably higher than of passenger cars or motorcycles of certification category Euro-3.

# The Solid-Volatile Challenge of Nanoparticle Emissions from 2-Stroke Scooters

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## ABSTRACT

Small scooters, which are very much used in the congested centers of many cities, are a significant source of air pollution. Therefore, every effort to reduce their emissions is an important contribution to improved air quality in urban centers.
The present work is part of detailed investigations of particle emissions from different 2-stroke scooters with direct injection and with carburettor.
Nanoparticle emissions were measured using SMPS, CPC and NanoMet. Particle mass emissions (PM) were measured using the same method as for Diesel vehicles.
The quality of lube oil and fuel were found to have a considerable influence on the particle emissions, which are mainly oil condensates. Engine technology influences the (nano)particle emissions by: mixture preparation; mixture tuning; oil consumption; postoxidation; quality; condition and temperature of the catalyst.
Since the particulate emission of the 2-S consists mainly of lube oil condensates the minimization of oil consumption stays always an important goal. The amount of total PAH, as well as the toxicity equivalence factor TEQ correlate roughly with the total particle mass PM.

# Low pressure fuel injection strategies for low emission two-stroke scooter engines

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## ABSTRACT

Nowadays, 50cm³ two-stroke engines make use of a simple carburetor for external mixture preparation. The cylinders are scavenged by air/fuel mixtures. Equipped with exhaust gas after treatment systems, such as secondary air or lean burn concepts with oxidation catalytic converters, the emission limits for EURO 2 homologation can be achieved with carbureted engines. The cost intensive air assisted direct injection, reducing the untreated emissions by minimizing the typical scavenge losses, is currently the only available technology which already achieves future emission limits. As the market is dominated by low cost carbureted products the impact on the fleet emissions of the low emission technology is very small.

Many other technologies with the special attention to reduce exhaust emissions of two-stroke engines have been introduced but they are not yet commercialized, mainly due to financial aspects. Hence, the key requirement for new low emission technologies are the production costs.

The Institute for Internal Combustion Engines and Thermodynamic investigated several technologies to reduce the scavenge losses of two stroke engines in the last decade. The latest approaches have been recently presented on the Small Engine Technology Conferences 2006 and 2008. These two approaches for low emission two stroke engines face the cost challenge by using low-cost low pressure fuel injection components from automotive pfi applications.

The emission results of the crankcase injection strategy (SETC 2006-32-0065) and the direct injection strategy (SETC 2008-32-0059)will be summarized in the presentation. Engine test bench results and emission results from the chassis dynamometer will demonstrate the high potential concerning the limited emission components CO. HC and $NO_x$. Additionally, the particle emissions of the direct injection system will be treated. Therefore, the particle mass as well as the particle numbers and particle size distribution at different operation points of a four-stroke naturally aspirated, a two-stroke engine with external mixture preparation and with low pressure direct injection will be discussed.

## Regulated and unregulated emissions of mopeds

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### ABSTRACT

Depending on the large percentage of powered two-wheelers (PTWs) in the circulating fleet, urban air pollution can be strongly influenced by emissions of this vehicle class which represents an high emitter of incomplete combustion products. In the recent years, therefore, the attention towards the contribution of exhaust emissions deriving by PTWs was increased. Particular concern has been raised over small scooters which include the so called “mopeds” (low-powered motor-driven vehicle with an engine capacity equal or less than 50 $cm^3$ and a maximum design speed of 45 km/h), widely used in Italian congested city centers. Mopeds are characterised by an high emission level, justified by the use of 2-stroke (2-S) engine technology for almost 80% of total circulating fleet. Contrary to 4-stroke case, the combustion process of a 2-S engine which involves a mixture of gasoline and lubricant, together with the scavenging process, produce a substantial emission of unburned hydrocarbons. The introduction of 4-S engine coupled with oxidation catalyst and secondary air injection are the main strategies introduced for lowering mopeds emissions making them compliant with more stringent Euro 1 and Euro 2 standards.

In this study, gaseous and particle emissions were measured at the exhausts of several 2-S mopeds responding to different European emission legislative standards (pre-Euro, Euro 1 and Euro 2). Mopeds were tested during type-approval driving cycle (R47) performed on chassis dynamometer for the evaluation of regulated emissions of carbon monoxide, hydrocarbons and nitrogen oxides. Moreover, the emissions of some unregulated compounds of particular concern for human health (benzene, formaldehyde, 1,3-butadiene, benzo(a)pyrene and particulate) were quantified. Particulate was characterized as total mass collected on filters and as the total number of particles and size distribution in the range 7 nm–10 micron measured by the ELPI (Electrical Low Pressure Impactor).

Results show that CO and HC emissions of Euro 2 mopeds were almost 50% lower than those of pre-Euro. NOx, instead, are not dependent by type-approval stage. Regarding unregulated compounds, the transition from pre-Euro to Euro 1 involve an appreciable decrease in emission levels, with the exception of benzene. The very high particle number emission has a similar behaviour of that relative to diesel engines: emission traces follow speed profile and the highest peak occurs during the acceleration phase of driving cycle.

Comparison of 2-S emissions with 4-S ones shows that 2-S emit about three times more quantified organic compounds and particles compared to 4-S.

# Recent research activities on particle emissions from two-stroke mopeds performed at ENEA.

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## ABSTRACT

In recent years the problem of particle mass emissions from in-use two-stroke (2-S) mopeds was addressed by ENEA, the Italian National Agency for New Technologies, Energy and Environment, on request of the Municipality of Rome. Further studies were undertaken in order to measure PAHs emissions as well as to characterize the emitted particles in terms of soluble organic fraction (SOF) and unburned lubricant fraction of particulate. The prevalent mechanism driving the gas-particle partitioning of PAHs in 2-S moped exhaust was assessed, too. All tests were performed under the ECE-47 driving cycle and all mopeds were fuelled with commercial gasoline mixed with synthetic, high-quality lubricating oil. Main conclusions were:

- PM emission from non-catalyzed 2-S mopeds is strongly related to lubricant oil consumption;
- Unburned lubricating oil accounts for a significant fraction of PM emitted from 2-S mopeds;
- PAHs emissions from 2-S mopeds are comparable or even higher than PAHs emissions reported elsewhere from gasoline- and diesel-powered passenger cars and light- and heavy-duty vehicles;
- Catalyst mopeds (EURO-1) reduce PM, unburned oil and PAHs emissions of approximately 80 %, 75 % and 45-60 %, respectively;
- Catalyst on EURO-1 mopeds mainly helps in reducing emissions of low molecular weight PAHs while for higher PAHs the reduced emissions should be attributed mainly to the reduced fuel consumption;
- Catalyst EURO-2 mopeds show a constraint behaviour regarding to PM, unburned oil and PAHs emission reduction and related to the different engine design (carburettor + secondary air injection and direct injection);
- The soluble organic fraction (SOF) of the emitted particulate range 72-98 %;
- The gas/particle partitioning in moped exhaust is mainly driven by the high fraction of organic matter of the emitted particles and that absorption seems the main partitioning mechanism of PAHs.

In the latest development of the study, the initial suite of target PAHs was expanded to include the alkylated naphthalene, fluorene, phenanthrene, and chrysene series as well as other un-substituted PAHs. Alkylated PAHs are generally more prevalent in

petrogenic than pyrogenic PAH sources because of the thermal dealkylation within the engine. The amount of alkylated PAHs (ratio of alkylated-to-parent PAHs) is affected by the temperature of combustion.
This paper gives an overview of the findings of the previous studies and presents the results on the characterization of alkyl-substituted PAHs in 2-S moped emissions compared to the gasoline used to fuel the tested mopeds.

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# Combinations of Technical Measures for Reduction of Particle Emissions & Toxicity of 2-S Scooters

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## ABSTRACT

2- and 3-wheelers with 2-S propulsion are still a very serious source of air pollution worldwide in many urban areas. Therefore every effort to reduce the emissions of those vehicles is an important contribution to improve the air quality.

In the present work detailed investigations of limited emission compounds and of particle emissions of 2-stroke scooters with direct injection and with carburator were performed. To demonstrate the emission reduction potentials some possibilities of emission improvements were combined in steps. These technical measures were:

- Higher tier lube oils
- Lower oil dosing
- Active oxidation catalyst
- Supplementary filtration & oxidation devise (WFC – wiremesh filter catalyst).
- Special fuel.

The works are a final part of an international scooter network project, which was performed (2004 to 2007) in the Laboratories for IC-Engines & Exhaust Emission Control of the University of Applied Sciences, Biel, Switzerland with main support of the Swiss Federal Office of Environment (BAFU), Swiss Petrol Union (EV) and Swiss Lubes (VSS) and with a partnership of the EU-JRC Analytical Laboratories, Ispra, Italy.

The PM-measuring filters from the test series were analyzed for PAH at Analytical Laboratory of JRC-Transport and Air Quality Unit in the Vehicle Emissions Laboratory (VELA).

In order to evaluate the potential toxicity and carcinogenicity of these pollutants the method based on the benzo(a)pyrene Toxicity Equivalency (TEQ) approach has been used.

The amount of total PAH, as well as the toxicity equivalence factor TEQ correlate roughly with the total particle mass PM.

The combinations of technical measures to lower the particle emissions of scooters confirmed the expected effects and showed considerable reduction potentials of emissions and toxicity.

# The effect of (hydrous) ethanol on the emission and performances of 2- and 4-stroke scooters

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## ABSTRACT

The growth to sustainability in the transportation fuel is highly stimulated by the EU directives and blending of 5.75 % fuel derived from biomass should be achieved in 2010 and the legislation is aiming for 20 % into the year 2020. Ethanol produced by fermentation of corn (the first generation in competition with the food chain) and biomass (the second generation) and methyl esters of fats and oils (the first/second generation bio diesel). Ethanol is used for passenger cars since a long date (Brazil). In the last years, due to the increasing prices of crude oil, there is a growing interest for ethanol. Several countries have objectives to substitute a part of the energy of traffic by ethanol as the renewable energy source.

The objectives of the present work are to investigate the limited and the unregulated emissions of a classical and modern 2-stroke and a typical 4-stroke scooter with different ethanol blend fuels. There will be also comparison of two different ethanol fuels: pure ethanol (E) and hydrous ethanol (EH) which contains 3.9% water and is denatured with 1.5% gasoline. Special attention is paid in this research on the hydrous ethanol, since the production costs of hydrous ethanol are much less than those for (dry) ethanol. The vehicle will be with carburettor and without catalyst, which represents the most frequent technology in Eastern Asia and offers the information of engine-out emissions. Exhaust emissions measurements of three scooters with gasoline-ethanol blend fuels have been performed with fuels contained ethanol (E), or hydrous ethanol (EH) in the portion of 10, 15 and 20% by volume. During the test a systematically analysis of particle mass (PM) and nano-particles counts (NP) were carried out.

The most important results are:

- there are no significant differences of results between the blends with pure ethanol (E), or hydrous ethanol (EH).
- addition of ethanol to the gasoline provokes a leaner tuning of the engine operation,
- the operation of 4-S scooter was without problems, the leaning by ethanol caused: lowering of CO, HC & fuel consumption, increase of NOx, no effect on PM and reduction of nanoparticles count concentrations especially at transient operation,
- for the investigated newer 2-S scooter the irregularities of combustion and loss of power were remarkable with higher ethanol content (richer basic tuning of the newer 2-S scooter enabled a satisfactory driveability with E10),

- the older 2-S scooter showed good performances and reduction of CO and of fuel consumption up to E20, no impact on (nano-)particles emissions.

The present investigations did not concern the durability of parts exposed to the chemical influences of ethanol. Also the cold start, particularly in extreme conditions and the lube oil dilution were not addressed.

Process Design Center B.V. is acknowledged for their financial support.

# Effects of ethanol-gasoline blends on exhaust emissions for a two-stroke motorcycle

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## ABSTRACT

The application of alternative fuels has received considerable attention due to increased fuel prices as well as stringent emission restrictions. Many researchers have focused on the correlation between ethanol-gasoline blended fuels (3-30 vol%) and pollutant emissions. Unfortunately, the quantification of pollutant emissions has mostly been done with passenger cars. Information related to ethanol blended fuel on the emission reduction of air pollutants for motorcycles is rather limited. This study investigated the effect of ethanol-gasoline blends on criteria air pollutant emissions of a new two-stroke motorcycle with a displacement of 50 $cm^3$ and without a catalytic converter. Three types of ethanol blends with various ethanol content, 3, 10, and 15% v/v, and a commercial gasoline (with MTBE) were tested in this study. CO, THC, and NOx emissions were evaluated using the Economic Commission for Europe cycle on the chassis dynamometers. The results of the ethanol-gasoline blends were compared to those of commercial unleaded gasoline. The emission factors of each test blend are 8.8 to 12.6 g/km for CO, 7.5 to 8.6 g/km for THC, and 0.02 to 0.04 g/km for NOx. In general, the exhaust CO and THC emissions decreased with increasing ethanol content in fuels. The 15 % ethanol blend had the highest emission reductions relative to the commercial gasoline. The reduction percentages are 30 % for CO and 8% for THC. Using 10% ethanol blend as the fuel was also showed an 8.8 % and 7.5 % emission reductions for CO and THC, respectively, as compared to the commercial gasoline. In contrast, NOx emissions are increasing about 50 to 144% while ethanol blends were used. According to our findings, ethanol-gasoline blends reduce exhaust CO and THC emissions but increase NOx emissions in catalyst-free two-stroke motorcycle engine.

*Keywords: Ethanol-gasoline blends; Two-stroke carburetor engine; Criteria air pollutants; Chassis dynamometer.*

# Electric Scooters: Technologies and Markets

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## ABSTRACT

### 1 Introduction

In this text, the term “e-scooter” is used for motorcycles and mopeds with an electric or hybrid drive-train. Compared to conventional motorcycles and mopeds, these vehicles offer significant benefits regarding energy consumption, greenhouse gas and air pollutant emissions as well as noise emissions.
In the past few years, the development in this vehicle category has made tremendous progress in different ways:

- Battery technology: After the breakthrough in electric bicycles, the Lithium-technology has become feasible for e-scooters.
- Vehicle concepts: There is a huge variety of innovative vehicle concepts such as Segway, Easyglider, Bikeboard, Quantya, Vectrix. The high satisfaction of people having done a test ride proves the fun to drive as an additional benefit of these vehicles.
- Market development: In China, e-scooters are already well established on urban roads. In Europe, a growing presence at motorcycle fairs such as Intermot (Cologne), EICMA (Milan) or Swiss-Moto (Zurich) as well as orders from fleet owners such as the Swiss postal service (250 Oxygen cargo scooters) shows, that the market introduction has started there, too.

Despite of these exciting perspectives, there are some barriers for the market introduction of e-scooters. A study financed by the Swiss Government and an action plan by NewRide, the Swiss association for the promotion of electric two wheelers, will study these barriers and develop ways to overcome them.

### 2 Barriers and objectives

Information and communication: Today, the global motorcycle manufacturers haven’t started volume production of e-scooters, although they are developing them since many years. The actual suppliers - not famous brands – first have to prove their confidence. Unfortunately some of them misjudge the time and investment for developing and introducing new vehicles on the market. As a consequence, these suppliers get the image of not being serious and harm the reputation of the whole technology.
Therefore there is a need for neutral and reliable information. Target groups of the corresponding communication are not only the buyers of e-scooters, but, much before, dealers and media people. Communication tools include market overviews, websites,

press releases, exhibitions (with test rides, if possible) etc.

Distribution Networks: As mentioned above, the actual e-scooter suppliers are not present on the markets yet. Therefore, they first have to establish a distribution network.

Energy consumption and range: Actually there is no norm for a test cycle as for passenger cars (NEDC). Manufacturers publish figures on energy consumption and range based on optimistic conditions (traffic flow, topography, driving style, top speed, climate etc). NewRide will develop a test cycle for e-scooters as a base for comparable range and energy consumption.

Charging facilities: At most of e-scooters, the battery cannot be removed for charging. Therefore, the user needs a place closed to a socket. If he has access to a parking garage, he can install a socket or an independent metering on an existing socket. If he doesn't, he needs a public charging station. Because the amount of electricity is small, the cost of access and billing is a critical issue. In an initial stage, electricity can be provided at simple outlets for free, but in the long term there is a need for a low cost and consumer friendly, but still safe system.

## 3 Methods and first results

Information and communication: NewRide has presented in a special sector of the Swiss-Moto in February 2008 in Zurich nine makes and more than 20 models of e-scooters. A brochure with a portrait of the exhibitors and a table with the technical data was distributed before and during the exhibition. During these four days more than 1'000 test rides were carried out by the visitors. Thanks to its neutral status this exhibition became a high interest of the media incl. the daily news on the Swiss National Television. (http://www.newride.ch/swissmoto08.html).

Distribution Networks: In collaboration with the Swiss Bicycle and Motorcycle Dealer Association (sfmgv) NewRide invited the members of this Association (500 dealers) to this show, which was a unique opportunity for contacting the vehicle suppliers and their products and services. In addition, NewRide organized excursions for motorcycle dealers to EICMA (Milan) in 2007 and 2008, visiting the most important booths with e-scooters. Thus, the dealers got in a short time an insight in the technology and market development.

Energy consumption and range: A measurement of the energy consumption on a test bench at the EMPA has shown that an e-scooter is difficult to run on a test bench, mainly because of its small weight. In a second approach, a new method will be investigated based on a GPS system which reports topography, speed and acceleration as main factors for the energy consumption. Mounting this instrument on an e-scooter, the consumption measured for any trip can be uniformed by these parameters.

Charging facilities: Together with committed cities, NewRide will collect public and private outlets where e-scooter drivers can charge their batteries. This is considered as an intermediate solution until a simple and robust charging system including user access and billing is available on the market.

## 4 Conclusion

E-Scooters are on the way to market introduction. They have a high potential to replace not only conventional scooters, but also passenger cars. As these products and – at least today – the suppliers are new on the market, there will be some barriers which are described above. Considering their environmental benefit, a political support is justified.

# Emissions from 2-wheels vehicles in Lombardy: results and uncertainties in the regional emission inventory

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## ABSTRACT

Within the framework of the atmospheric emission inventory of the Lombardy Region, a detailed assessment of emissions from 2-wheels vehicles has been carried out.
Emission assessment is based on the algorithms proposed by Corinair COPERT IV methodology, with the distinction between non-urban (highway and other main roads) and urban driving; data proposed in the last edition of the European Guidebook have been used for non-exhaust PM emissions due to road vehicle tyres, brake and road surface wear.
The paper shows the emission inventory results and specifically the contribution of different 2-wheelers (2/4 stroke, cylinder capacity, Euro categories) to primary particulate matter (PM) and precursors, as well to Greenhouse gases (GHGs) emissions. As results point out, conventional 2-stroke mopeds are the main source of Volatile Organic Compounds (VOC) from road transport, whereas as regards to other pollutants contributions from other vehicles are more widespread. In the paper average emission factors of 2-wheels vehicles are compared with those of other vehicles, highlighting the lower GHG emission factors for all the 2-wheels vehicles.
The main critical points of the emission assessment that could lead to substantial variations in the resultant estimates are the average fleet age composition for mopeds and mileage data availability, in particular for old 2-stroke vehicles.

# Prevalidation of in vitro continuous flow exposure systems as alternatives to in vivo inhalation engine emission safety evaluation experimentations.

Outcome from MAAPHRI-PCRD5 research program.

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## ABSTRACT

Diesel engine emissions aerosol induced toxicity patterns were compared using both in vitro (organotypic cultures of lung tissue) and in vivo experimentations mimicking the inhalation situation with continuous aerosol flow exposure designs.
Using liquid media resuspended Diesel particles, we show that toxic response pattern is influenced by the presence of tensioactive agent in the medium which alter particleborne pollutant bioavailibility.
Using continuous aerosol exposure in vitro, we show that with high sulphur fuel (300ppm) in the absence of oxidation catalysis, particulate matter was the main toxic component triggering DNA damage and systemic inflammation, while a very limited oxidant stress was evidenced. At the opposite, with ultra-low sulphur fuel in the presence of strong Diesel oxidation catalysis, the specific role of particulate matter is no more evidenced and the gas phase then becomes the major component triggering strong oxidant stress, increased NO2 being the most probable trigger.
A selective particle sizer has been developed which allows so select a given particle size range from the aerosol which allowed to show that according to the particle size, biological reaction profile could be modified, thus showing the selectivity and discriminant potential of our in vitro tools for complex aerosol safety evaluation.
In vivo, Plasma TNFalpha, lung SOD, catalase and GPx activity levels were varied in agreement with in vitro observations. Diesel emission treatment with oxycat provokes a marked systemic oxidant stress. Again NO2 proved to account for major part of these impacts. In conclusion, similar anti oxidant responses were observed in in vitro and in vivo experiments after Diesel emission aerosol continuous flow exposures.
The lung slice organotypic culture model exposed complex aerosols appears to be a very valuable alternative to in vivo inhalation toxicology experimentations in rodents for screening the potential impact of fuel, engine technology and or depollution strategies on engine emitted combustion aerosol health safety.

Keywords : In vitro alternatives, inhalation toxicology, cell cultures, lung, aerosol exposure, Diesel exhausts, oxidant stress, inflammation

# Cytotoxicity and inflammatory potential of two stroke scooter exhaust in lung cells *in vitro*

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## ABSTRACT

The number of registered scooters in Switzerland and in other countries is increasing every year. Because of their simple technology they produce exhaust with a lot of fine and ultrafine particles which can cause adverse health effects. It is known that combustion-derived particles, e.g. diesel exhaust particles, are associated with pulmonary and cardiovascular diseases by inducing oxidative stress, inflammatory reactions, and there is a link between exposure to diesel soot and lung cancer. Human lung cell cultures offer a good tool to study the toxicity of those particles. Therefore we have developed an *in vitro* test system modelling scooter exhaust toxicity.

We have used a triple cell co-culture model of the epithelial airway barrier composed of 16HBE 14o bronchial epithelial cells, macrophages and dendritic cells. The cultures were exposed at the air-liquid interface directly to exhaust emissions of scooters. The exhaust was diluted 1:100 with absolute clean air, heated to 37°C, enriched with $CO_2$ (5%) and humidified (relative humidity of 80%). Before the exhaust passed the chamber and after the chamber control measurements (CO, $CO_2$, temperature, pressure, relative humidity) were conducted. The scooter exhaust was spread evenly over the exposed cell cultures with a flow of 2 l/min. The conditions in the chamber during the exposures were stable (80-85% of humidity, 36.5-37.5°C, 5% $CO_2$; as are required for cells cultures). Parallel to the exposure chamber a reference chamber was treated equally, but without exhaust. In order to control the cell exposure, the exhaust was analyzed by measuring the elementar carbon mass, the total particles surface, the number of particles and the distribution of particles between 10-400nm. Cellular cytotoxicity and the inflammatory response were assessed in the cultures after particle exposure for 2h and different after-incubation times (0h, 4h, 8h, 12h, 24h).

First experiments were performed with a Peugeot two stroke direct injection scooter using worst case setting (dummy muffler, worst lube oil, oil ration of 100% and unleaded fuel). The cytotoxicity in exposed cells was increased after an incubation of 8h, 12h and 24h compared to control cells in the reference chamber. The inflammation markers tumor necrosis factor α and interleukin 8 were enhanced after 0h to 12h after-incubation, but not after 24h.

With the described exposure system we have a sensitive *in vitro* method to investigate the toxicity of different exhausts, e.g. scooter exhaust. We will use it in further experiments to compare various scooter types and aftertreatment measures.

# Analysis of exposure levels to particle mater of cyclists and car drivers in 11 Dutch cities

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## ABSTRACT

Cycling is an environmental friendly way of transport. Therefore (more) cycling can have a positive effect on the air quality in cities, specially if cycling substitutes car traffic. However, it is undesirable if cyclists are exposed to high levels of air pollution for it will reduce the positive health effects and people could decide to use their cars instead and thus adding to the problem.

To address this, the Fietsersbond has introduced in their benchmarking project 'Fietsbalans' measurement of particle matter (PM) on the specially designed measuring bicycle and in a car. Measurement of two fractions of particle mater are made every second: PM_2,5 and ultra fine particles (UFP). These data can be linked with data on speed, sound, type and quality of road surface, type of road or intersection, maximum speed of motorised traffic, intensity of motorised traffic, etc. First research shows that reliable and meaningful measurements and assessments of exposure levels of both cyclists and car drivers can be made.

In September and October 2006 measurements have been made in 11 Dutch larger cities. In each city data was collected on 12 cycling routes in and around the city centre, in total 30 to 40 kilometres per city, thus creating a data-set that is unique in size, quality and comprehensiveness.

These data are analysed on the following questions: How high are exposure levels of cyclists and car drivers on an average inner-city trip? What are the health effects? Where do high exposure levels occur? Can they be reduced by different road design? By different circulation? Do different network designs lead to different exposure levels? Ultimately this project leads to advice on what city councils can do to make cycling in their cities a truly healthy experience. This is important to cyclists everywhere.

The results were quite clear: passing mopeds gave a big peak in exposure level for the cyclists'. I did copy the presentation about it by IRAS, the organisation which did the analysis of the data.

# Characterization of submicron particles in scooter parking garage

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## ABSTRACT

Scooter is a common transportation mode in Asia, and also in Taiwan. There are about 1.03 million registered scooters in Taipei metropolitan area. In general, two-stroke scooters are about 29% of the total scooter amount. This study compared number concentrations of submicron particles in scooter parking garage which is operating for 24 hours in Taipei. The size distribution of particles ranging from 11.1 to 1083.3 nm was measured by a scanning mobility particle sizer (SMPS) for three consecutive days, from 27th October to 30th October, 2008. The particle data were then classified to ultrafine particles (number concentration with size between 10nm ~ 100 nm, $NC_{0.01-0.1}$) and nano particles (number concentrations with size between 10nm ~ 50 nm, $NC_{0.01-0.05}$). The highest total particle number concentration (11.1nm~1083.3nm) was found to be 4,447,155 number/$cm^3$ in the evening (at 21:33), and the lowest particle number concentration was found to be 164,343 number/$cm^3$ in the early morning (at 04:38). Due to different pattern of traffic volume in scooter parking garage, the particle concentration levels peaked near 21:00. In addition, ultrafine particles and nano particles averagely accounted for 89% and 73% of the total particle concentration, respectively.
This means that an inspection and maintenance programme for mopeds can be very effective in reducing emissions. Anti-tampering measures should put in place in order to prevent people from this practice.

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## EEA calls for Suspension of Biofuels Target

The European Environment Agency (EEA) Scientific Committee has called for the suspension of the EU target of 10% biofuels use in transportation by 2020, and is recommending a new, comprehensive scientific study on the environmental risks and benefits of biofuels. The EEA Scientific Committee expressed concerns on the benefits of 1st generation biofuels, the amount of available arable land for bioenergy production without harming the environment and the potential need for large amounts of additional imports of biofuels resulting in destruction of rain forests.

## Health Experts support EU MMT Ban

On 24 April 2008, 12 European health experts sent letters to Ministers of Environment and Health in the EU member states in support of the ban on Methylcyclopentadienyl Manganese Tricarbonyl (MMT) proposed by MEP Corbey in the revised Fuels Directive. The letter notes that “Manganese is a well recognized neurotoxicant. Evidence strongly suggests that manganese exposure through inhalation and drinking water can damage brain development in children and permanently impair motor control and behaviour in adults. In Italy and Canada, environmental exposure to manganese through industrial and traffic emissions has been linked to an increased risk of Parkinsonism among exposed populations”. They further highlighted the Brescia Declaration which concluded that “results presented at this scientific meeting raised grave concerns about the likelihood that manganese-based additives in petrol could cause widespread developmental and neurological toxicity similar to that caused by lead-based additives now banned nearly worldwide”.

## Austria to introduce Euro 6 Incentives with $CO_2$ Bonus/Malus System

From 1 July 2008 Austria will give an incentive of €300 for new cars emitting less than 120g/km $CO_2$ and €200 if Euro 6 NOx standards are also met. There will also be a general incentive of €500 for hybrids and vehicles powered by E85, methane, biogas, hydrogen or LPG. For new cars with $CO_2$ emissions over 180g/km there will, from the same date, be a penalty, levied at a rate of €25 per gram $CO_2$ above the limit. From 1 January 2010, the threshold will be lowered to 160g/km. Austria says that the system is expected to steer the market in the same way as the support for cars with diesel particulate filters has since July 2005. The proportion of newly registered cars with DPFs has risen from 8% to over 85% by December 2007.

The announcement follows the publication of the Austrian Umweltbundesamt’s annual report on new car $CO_2$. This showed that in 2006, on average, new cars in Austria emitted 164g/km $CO_2$, an increase on the previous year. Diesels are 62% of the market and for the first time the average $CO_2$ emissions of diesels were slightly higher than other vehicles, due to a trend to larger, higher performance vehicles.

## Austrian Ambient Particulate Levels have already exceeded Annual Limits

Particulate matter emission records for the first 100 days of 2008 are looking very poor, according to an investigation by the Austrian Auto Club. The annual limit of 30 days in which PM10 levels exceed $50 \mu g/m^3$ has already been exceeded in Graz and Leibnitz. Emissions are also high in Klagenfurt, Innsbruck, Linz, Salzburg and Vienna. Since the start of the year, Graz already had 41 days where the limit was exceeded.

## UK Incentive for Euro 5 Vans

The UK Chancellor made “an environmentally sustainable world” a key part of his 2008 Budget on 12 March 2008. The measures include a reform of car taxation to encourage consumers and businesses to use more efficient vehicles, changes to fuel duties and a proposal to give an incentive on annual circulation tax for Euro 5 vans. The budget statement says that a measure will be introduced with effect from 1 January 2009, giving an incentive on Vehicle Excise Duty for early take-up of Euro 5 technology diesel vans ahead of mandatory introduction in 2011.The incentive will remain for the lifetime of the vans.

## Belgian Reports on Ultrafine Particles

New measurements from the Flemish Institute for Technological Research (VITO) show that mopeds emit more ultrafine particles than trucks. VITO made measurements on a bicycle path along a quiet road in Geel, enabling them to measure the quantities of ultrafine particles which cyclists inhaled when a moped or truck passed. The VITO measurements showed that a truck emitted 300 000 ultrafine particles per cc but a two-stroke moped emitted no less than 350 000. The measured values are ten times higher than those from Dutch research published at the end of February. This is possibly because in the Netherlands cycle lanes are much more separated from the regular traffic; the closer a cyclist rides to the source of pollution, the more he is exposed to ultrafine particles.

A second report, commissioned from Transport & Mobility Leuven (TML) by the Flemish Institute for Scientific and Technological Assessment, which is

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linked to the Flemish Parliament, discusses the link between fine particles, cars, traffic and health. The report is to serve as input for a public consultation on the topic. Some key points from the report are that:

- fine particles diminish life expectancy by 3 years
- traffic causes one third of fine particles emissions
- if all European diesel cars were replaced by diesel cars with a particulate filter, Flemish air would contain 10% less fine particles.

## Lyon sets Environmental priorities for Vehicle Purchase

The Communauté urbaine de Lyon, France, has set environmental targets as a key part of its latest tender for vans and light trucks for use in local communities. The tender document sets 3 criteria for supplier selection. Environmental performance counts for 50%, technical considerations (including capacity, comfort and power supply system) for 25% and overall 3-year cost for 25%. Under the environmental criterion, minimisation of $CO_2$, PM and NOx emissions each counts for 15% of the total and waste minimisation/ recyclability for 5%.

## Report on Environment in Italian Cities

The Italian Environmental Protection Agency's (APAT) annual study of the environment in cities of over 150000 inhabitants says that cars were the chief culprits for poor air quality in 19 of the 24 Italian cities it looked at. In 11 cities, cars were to blame for over 50% of emissions dangerous to human health, rising to over 60% in Rome, Turin and Messina. The report says that levels of NOx, benzene, and CO have all risen. Levels of PM10, thought to cause over 8000 deaths in Italy each year, have fallen in recent years nationwide but are still dangerously high, said the report. APAT also reports that over 10% of cars on the road now meet Euro 4 standards, rising to nearly a quarter of all vehicles in Rome.

## Dutch Retrofit Subsidy reaches Ceiling for Heaviest Vehicles

The Dutch subsidy scheme for retrofitting soot filters to trucks and buses has reached its ceiling of 1000 vehicles for the heaviest power category. The subsidy Regulation, which has a total budget of €34 million, set a limit of up to 1000 vehicles with a power capacity over 225 kW in 2008. At 7 February 2008, 1000 vehicles in this heaviest power category have already been equipped with a retrofit soot filter. As a result, vehicles with a power capacity over 225kW are no longer entitled to a subsidy. Trucks and buses below 225kW can, however, still apply for a subsidy for retrofitting a soot filter in 2008.

## Romania to introduce Emissions-based Car Taxes

Romania has announced that a revised, pollution-based annual tax will be introduced from 1 July 2008. The new tax is to be based 30% on $CO_2$ emissions and 70% on pollutant emissions for the Euro 3 and Euro 4 cars. There will also be rates for Euro 5, hybrid and electric cars. For Euro 1, Euro 2 and non-Euro cars the present formula will continue.

## Germany cancels Plans for E10

Germany's Federal Environment Minister has announced that the country will not proceed with plans for the mandatory introduction of petrol containing up to 10% ethanol (E10). The current European Standard EN228 allows only up to 5% ethanol as a blending component. The introduction of B7 (Diesel with 7% biodiesel), though, remains a target.

The German motor industry association, VDA, had originally said that 189 000 of its members' vehicles would not be compatible with E10, and had assumed that this scaled up to some 360 000 vehicles for the whole market. But discussions with the importers association, the Verband der Internationalen Kraftfahrzeughersteller (VDIK), raised this figure to over three million vehicles. Motorists whose vehicles are not compatible with E10 would be forced to use the more expensive, higher octane Super Plus grade, which is not blended.

## Eurotunnel asks for Retrofit Emissions Systems for Shunting Locomotives

Eurotunnel, operator of the channel tunnel rail link between France and the UK, has issued a tender notice for the installation of Exhaust Gas Emissions Control Systems on 9 diesel shunting locomotives to replace the current exhaust systems so as to meet European Stage IIIB/IV specifications. The new system must be installed on the locomotive in the space currently taken by the existing exhaust. The engines will be fuelled by ultra-low sulfur diesel to the European diesel fuel standard EN590.

# NORTH AMERICA

## US EPA announces new Locomotive and Marine Diesel Emissions Rules

The US Environmental Protection Agency (EPA) has announced the final version of its new emissions standards for locomotive and for marine diesel engines, which EPA says will reduce their PM and NOx emissions by up to 90%. The new rules set near-term Tier 3 standards and longer-term (2014/2015)

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# Performance and Emissions of a Natural Gas Fueled Two-Stroke SI Engine

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## ABSTRACT

This paper presents the results of an experimental activity carried out on a two-stroke SI engine for moped (with a displacement 50 $cm^3$) fueled alternatively by gasoline and natural gas.

The effect of the fuel on engine performance and efficiency was evaluated comparing both instantaneous (pressure signal in the crankcase, cylinder and exhaust pipe) and overall data (torque, power, fuel consumption, emissions).

Cylinder pressure was measured in order to evaluate the effect of fuel on the optimum ignition timing angle and on cyclic dispersion.

Engine emissions were measured by means of a gas analyzer and a gas-chromatograph.

Moreover this experimental analysis has been carried out also to validate the 1D-3D numerical model for the simulation of the scavenging and combustion processes in a small-size spark-ignition two-stroke engine. This activity is reported in another paper [1].

## INTRODUCTION

The number, size and geographical distribution of large urban centers have increased dramatically during the second half of the 20th century and higher levels of pollution accompany this growth [2], where the principal cause is due to the transportation of goods and people.

Despite the huge industrial and research costs undertaken and despite the good technical results already obtained for the reduction of the pollutant species produced by gasoline and diesel cars, additional efforts and solutions to diminish the urban centers pollution are still today required within a relatively short term.

A possible solution to reduce pollutant emissions, waiting for some others that will require a longer development period (electrical vehicles of satisfactory operation, fuel-cells, hydrogen utilization, etc.), could be the use of gaseous fuels, in particular natural gas. This fuel can give a strong contribution in reducing exhaust emissions, due to its own chemical composition, reducing the $CO_2$ and consequently the "greenhouse effect" [3], and to its capability to assure a stable combustion process even under unfavorable conditions such as in the presence of diluted mixtures, typical of two-stroke engines running at partial load.

The above considerations also hold for the two-wheels vehicles (mopeds and motorcycles) which represent today a partial answer to the mobility problems coming from automobiles congestion in the urban centers. However they do not also offer a valid solution to the problems connected with the environmental impact [4,5].

Emission limits for moped and motorcycles have been enforced recently if compared with passenger cars and heavy duty vehicles. At the present these limits are not particularly severe, however in the future they will become stricter, as also demonstrated by the research efforts performed in this field by important manufacturers [6-8].

There hence exists an increasing demand for technological innovation of small-size 2- or 4-stroke engines, equipping such vehicles, even if this could create problems due to cost restraints. In fact, it must be realized that the two-wheels vehicles cannot bear the same cost increase that have been approved in the automotive industry, to reduce the pollutant emissions.

The challenge is therefore to realize a technological transfer of the abatement methodologies available in the automotive field [9-11], with the awareness of the necessity of a simplification and a partial redefinition of the different solutions. Simultaneously, the scientific community must also undertake the search of innovative strategies [12,13].

In the current literature, with reference to the automotive application, important contributions are available dealing with the development of new natural gas fuelled engines [14], or complying with the conversion of existing engines to allow for the employment of the natural gas [15-17]. Such studies are indeed practically absent in the case of the small-size two-stroke engines. The utilization of the natural gas within such engines can lead to a considerable improvement of both emissions and fuel consumption.

Despite the considerable research effort focused on the application of the direct fuel injection [18-20], engine producers are trying, especially in the near-term, to preserve the simple two-stroke engine architecture and to find alternative solutions to reduce the pollutant emissions, with a more limited cost increase. This, of course, is in each case linked to the need to reduce the typical short-circuiting flow of unburned mixture through the exhaust duct, that was the main cause of its commercial limitation.

In the present paper an experimental analysis on a two-stroke SI engine for moped fueled alternatively with gasoline and natural gas is reported.

Cylinder pressure data have been analyzed in order to compare burn rates and to evaluate the effect of fuel on flame front speed and consequently on combustion phasing angle. This analysis permits to evaluate the correct ignition timing when running on NG.

A complete look of the engine behavior has been carried out not only to evaluate the typical engine performance variables, as power, overall efficiency, emissions, etc., but also to pick up instantaneous pressures, flow mass rates and flow temperatures in most of engine running conditions, to validate, as said in the abstract, numerical simulation models of the thermo-fluid-dynamic phenomena in a two stroke SI engine.

## THE ENGINE

Experimental investigations were carried out on a traditional one-cylinder crankcase scavenged, carbureted, spark-ignition, two stroke engine, of 50 $cm^3$ displacement (Fig. 1).

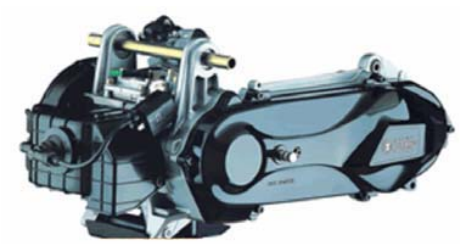

Fig. 1 – The Engine

Additional engine data provided by the engine manufacturer are listed in Tab. 1.

| | |
|---|---|
| Engine model | Ported Two-Stroke SI |
| Scavenging type | Schnurle |
| Displacement | 50 $cm^3$ |
| Compression ratio | 11.7:1 |
| Bore, Stroke | 41, 37.4 mm |
| Maximum Power | 4.1 kW @8000 rpm |
| Maximum Torque | 4.7 Nm @7500 rpm |
| Intake Port Open/Number/Width | 56° BBDC / 5 / 11 mm |
| Exhaust Port Open/Number/Width | 81° BBDC / 1 / 26 mm |

Tab. 1 – Engine Specifications.

## EXPERIMENTAL TEST BED AND TESTING METHOD

A two-stroke engine has been installed on DC testbench and equipped of both instantaneous and overall sensors, according to the outline and the relative legend shown respectively in Fig. 2 and Tab. 2.

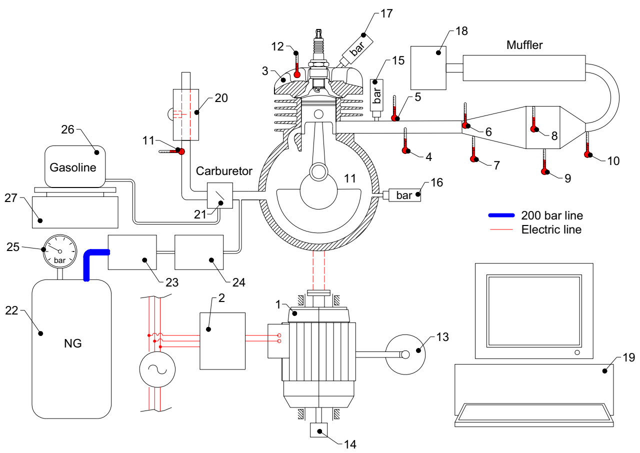


Fig. 2 – Experimental testbed scheme.

| | |
|---|---|
| 1 | DC Electric motor |
| 2 | Central Command electric motor |
| 3 | Engine |
| 4-12 | Thermocouples |
| 13 | Force transducer |
| 14 | Encoder |
| 15-16 | Fast piezoresistive pressure transducer |
| 17 | Miniature dynamic pressure transducers |
| 18 | Exhaust Analyzer |
| 19 | PC + DAQ Card |
| 20 | Hot wire anemometer |
| 21 | Angular position sensor |
| 22 | Gas Tank |
| 23 | Natural Gas pressure reducer |
| 24 | Natural gas mass flow meter |
| 25 | Pressure Gauge |
| 26 | Petrol tank |
| 27 | Balance |

Tab. 2 – Sensors Legend.

Pressures inside the crankcase, the cylinder and the exhaust pipe were measured with piezoquartz-transducers at engine speeds ranging from 4000 to 8500

# Development of a Direct Injection Retrofit Kit for Reducing Emissions from 2-Stroke Cycle Engines in Asia

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## ABSTRACT

There are over 50 million 2-stroke cycle engines in Asia, powering motorbikes, mopeds, "three-wheelers", "tuk-tuks", and "tricycles". There are over 100,000 2-stroke "tricycles" in Metro Manila used in taxi service, and over 1.7 million in the Philippines. The tricycles' 2-stroke engines are characterized by high levels of hydrocarbon (HC), carbon monoxide (CO), and particulate matter (PM) emissions. A project has been initiated in Metro Manila to demonstrate the potential of "direct in-cylinder fuel injection" (DI) to reduce these emissions. Based on other retrofit applications of the technology, expectations are for a 70%-90% reduction of HC, 50%-70% reduction in CO, 80% reduction in PM, 50% reduction in oil consumption, and 35% reduction in fuel consumption. Phase I of the project involved demonstration of a single tricycle with "retrofit DI". The initial demonstration was performed in Manila in November of 2003. A complete emissions characterization of the vehicle will begin in January 2004. Phase II (2004) is a 10-15 vehicle field test in Metro Manila to document in-use emissions reductions and fuel savings. Phase III (2005) involves the establishment of the infrastructure for widespread dissemination and initiation of a large retrofit program. The final installed cost of the unit has been targeted between $10,000 - $12500 Philippine Pesos ($200-$250USD). An important part of the project involves capacity building; Colorado State University is the technical lead, but is working with NGOs, universities, development agencies, and driver organizations in Metro Manila to develop the necessary skills, technical capabilities and organizational infrastructure. If successful, expansion of the project throughout the Philippines and to other Asian countries will likely occur.

**Keywords:** two stroke, direct injection, tricycle, emissions, pollution, poverty alleviation

# 1.0 INTRODUCTION / PROJECT CONCEPT

## *Carburetion*

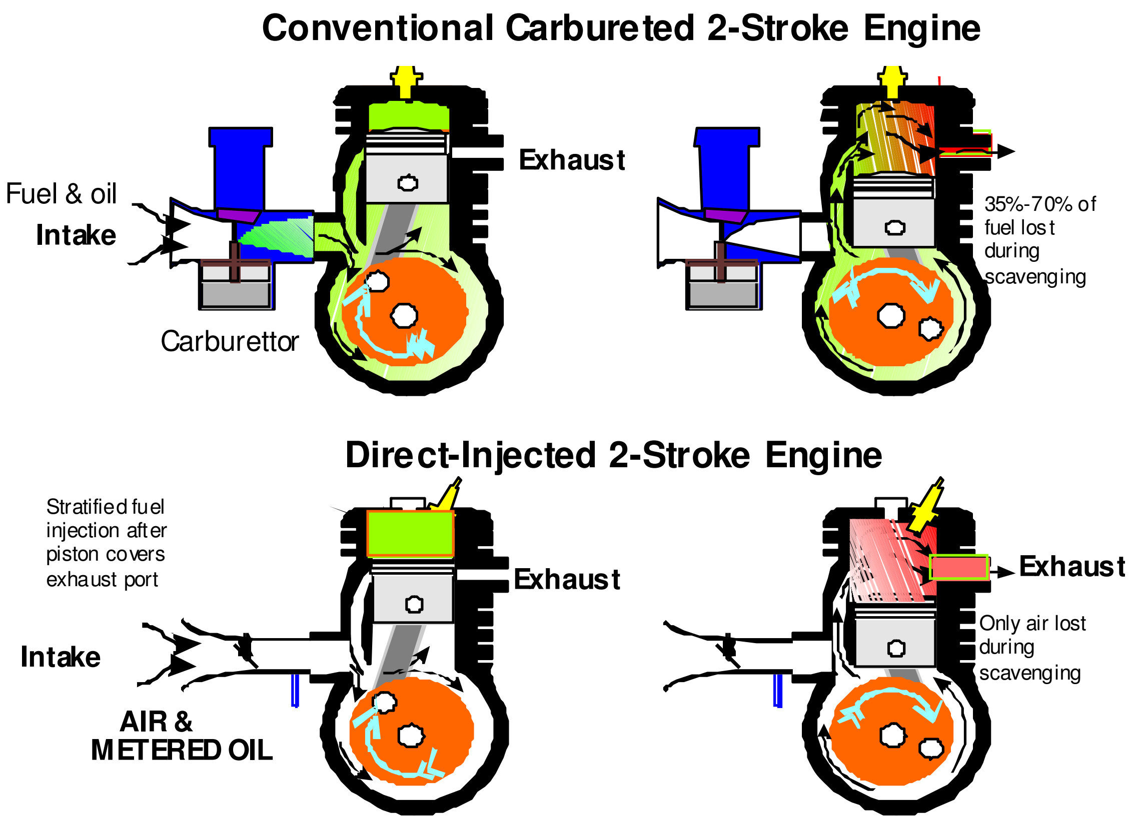
Air pollution is on the increase in many Asian cities due in part to the widespread use of carbureted two-stroke cycle engines. These engines are typically used as the power source for "two-wheelers" (i.e. motorcycles, mopeds, etc.) and "three-wheelers" such as tricycles and tuk-tuks. The main reasons for this are the rugged construction, low cost and high power-to-weight ratio of the two stroke engine. Unfortunately, two-stroke cycle engines are also characterized by high levels of unburned hydrocarbons, carbon monoxide, and particulate emissions. The high hydrocarbon emissions result from the scavenging process used by two stroke engines. Scavenging refers to the process by which the burned exhaust gasses are flushed from the engine. In a conventional "carbureted" two-stroke engine the fuel is entrained in the intake air stream before the combustion air enters the crankcase. The charge is compressed in the crankcase by the underside of the piston, and enters the cylinder when the piston uncovers the transfer ports. Combustion products from the previous cycle are forced or "scavenged" from the cylinder with this new air/fuel charge. Unfortunately, the exhaust ports are also open at this time, allowing 30%-40% of the fuel to be lost directly into the exhaust stream.[1] At idle conditions the losses can be as high as 70%. The high carbon monoxide emissions result from the unstable combustion inherent to carbureted two stroke engines. This instability requires that the engine be operated with rich air/fuel ratios to maintain acceptable combustion stability. This leads to incomplete combustion and high carbon monoxide levels. Finally, the high particulate emissions result from the unstable combustion, excessive lubrication (typical in small two stroke engines), and a lubrication system which allows lubricating oil to be dissolved in the fuel. In a typical 2-stroke, the oil mixes with the fuel at the carburetor. As the air/fuel/oil mixture transfers into the crankcase, the fuel dissolves the oil. This action reduces the amount of oil deposited on the cylinder wall (or other critical components) as it is essentially 'washed' out of the engine by the fuel.

## *Direct In-Cylinder Fuel Injection*

Direct in-cylinder fuel injection (direct injection, DI) is a technology that has shown the ability to greatly reduce emissions from two-stroke engines. In a DI system the carburetor is eliminated, and the fuel is introduced into the combustion chamber via an injector mounted in the top of the chamber's cylinder head. This allows exhaust products to be scavenged from the cylinder using air only. Fuel is injected into the cylinder later in the cycle, greatly reducing the amount of unburned fuel that is allowed to escape during scavenging. The DI process allows for a locally rich region around the spark plug, eliminating the need to enrichen the entire cylinder to achieve stable combustion. Elimination of rich air/fuel ratios significantly reduces carbon monoxide emissions.

## *Retrofit Applications*

The goal of this project is to implement a widespread dissemination program which would enable widespread conversion of carbureted two stroke engines to operation on direct injection. The direct injection technology has been well proven in original engine manufacture (OEM) applications, but has never been commercialized in a retrofit application. In order to successfully implement a widespread retrofit program, a three-phase plan has been established. Phase I of the project involves conversion of a single vehicle. This Phase I milestone was achieved on schedule, with the successful demonstration of an "alpha" prototype DI tricycle at the Clean Air Now conference in Manila in November 2003. The vehicle used was a Kawasaki HDIII 125 cc motorcycle; it was selected because it is the most popular motorcycle used in tricycle service in




the Philippines. Phase II involves retrofitting 10-15 motorcycles in 2004 with a near production level "beta version" retrofit kit and testing them extensively, primarily in Metro Manila. Phase III is the launch of the widespread retrofit program and is scheduled for 2005.

## 2.0 TECHNOLOGY DESCRIPTION – DIRECT INJECTION

In a carbureted engine the fuel is largely vaporized before entering the engine. In a DI engine, the fuel is injected as the piston is returning upward on its compression stroke, limiting the time for fuel to vaporize and mix into a combustible mixture. This time constraint can be overcome by use of an injector that atomizes the fuel into very fine droplets as it is injected. Currently there are several competing DI technologies, each characterized by a different method of atomizing the fuel. The project team selected the Orbital air assisted fuel injection system as most appropriate for use in retrofit applications.

Orbital Engine Corporation (OEC) has developed the air-assisted, spray guided injection system known as the Orbital Combustion Process (OCP).[2] The OCP system utilizes a gasoline injector to meter the fuel. Compressed air is then used to atomize the fuel into tiny droplets. This requires the use of a second injector - the air injector - supplied by a small engine-driven air pump. The OCP system incorporates these injectors into a single injector housing that can be seen on the retrofitted engine in Figure 2. This system results in improved charge control, increased combustion stability, decreased short-circuiting of fuel, and reduced knock sensitivity. The engine control unit (ECU), a low-cost computer, controls the timing and duration of fuel and air injection.

Lubricating oil must still be metered into the engine. However, since the oil is no longer dissolved in fuel, its behavior in the combustion process is fundamentally different, resulting in dramatically reduced production of "white smoke". This is demonstrated by that fact that a fuel-to-oil ratio of 30:1 (typical of carbureted two-strokes) results in virtually smoke-free operation on a DI two-stroke, but produces copious quantities of smoke on a carbureted two-stroke. In addition, since the oil is not washed from internal components by the fuel, the overall oil requirement can be reduced in a DI two-stroke. The OCP system uses a solenoid-driven oil pump controlled by the ECU. This provides the flexibility to "map" the lubrication rate based on speed and load, thus tailoring the oil admission to the engine's lubrication requirements.

As the above description confirms, additional hardware is required to retrofit DI on an existing engine. Figure 2 shows key elements of CSU's successful retrofit kit installed on a 125 cc Kawasaki HD-III engine. A few items are not visible in the picture: the ECU, throttle body, throttle position sensor and ignition coil.

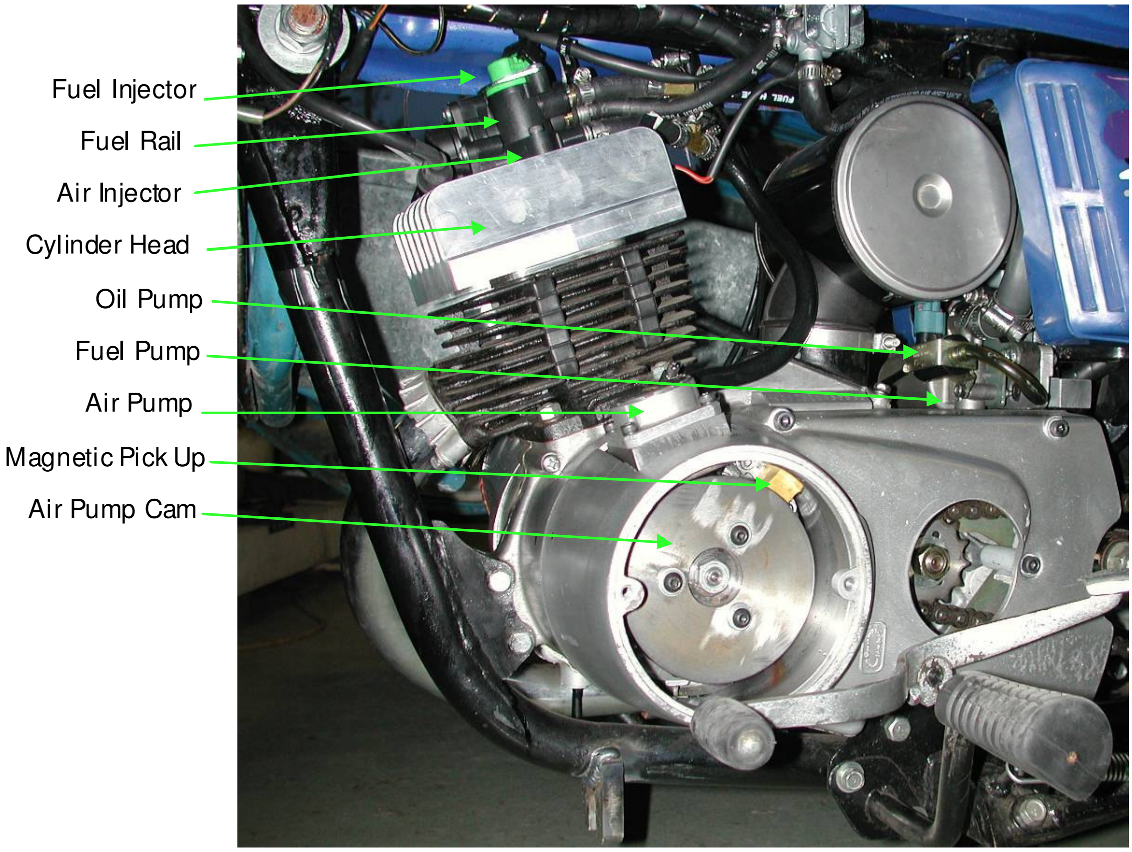



**Figure 2 – Retro fit kit installed on a 125cc Kawasaki HD-III motorcycle**

## 3.0 PROJECT PHASES

The structure developed for implementation of this project involves three phases. The first phase involves building one prototype conversion kit. The second phase is a beta test of 10 to 15 units, and the final phase is widespread implementation. Phase I of the project began in June of 2003 with the shipment of a Kawasaki HD-III to Colorado State University. There, a team of engineers designed and manufactured the components necessary to convert the motorcycle to direct injection. Initial calibrations are complete, and the motorcycle was demonstrated in Manila in November, 2003. This unit is an "alpha unit", which means that the hardware is in an early form - not in the final embodiment envisioned for the Phase III implementation. For example, the new head for the Phase I alpha unit was machined from a solid billet of aluminum, a prohibitively expensive approach for widespread production.

Phase II of the project is scheduled to begin in January 2004. The equipment used in the Phase II field test will be "beta hardware," signifying that it is a step closer to the final production configuration. The heads for the beta engine will be cast (in the Philippines), instead of being machined from billet stock. Significant effort will be directed to the reliability and cost reduction of the kit. The beta units will operate under 'real world' conditions to validate reliability, fuel economy, in-use emissions, and real world performance. During this field test, the motorcycles will be closely monitored, with particular emphasis on fuel consumption, emissions, maintenance requirements, and driver acceptance. This data will help to finalize the design constraints used for production design and calibration.

Phase III, currently slated for early 2005 involves the widespread implementation of direct injection retrofit kits and continued capacity building. Results from the engineering tests in Phase II will be implemented to increase reliability and minimize production costs. Installation centers will expand to cover a larger geographical area in the Philippines.

## 4.0 EXPECTED OUTCOMES

Expected outcomes of the overall project are summarized in this section. Table 1 shows emissions results that were achieved during investigation of a retrofit conversion project in India by Orbital. Unburned hydrocarbons (HC's) and carbon monoxide (CO) were significantly reduced in the transition from carburetion to direct injection. Colorado State University has significant experience in applying the OCP system to snowmobiles. The snowmobile application has demonstrated 90% reduction in HC's, 70% reduction in CO, and 35%+ reduction in fuel consumption. The project team expects comparable results for the tricycle retrofit.

| Vehicle Tested | HC+NOx (g/km) | CO(g/km) | Fuel consumption (km/l) |
|---|---|---|---|
| **Carb. Baseline 150 cc scooter** | 3.8 | 1.2 | 50 |
| **Orbital DI 150 cc scooter** | 0.9 | 0.7 | 70.5 |
| **2005 India emissions legislation proposal** | 1.5 | 0.7 | NA |

**Table 1 - Indian motorcycle exhaust emissions results with air-assist direct injection[3]**

Another expected outcome of the tricycle conversion project is for the owner/operator to see a significant savings in fuel and 2T oil consumption. Based on work completed by both Orbital and CSU[3,4] fuel savings should be on the order of 35%, and 2T consumption should be reduced by half. This has significant energy implications. If 1 million of the 1.7 million registered two-stroke tricycles in the Philippines were converted, the potential fuel savings would exceed 700 million liters per year. These fuel savings produce a significant reduction in greenhouse gases, saving nearly 650,000 tonnes per year. Thus, the project could show very real and lasting results in the Philippines and in other Asian countries where 2-stroke emissions have a major role in air quality.

The energy savings above are expected to produce economic benefits. For a typical driver, the "fluid savings" from reducing the consumption of fuel and lubricating oil are approximately $50 PhP/day ($1 USD). These savings should be compared to a typical driver's net income of approximately $250 Php[5] ($5 USD) per day. A secondary economic benefit involves the creation of small and medium enterprises. Heads, brackets, and wiring harnesses will be manufactured in the Philippines. Kit installation centers will be established close to concentrations of tricycles, and will employ mechanics and apprentices. Production estimates have been established for the retrofit program. These estimates show that at the end of the first year of Phase III, 5,000 - 10,000 retrofit conversions could be completed. Aggressive ramp-up is proposed, with the potential for 500,000 conversions by the end of the third year.

**Figure 3 – Students at Don Bosco Technical College watch the CSU team install the prototype DI retrofit kit on an HD-III motorcycle**

## 5.0 PROGRAM ORGANIZATION

For Phase I and Phase II of the project, Colorado State University is providing the technical leadership. Swisscontact, a Philippines NGO, is undertaking project management within the Philippines and Foundation for Sustainable Society (FSSI) provides a project oversight role. Phase III of the project involves widespread conversion, requiring a "business-like" operation which does not fall under the charters of these organizations. To prepare for Phase III, Colorado State University has formed a standalone non-profit organization, EnviroFit International, to support the widespread implementation program. It is anticipated that a corresponding organization will be established in the Philippines during 2004 to organize and operate the retrofit program. This will be a Philippines-based organization with local ownership and oversight. The structure (for-profit vs. non-profit, etc) is currently being explored.

An element which is anticipated to be critical for the project's success is the issue of financing for the tricycle owners. While all efforts are being made to minimize the cost of the system, the $10,000 – $12,500 Php ($200-$250 USD) cost of the kit may be an obstacle for the tricycle owner. It should be noted that the fuel and oil savings seen from the system allow for a one-year straight pay back of the cost of the kit, but few drivers would have the financial means to invest this sum "up front". If the initial capital can be provided through a micro-financing institution, the potential for the success of the retrofit program will be greatly enhanced. It is anticipated that the Phase III program may ultimately include micro-finance, partial subsidies, driver incentives, and direct driver investment. All of these issues are currently being explored.

## 6.0 CONCLUSION

This paper describes an ongoing project to develop a direct injection retrofit kit for existing two-stroke motorcycles in Southeast Asia. Phase I of the project has been completed and a functioning prototype is now in operation. Phase II will begin in early 2004 and will consist of field-testing 10-15 units to verify reliability and emissions consistency. Phase III is scheduled for 2005 and will take the technology into production for widespread dissemination. Implementation of this technology is expected to result in a 70%-90% reduction of HC, 50%-70% reduction in CO, 80% reduction in PM, 50% reduction in oil consumption, and 35% reduction in fuel consumption. The estimated installed cost for the kit is $10,000 –$12500 Php ($200-$250USD). This cost is approximately equal to the savings that an owner/operator would see in reduced fuel and oil consumption over the course of a year. After that year of operation, the fluids cost savings of approximately $50 Php per day ($1 USD) would equate to a 20% increase income contributing to poverty alleviation. The infrastructure required to facilitate installation and service on the retrofitted vehicles would provide new economic opportunities, providing jobs and training to Filipino workers. Conservative estimates predict 5,000 kits in the first year, with 500,000 installed by the end of the third year. If successful in the Philippines, this approach could be adapted to other Southeast Asian countries that are impacted by high populations of vehicles with two-stroke cycle engines.

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# Emissions Reduction of Small Displacement High Power Engines

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ANDREAS STIHL AG&Co.KG 8. Stuttgarter Symp. März 2008



## 0 Abstract

Small 2-stroke engines are the main power source world wide for handheld products, because they are a simple and robust, their performance matches excellent the various applications. During recent years emissions legislation and fuel cost force a significant change of the development targets and thus, the engine design.

The actual target is to maintain the advantageous design and performance characteristics of the 2-stroke engine with emissions reductions down to 25% the former levels. Stratified scavenging concepts became the main approach, requesting only new cylinder, carburator and piston designs, additional parts such as actuators or valves must not be applied due to the packaging, weight and cost limitations of these products. This paper addresses the major design factors which influence the power and emissions behaviour. A modern engine today is capable to meet the trade-off between power and emissions output on a very competitive level. The new engines STIHL has recently introduced into the market are the first in their class meeting the Phase II limits without exhaust gas aftertreatment. This paper provides the key aspects of the development work for Phase II emission engines at the low displacement end and outlines the future development trends for small engines.

## 1 Introduction

The simplicity and compactness, the competitive power to weight ratio and cost advantage made the small 2-stroke the number one choice during decades. As the emissions legislation began regulating small handheld products and fuel cost now more and more become a considerable issue, the development focus is redirected towards low emission behavior. The concept related scavenging losses made it doubtful whether the 2-stroke will face a future at all. Some manufacturers already questionend the potential of the 2-stroke engine and announced its end. The challenge actually is the low emission engine that combines the advantages of the known technology with the new requirements. Therefore, enormous research and development efforts have been invested to reduce the emissions of the 2-stroke engine as far as possible instead of switching to other technologies.

## 2 Emissions Legislation for Small Handheld Engines

### 2.1 Emission Limits

Beginning in 1997, U.S. EPA and CARB introduced Phase I emission limits for handheld products. Handheld equipment is defined as a product with less than 14 kg (20 kg in the EU) that is being maneuvered or carried by hand during operation, including pumps and generators. The requirements are different to ground equipment, i.e. lawn mowers, considering the special weight and space requirements of this product category. Legislation more and more drives the development efforts, stepwise lower emission limits have to be met in the U.S. and Europe, see Figure 2-1. Today, Phase II limits are active in the U.S., in Europe the implementation is currently in progress. Then, both emission legislations will be harmonized in terms of limits, but not in terms of engine development: The U.S. implemented an averaging, banking and trading (ABT) system, Europe in contrast limits the emissions of each individual machine. This requires expensive parallel product portfolios and product development to meet both legislations. In the U.S. a manufacturer has the opportunity to balance his fleet by offering very low emission engines in suitable applications and gain emission credits. In contrast, all European products must individually comply with the limits, very low emission models cannot be credited.

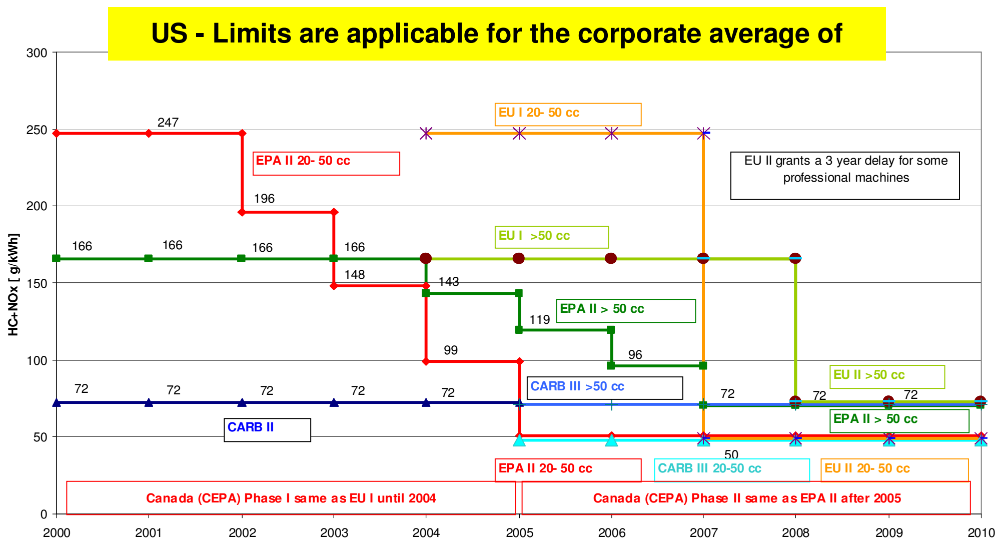


**Figure 2-1:** U.S. and European Phase I and II emission legislation

The limits are defined as a combined $HC+NO_x$ and a CO limit. While $NO_x$ emissions of a 2-stroke engine are in general on a low level, hydrocarbons are the major pollutant, originating from the scavenging losses and incomplete combustion due to rich air/fuel qualities. CO emissions are mainly determined by the $\lambda$-calibration of the engine, the air-cooled engines are operated in $\lambda$-ranges from 0,70 to 0,95 for safe performance with respect to durability and heat control.

The limits are set up for two engine displacement categories: displacements smaller than 50 $cm^3$ must meet a combined $HC+NO_x$ limit of 50 g/kWh and 805 g/kWh CO, displacements bigger than 50 $cm^3$ must meet 72 g/kWh $HC+NO_x$ and 603 g/kWh CO. The limits for the smaller class are more difficult to achieve, because the smaller the dimensions are the more effort is necessary for optimization and tuning work, also manufacturing tolerances have a significant influence.

## 2.2 Test Cycle

Handheld power equipment products are certified in the weighted 2-mode G3 cycle with 15% idle and 85% rated power emissions, see Table 2-1. The emissions are calculated from the two modes as weighted, specific values relative to the rated power level. They must be guaranteed throughout product lifetime, which reaches up to 500 hrs for professional products used in landscaping, construction or logging applications. The emissions increase over lifetime is taken into consideration by a deterioration factor DF applied to the certification value. A second factor describes the statistical tolerances during production. Thus, the certification value modified by the DF and production uncertainties results in the Family Emission Limit FEL, which has to meet the emission limits. This paper focuses on the engines in the range of 30 cm³, therefore, in the following test results are discussed in relation to the low limit of 50 g/kWh ($HC+NO_x$), also called FEL50.

**Table 2-1:** G3 2-mode test cycle for handheld engines

| Test Phase | 1 | 2 |
|---|---|---|
| Engine speed | Idle speed | Rated speed |
| Engine Load | 0% | 100% |
| Weighing factor | 0,15 | 0,85 |

# 3 Development Targets and Engine Concepts

## 3.1 Development Targets

The emissions compliance of the engine is only one of the multiple requirements the engineer has to face during the development of a handheld product. Low emissions in general are not considered a direct customer benefit, despite the advantages for the environment and the operator in terms of health. The primary customer demands are light weight, compact packaging volume, high power, reduced noise, minimum vibrations, low heat load to the user and good handling at a competitive price. The product must stand all operating conditions and have superior all-position ability, and last but not least a long lifetime. As the actual $CO_2$ discussion and fuel cost get into the customer's mind, fuel efficiency becomes a factor of growing importance with these products. The development goals are now extended to comply with the legislation and reduce fuel cost, in addition to the optimization of the established customer-related performance properties.

Handheld applications require high engine speeds to achieve high specific power output and enable small displacements. Rated power occurs in the range of 8.000 rpm for low speed and 10.500 rpm for high speed applications up to 15.000 rpm. The maximum torque is desired in the medium speed range of 6.000 rpm to provide favorable surplus torque during working.

Idle speed is in the range of 2.800 rpm, enabling a comfortable idle quality of the single-cylinder engines.

The major scope today is the reduction of the HC emissions. Their biggest portion originates from unburned fuel due to the scavenging losses, when the fresh gases leave the combustion chamber before exhaust port closing. The second mechanism is incomplete combustion. Therefore, the development target is to improve the trapping efficiency, which describes the portion of fuel trapped in the cylinder at exhaust closing, without infecting the delivery ratio as the indication for power output.

The other optimization target is the increase of the combustion efficiency. When the fuel losses have been minimized, combustion effects begin to account considerably to the emissions performance. Due to the unfavorable surface-to-volume ratio of their small combustion chambers, and the inadequate mixture formation in the carburator, boundary conditions for complete combustion are critical.

## 3.2 Low Emission Concepts for Handheld Products

There are several ways to reduce the emissions of a 2-stroke engine. One approach would be the adaptation of an exhaust gas aftertreatment technique (1). However, such systems are difficult to adapt to handheld products in terms of weight, durability and heat release. Catalyst applications suffer from the high hydrocarbon values, which create a significant heat load at the necessary conversion rates, impacting the user and potentially the environment. The exothermal heat load of a catalyst is in a similar range as the engine power output. This means that with mid size products up to 3 kW of heat are being produced next to the user's body. Significant effort is necessary to handle such a system, especially the heat and flame control devices make it bulky and costly. The vibration and lifetime requirements especially of professional products result in expensive solutions to achieve mechanically and emission-wise durable catalysts. Unfortunately, the final emission result is rather disappointing due to the limited feasible conversion rate.

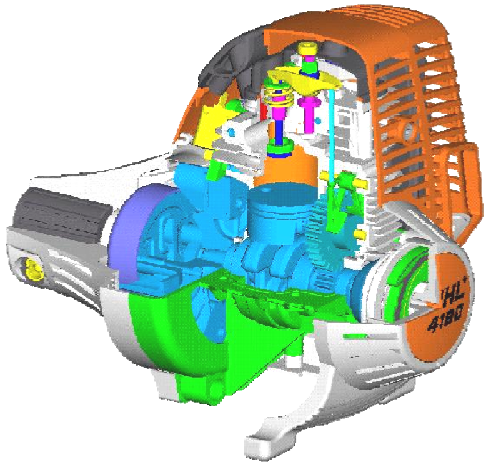

**Figure 3-1:** STIHL 4-Mix engine concept

## 4.2 Mixture Formation and Intake for a Stratified System

An important factor for a successful stratified scavenging is the absence of fuel in the intake air path. The more it is poisoned by fuel, the less efficient is the stratification and the lower the emissions reduction. For this reason two separate throttles were used with the first concepts (5). However, such systems are very sensitive to the timing of the two throttles especially at transient operation. Further, with smaller displacements the venturi diameters get beyond the manufacturable dimensions. Also the packaging requirements request a more compact design. Therefore, the split carburator design has being introduced, offering advantages for small engines: it uses the original carburator size and layout, the venturi is being split into the two intake path downstream the carburator, see Figure 4-1.

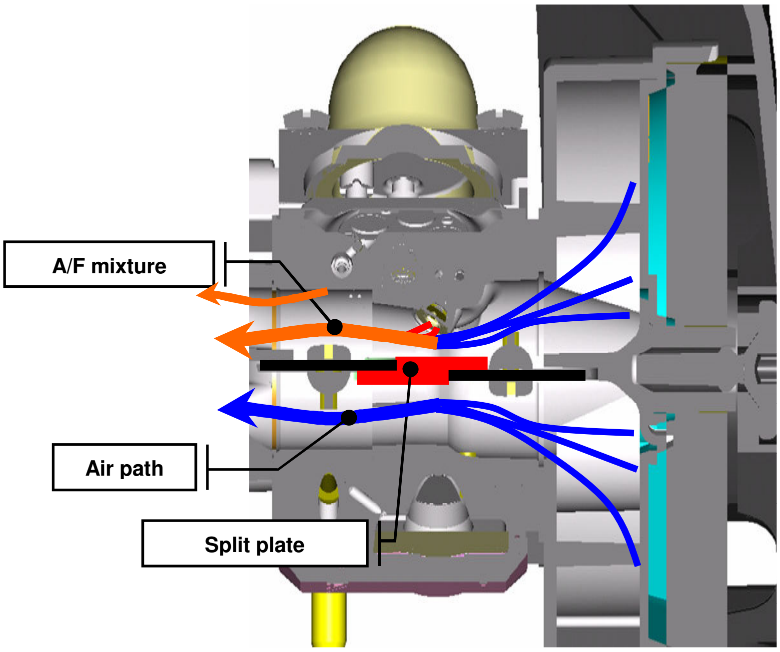


**Figure 4-1:** Split carburator layout for stratified scavenging

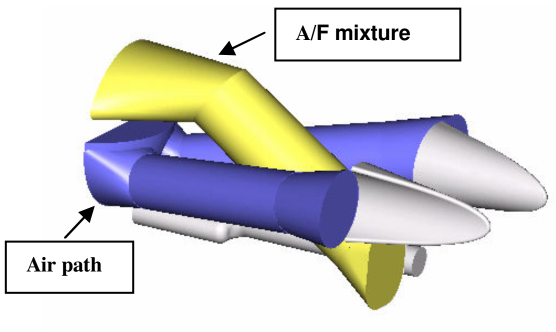


**Figure 4-2:** Two path intake flange of a stratified engine