Reducing transport emissions *today*: Global challenges and solutions

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Transport accounts for many of today's public health, climate change and environmental problems. Reducing transport emissions is crucial for climate change mitigation and air quality improvement, increasing energy efficiency and security and providing a pathway to low-emissions, climate-resilient development. Recent exposure of carmakers' antics in meeting emissions standards reveals problems of current approaches to reducing vehicle emissions, which do not deliver the expected results. IGES provides world-leading, pioneering solutions for reducing global transport emissions today!

The problem: Transport emissions

Transport emissions have significant negative impacts on public health, climate, environment and the economy. **Transport accounts for up to 90% of air pollution in towns and cities, with significant adverse effects on human health**. Air pollution is the main cause of mortality and morbidity globally, leading to at least 1 in 8 deaths, or 7 million deaths annually[1]. In Europe, costs of air pollution are estimated at US$ 1.575 trillion per year[2].

Transport is the largest energy-consuming sector in OECD countries[3] and the **second largest contributor to global GHG emissions**. It accounts for 23% of all energy-related CO_2 emissions globally[4]. Emissions of Short-Lived Climate Pollutants (SLCPs), to which transport is a significant contributor, are responsible for 45% of total global climate-forcing emissions[5]. Transport emissions also negatively affect the environment, biodiversity and food security[6].

Key Transport Pollutants with Adverse Health and Climate Impacts

- **Acetaldehyde**
- **Benzene**
- **Carbon monoxide** (CO)
- **Hydrocarbons** (HC)
- **Tropospheric Ozone**
- **Particulate Matter** (PM):
  PM_{10} – 10 microns or smaller
  $PM_{2.5}$ –2.5 microns or smaller
  Ultrafine particles – 100 nanometers or less
- **Volatile Organic Compounds** (VOCs)
- **Black carbon**
- **Carbon dioxide** (CO_2)
- **Formaldehyde**
- **Nitrogen oxides** (NO_x)
- **Polycyclic aromatic hydrocarbons**
- **Short Lived Climate Pollutants** (SLCPs):
  Black carbon
  Methane
  Ozone
- **Sulphur dioxide** (SO_2)

Below we present some key challenges to reducing transport emissions and IGES' solutions to these.

Challenge 1: What do we really know about vehicle emissions?

"Everybody knows – it's in the public domain – that there is a delta between the test regime and real world driving" (Paul Willis, Managing Director, Volkswagen UK, Evidence to UK Parliament in response to VW scandal[7]).

In order to control vehicle emissions, regulators use test cycles for type-approval and periodic vehicle inspections. However, test cycles do not check vehicles in real-world driving conditions. Manufacturers also have various ways of altering vehicle performance to comply with testing procedures[8], as seen in the 2015 emissions scandal. **On-road vehicle emissions are therefore often much higher than permitted**[9].

In Europe, real-world fuel consumption and CO_2 emissions from new passenger cars exceeded official type approval values by up to 50% in 2014[10]. NO_x emissions from diesel cars in the USA and Europe were also found to be up to 7 times higher than those permitted under Euro VI Standards[11,12]. **In practice, test cycles and type approval do not show actual on-road vehicle emissions**.

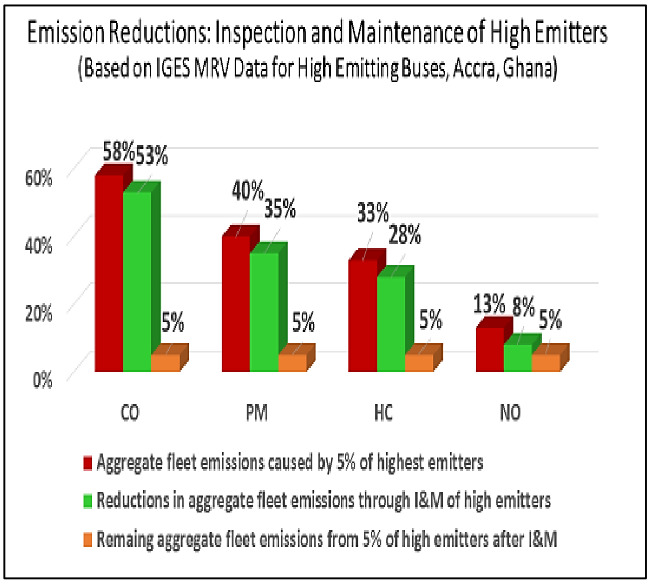
These differences entail significant costs. European drivers incur average additional fuel expenses of €450 a year[13]. Governments lose revenues from ineffective taxation schemes, while carmakers suffer from loss of public confidence and declining stock values. Climate change mitigation, air quality improvement and environmental protection efforts are blocked due to rising transport emissions and public health is severely compromised.

Our solution

IGES undertakes accurate **measurement, reporting and verification (MRV) of on-road vehicle emissions**. We deploy advanced MRV technologies that measure emissions of a large number of vehicles in free-flowing traffic. These technologies measure speed, acceleration and emissions, attributed to unique vehicle license plate numbers. Data are analysed and verified to highest international standards, showing emission plumes of individual vehicles, vehicle types and the vehicle fleet. **The result: highly reliable and accessible information on vehicle emissions.**

This information can then be used for:

- Implementing **real-world emission standards and in-use compliance and enforcement programs** to control and reduce emissions;
- **Targeting high emitting vehicles**: 5-10% of the most polluting vehicles are often responsible for a disproportionate share of overall emissions[14]. Reducing their emissions through, for example, Inspection & Maintenance (I&M) programs provides cost-effective and efficient emissions abatement solutions, as illustrated below.
- **Informing public** of real-time road and pollution conditions, allowing for better traffic and air quality control and management.



Challenge 2: Can existing emission standards reduce pollution?

Emission standards, limiting the release of pollutants from new vehicles, are perhaps the most commonly used means of regulating transport emissions. Euro Standards, originally transposed in the EU, have been widely adopted internationally. Euro Standards regulate the emissions of CO, NO_x, total hydrocarbons, non-methane hydrocarbons, PM and particle number.

There are several difficulties with emission standards that prevent the effective reduction of vehicle emissions:

- Standards up to, and including, Euro VI **do not adequately address the emissions of some problematic pollutants**. Notably, no standards directly regulate emissions of black carbon[15], or ultrafine particles and do not control real-world vehicle emissions;

- Standards **can only be applied to new vehicles** and therefore do not tackle emissions of older, on-road vehicles. These standards will therefore NOT have any significant impact on the reduction of air pollution for up to 20 years;

- While the EU is implementing the sixth set of Euro Standards, many countries in other **regions are adopting earlier sets of standards, with less ambitious emission reduction targets**, resulting in overall higher emissions[16];

The full effects of progressive emission standards suffer considerable time lag and will not be felt for up to 20 years. If no additional measures are undertaken, the problem of transport-related pollution will prevail in cities across the world – from Beijing to New Delhi, Manila, Nairobi, London and Sao Paulo.

Our solution

The unique MRV technologies deployed by IGES provide detailed emission baselines, allowing governments to implement effective, efficient and equitable emissions standards and **in-use compliance programs** on vehicle emissions.

- **Effective**: Establishing accurate emission baselines allows for identification of key polluters and pollutants that need to be targeted in order to mitigate climate change and improve local air quality, thus ensuring effective policies and technological measures can be introduced and continuously updated;

- **Efficient**: Identifying high emitters allows standards to be set efficiently, reducing the majority of emissions caused by a small share of vehicles. Significant emission reductions can be achieved in a highly cost-effective manner. In an MRV project IGES conducted in Ghana, we found that reducing emissions of high-emitting busses could result in direct and indirect savings of €25,000 per bus per year[17];

- **Equitable**: By targeting key pollutants and polluters, real-world emission standards ensure continuous air quality improvements are achieved at lowest social costs, providing maximum benefits to local populations and particularly to vulnerable groups that are often exposed to higher levels of air pollution.

Challenge 3: Do existing technologies & fuel switching reduce emissions?

Prevalent technologies may not effectively reduce vehicle emissions, or may lead to an "exchange effect", whereby targeted pollutants are transformed into more harmful pollutants.

Petrol engines

Most emissions are reduced by three-way catalytic converters. As exhaust gases pass through the converter, hydrocarbons are oxidised by oxygen that is released from the reduction of NO_x to N_2. Efficient functioning of the converter requires temperatures of 300-400°C. Engine cold start, urban drive cycles and colder climates can impede emission reductions. In lean-burn petrol engines, the three-way converter does not reduce NO_x emissions. Some manufacturers add NO_x traps to meet standards. However, their performance may be impaired over time, often undetected and requiring costly maintenance. Direct injection petrol vehicles also emit high levels of PM, requiring additional measures to reduce their emissions[18].

Diesel engines

In-cylinder techniques control air-fuel ratios in the engine, avoiding conditions that lead to incomplete oxidation of hydrocarbons and formation of PM, black carbon, NO_x and other hazardous pollutants. These techniques need to be matched with fuel injection and air management systems in order to improve air-fuel mixture, resulting in reduction of PM and NO_x[19]. However, NO_x emissions may rise sharply with high-load operation, often undetected in current test cycles. New vehicles can thus be type-approved, but may not comply with emission standards in real-world driving conditions[20].

After-treatment devices include diesel oxidation catalysts and diesel particulate filters. Diesel Oxidation Catalysts (DOC) **oxidize a range of pollutants into CO_2** and water in the oxygen-rich exhaust stream. Their operation can be obstructed by fuel-sulphur levels of over 150 ppm, increasing SO_2 emissions and their conversion to SO_4[21]. Partial flow filters comprise DOC and flow-through filters, which capture some of the black carbon until regeneration. While these are considered more effective than DOC alone, their performance and durability have yet to be fully confirmed.

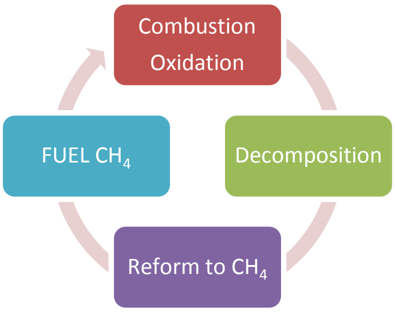
Diesel Particulate Filters (DPF) are designed to capture and eliminate solid accumulation of PM from engine exhaust by oxidising PM to CO_2. Once captured, particles are combusted through passive, active or continuous regeneration. When properly functioning, DPF oxidise PM into CO_2, thus **converting SLCPs and air pollutants to long-term climate pollutants**. If they do not reach the required operating temperatures, significant by-products and more harmful pollutants are produced.

Prevalent emission abatement technologies exhibit mixed performance[22]. Euro VI diesel vehicles may emit 7-10 times more NO_x than achieved in test cycles[23]. The share of NO_2 within these reaches 60%. NO_2 is the most toxic form of NO_x and is one of the main components of $PM_{2.5}$. In London alone, emissions of NO_2 and $PM_{2.5}$ result in the loss of nearly 9,500 lives a year[24]. NO_x also contributes to the creation of tropospheric ozone, an SLCP with adverse health impacts. In effect, emissions abatement technologies may lead to an "exchange effect" [25]. **At best, they transform short-lived climate pollutants into long-term climate pollutants, or may result in more harmful forms of pollutants being released into the environment**.

Alternative fuels have been hailed as a solution for reducing transport emissions. Fuel switching has been implemented in numerous projects and is promoted by many countries as a means of reducing the emissions of CO_2 and other harmful pollutants, including black carbon. For example, Brazil and New Delhi have implemented large-scale projects using ethanol and CNG (respectively) over the past 15 years. However, these efforts have not resolved problems of rising air pollution. New Delhi is considered by the WHO to be the most polluted city in the world[26]. Monitoring of CNG buses in Barcelona demonstrated that these busses emit up to 4 times higher levels of hydrocarbons than diesel-fueled buses, due to incomplete combustion.

Similar problems arise with the combustion of ethanol, which results in higher emissions of hydrocarbons, and particularly methane[27]. The global warming potential of methane is 21 times that of CO_2. Even low levels of emission through incomplete oxidation will have a significant impact on global climate change, negating any potential benefits of fuel switching. While using alternative fuels may lower the emissions of some pollutants, **fuel switching does not address the underlying cause of vehicle emissions – incomplete combustion and oxidation.**

Our solution: Beyond oxidation



Emissions of most pollutants are the result of incomplete oxidation and/or exposure to oxygen at incorrect temperatures in combustion engines. IGES supports advanced innovative technologies to improve fuel combustion and oxidation, advancing combustion beyond oxidation.

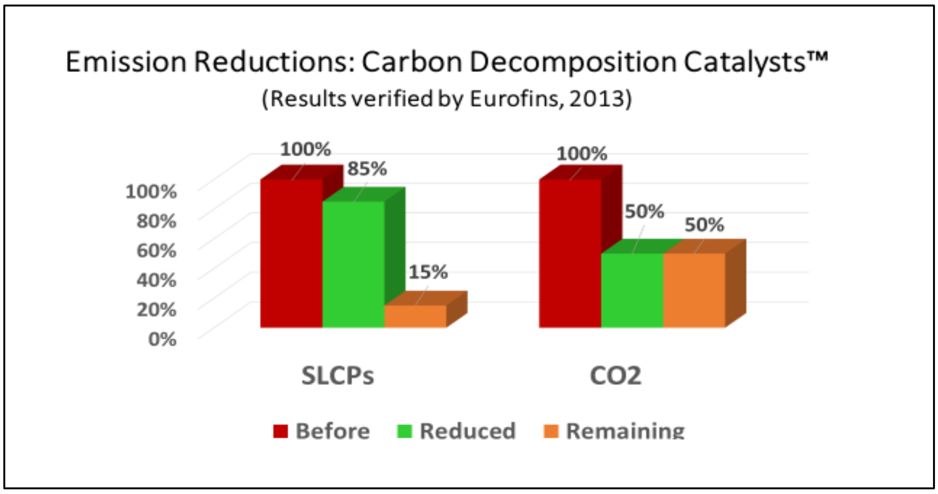
These technologies **significantly reduce vehicle emissions, decomposing particulates, SLCPs *and* carbon dioxide** and subsequently reforming them into methane, which can then be used as a source of fuel or energy storage and not emitted into the atmosphere, as shown above.

These unique Carbon Decomposition Catalysts™ are based on the science of carbon decomposition. Also referred to as Carbon Capture and Reforming (CCR), or Carbon Capture and Utilisation (CCU), carbon decomposition provides significant benefits without the need to store CO_2. It is based on a chemical process called Sabatier Reaction, which involves reaction of carbon dioxide and hydrogen at temperatures of 300-400°C, with the presences of a metal catalyst[28]. Carbon dioxide and hydrogen are transformed into methane (CH_4), water and energy:

$$CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O + \text{energy}$$

By adding hydrogen to internal combustion, carbon dioxide can be decomposed in a closed loop, improving combustion cycle efficiency and creating methane, which can be used immediately or stored for redistribution. This decomposition technique causes a fuel oxidation reaction, which combusts more of the fuel, producing more complete burn ***through oxidation to decomposition*** and hence **significantly reduces the emissions of hazardous pollutants, SLCPs and CO_2**, as illustrated below**.**

This application has significant economic, environmental and social benefits. Reducing the emissions of CO_2, SLCPs, particulates, black carbon, NO_x and other pollutants will generate **co-benefits of mitigating climate change and improving human health**, **energy efficiency and energy security, while creating opportunities for sustainable low emission development**. Carbon decomposition technologies can be used on existing vehicle fleets, eliminating the need for investment in supporting fuel infrastructure, or a shift to electric vehicles.



Challenge 4: Are fuel quality standards helping to lower emissions?

Existing emission abatement technologies require the provision of low-sulphur fuels. High levels of sulphur in fuels reduce the effectiveness of many current technologies, including NO_x and PM after-treatment, SCR catalysts, exhaust gas recirculation systems and diesel particulate filters[29]. As discussed above, when functioning properly, these technologies oxidise particulates into CO_2. When their functioning is impeded, for example by high levels of sulphur in fuel, emissions of more harmful forms of pollutants may result.

The uptake of Euro VI vehicle emission standards requires the introduction of fuels with sulphur content of maximum 15 ppm. While the global availability of low sulphur fuel is increasing, many countries still allow the sale of diesel with sulphur levels of 500 ppm or more. **There are high costs associated with both investments in refinery upgrades necessary for the introduction of low-sulphur fuels and with the introduction of current emission abatement technologies**[30].

The prerequisite for low sulphur fuels for meeting current emission standards, challenges many developing countries and imposes higher fuel costs at the pump for drivers globally. In practice, therefore, emission reductions achieved by this means are limited and entail high, inequitable costs, hindering sustainable low emission development.

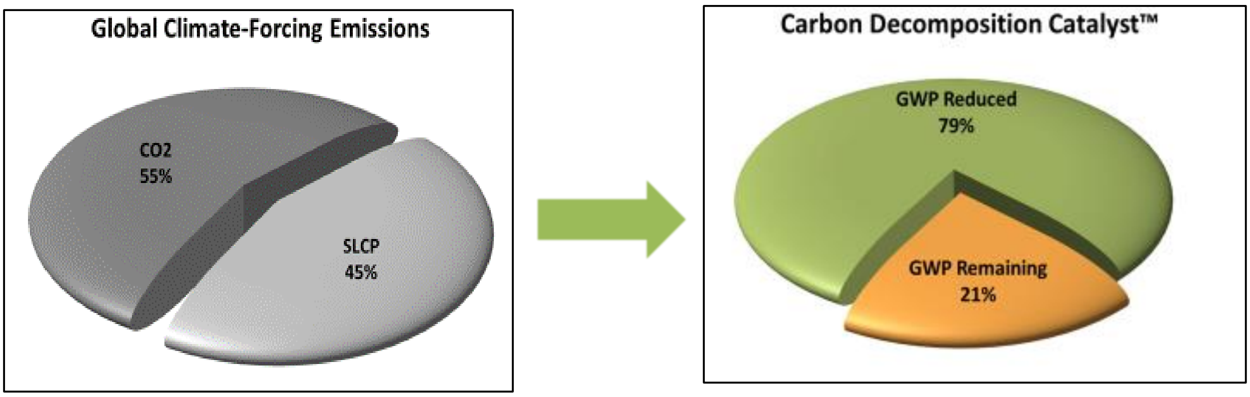
Our solution

Unique Carbon Decomposition Catalysts™ do not require the introduction of low-sulphur fuels and can be retrofitted onto older vehicles that run on high-sulphur fuels. They provide cost-efficient, effective and equitable solutions for reducing vehicle emissions, including those of SLCPs and CO_2, particularly in developing countries that have not introduced low-sulphur fuels. Vehicles can continue operating at greater fuel efficiency and with a lesser impact on human health, climate and the environment, without the need for driving bans or scrappage schemes with high lifecycle emissions and economic costs.

Carbon Decomposition Catalysts™ are:

- Easily applied to existing vehicle fleets, eliminating the need for vehicle scrappage or use bans on older vehicles;
- Competitively priced in comparison to existing emissions reduction technologies;
- Require only limited maintenance, providing cost savings for drivers;
- Eliminate the need for expensive infrastructure investments;
- Allow for continued mobility, while reducing the societal and environmental costs of transport emissions.

These technologies provide a revolutionary impact on global emissions, reducing the global warming potential (GWP) of SLCPs and CO_2 by a staggering 79%, as illustrated below.



Conclusions

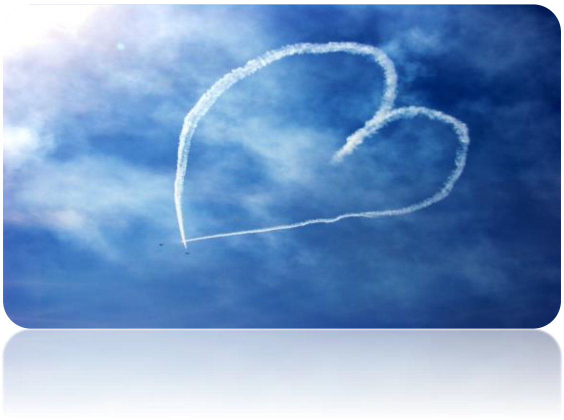
- X Emissions of CO_2, SLCPs and other air-borne pollutants from the transport sector are directly responsible for the lion's share of climate change, with direct correlation to health problems, mortality and morbidity.
- X Inadequate monitoring of real-world emissions, lack of in-use vehicle emissions compliance and enforcement programs and effective policy-based controls have little or no effect on reducing real-world transport emissions.
- X Vehicle emission standards alone are insufficient for reducing transport emissions.
- X Existing emission abatement technologies and particularly DPF and DOC, at best oxidise SLCPs and other pollutants to CO_2 – a long-term climate pollutant. In worst case, they create more harmful pollutants, which increase mortality and morbidity and may negatively affect climate change mitigation efforts.
- X Fuel switch may cause higher GHG emissions through methane slip and may increase emissions of $PM_{2.5}$ or smaller and other hazardous pollutants.
- X Fuel quality standards are expensive to implement, inequitable and inefficient.
- X Electrification and zero emission vehicles require significant investment in infrastructure and are currently cost-prohibitive.

Solutions: Win-Win-Win-Win!

IGES promotes innovative, efficient, effective and equitable solutions for reducing transport emissions, by:

- ✓ Improving monitoring, reporting and verification of transport emissions, providing accurate emission baselines in **real-world driving conditions** and identifying high emitters;
- ✓ Facilitating the introduction of effective real-world emission standards and in-use compliance programs that have immediate impact;
- ✓ Advocating highly effective, efficient and equitable technological solutions for reducing transport emissions and avoiding conversion of SLCPs to long-term climate pollutants;
- ✓ Eliminating the need for major infrastructure investments to improve fuel quality or promote electric mobility, allowing for continued sustainable use of existing vehicle fleets.

A new approach is needed now to maximize the economic, environmental and social benefits of reducing tomorrow's transport emissions today!



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