The Santiago de Chile Diesel Particle Filter Program for Buses of Public Urban Transport

Model Case for Cities of Emerging Countries
and Success Story of the Swiss-Chilean Cooperation

Berne – Switzerland / Santiago de Chile – November 2011

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

Gobierno de Chile

Ministerio del Medio Ambiente (MMA)

This document has been drafted by the Swiss Agency for Development and Cooperation (SDC) and its experts, and has been thoroughly reviewed, discussed and revised by the Chilean environmental authorities.

Preface

As in many cities in the world, for more than 3 decades Santiago de Chile has been suffering serious problems with air quality, particularly with elevated concentrations of particulate matter. Urban transport became the main source of emissions.

Particles from diesel engines are of major concern. They are a toxic air contaminant. Especially the ultrafine particles (nanoparticles) cause severe adverse effects on human health. Moreover, the main component of diesel particles is black carbon: following recent scientific understanding, this is possibly the second-most significant global warming pollutant after carbon dioxide and ahead of methane.

For more than two decades, Diesel Particle Filters (DPF) are the best solution and the best available technology to reduce emissions of ultrafine particles from diesel engines. Nowadays, the variety and scale of available DPF technologies is such that technical solutions can be found for all types of engines, driving cycles and operation modes as well as fuel qualities; whereas in the 1990s, the DPF systems required low sulfur fuel (< 50ppm sulfur content), nowadays quite a few systems are available also for high sulfur fuel. High quality DPF systems achieve emission reductions of ultrafine particles of 99 % and even more. One can even say that such systems not only reduce particle emissions, but also actually eliminate them. Thus, regulations, emission standards and economic instruments implying Diesel Particle Filter (DPF) applications for new heavy duty vehicles and retrofit of in-use heavy duty vehicles are highly impact-oriented, very effectively reduce health costs of air pollution and achieve quick wins for the mitigation of climate change.

The good operation of DPF systems has been demonstrated in tens of thousands of buses, trucks, construction machines and other applications. Nevertheless, before the start of the Santiago de Chile DPF Program, most of the DPF development and application occurred in developed countries of the northern hemisphere and practically no experience existed in the southern hemisphere. Thus, rather differently from close replication among European countries, the Chilean experience had to be newly designed in the context of an emerging country and far away from a neighborhood of natural dissemination processes. The program was conceived and developed on the background of a technical cooperation with Switzerland, one of the pioneers in policy and applied sciences for DPF development and application.

Maturing gradually over the years, the Santiago de Chile DPF Program has become a success story. Nevertheless, it cannot yet rest on its laurels: to achieve fully the expected impact, it is still challenged to develop further its instruments for enforcement and success control. The Chilean experience shows in an exemplary way the challenges, facets and strategic solutions for DPF promotion. With its successful implementation, it stands as a model for similar efforts for cities in emerging countries and for countries in transition.

DPF retrofitted Euro III bus operating in the metropolitan region of Santiago de Chile. Source: Subus.

Contents

1 Introduction

Background

For more than three decades, Santiago de Chile has been facing serious problems with air quality, particularly with elevated particulate matter (PM) concentrations. The annual average concentrations of PM10 (particulate matter with particle size less than 10µm) have been in the range of 70–100 µg/m3, thus clearly above the national air quality standard and the World Health Organization (WHO) reference value of 50 µg/m3. Nearly every year the population suffers several critical episodes with 24-hour average PM10 concentrations higher than 150 µg/m3.

View on Santiago Centre during the critical episode of Pre Emergency. Source Newspaper 'El País'; 25 May 2007.

During the last three decades, the smoking buses of public transport were one of the most visible symbols of Santiago pollution. Consequently the public transport system became one of the main focuses for authorities in the fight against air pollution.

In fact urban transport was the main emission source of PM. According to the official records of the early years of the 21st century, an important share of 22 % of the PM inmissions was attributed to urban public transport with city buses (source Ministry of Environment, Decree N°58 of January 2004).

31 de julio de 1980

OJO ACUSADOR. Un funcionario del Ministerio de Transporte sostiene en su mano la "Carta Ringeling", que le permite medir la intensidad de las emanaciones del tubo de escape de vehículos petroleros con solo la observación visual. Esta medida es una más, en el intento de disminuir la agobiante contaminación ambiental que afecta a Santiago.

An official of the Minister of Public Transport during a public transport bus control on 31 July 1980. Source: Newspaper 'El Mercurio'. Translation of text: "An official of the Minister of Transport holding in his hand a "Ringelmann Chart" in order to enforce the exhaust emissions of diesel buses by visual inspection. This is another action to reduce the overwhelming pollution that affects Santiago City".

To improve the air quality of the Santiago metropolitan region, the Chilean authorities through ENAP, a state oil company, made substantial efforts to improve continuously the fuel quality and reduced stepwise the sulfur content of diesel from 3000 ppm (before 1997) to 50 ppm (2004). One of the motivations of that improvement was to enable the introduction of post-combustion technologies[1].

Overview evolution

90tes	3000 ppm sulfur
1997	1500 ppm sulfur
2001	300 ppm sulfur
2005	50 ppm sulfur
2011	15 ppm sulfur

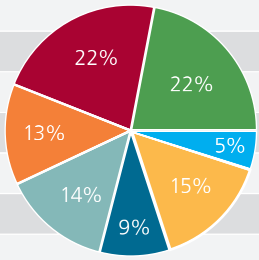
In the last decade, Santiago's public transport system was thoroughly modernized. With Transantiago, which started operation in early 2005, an integrated transport system was introduced. The service network was completely reshaped, infrastructures with separate bus lanes on major traffic routes, bus stops and terminals were built. The number of concessionaires offering bus services was reduced from over 250 to 15 and the number of buses operating in the metropolitan area from 8000 to 6000. With the new transport regime all concessions were redesigned and the subject of new bidding, and the tariff system became integrated.

Obviously, the Transantiago public transport system also aimed at reducing the emissions of atmospheric pollutants, by transformation of the overall system (organizational measures) and by promotion of cleaner buses (technical measures).

1 Note, in parallel also DPF technologies evolved further. Nowadays quite a number of DPF systems no longer depend on the availability of low sulfur fuel. Thus, for any other interested city, high sulfur content is no longer an obstacle for DPF application; it is only a matter of the right system choice.

Population exposure to PM10 (2002)	
60–70 µg/m3	10 %
70–80 µg/m3	6 %
80–90 µg/m3	59 %
90–100 µg/m3	25 %

Responsibility regarding inmissions (1999)



- Bus Fleet
- Trucks
- Light Duty Vehicles
- Combustion Process
- Other Industrial Process
- Residential Sources
- Farming Burning and Others

Bus fleet before Transantiago	
Standard	N° buses
Pre - Euro	1’518
Euro I	2’713
Euro II	3’286
Euro III	642

PM10 population exposure (2002), inmission responsibilities (1999), bus fleet composition (2004); Sources: Ministry of Environment and Coordination of Public Transport of Santiago.

Program start

Since 1996, the Swiss Agency for Development and Cooperation (SDC) has been cooperating with Chilean authorities in matters of clean air. In that context, and – coincidently with Transantiago, looking for clean technologies for new and retrofitted buses – a delegation of Chilean environmental and transport authorities, composed of a mix of high-ranking professionals and key technicians, visited Switzerland in late 2003 and were able to witness on-site the performance and good operation of DPFs in buses. The idea was born to incorporate DPFs in the Transantiago scheme and to support this initiative with Swiss know-how. The Transantiago scheme was a unique opportunity to promote the application of Diesel Particle Filters (DPF) in Santiago de Chile.

The idea of the Santiago de Chile DPF Program was born during the visit of a Chilean Delegation to Switzerland in 2003. The picture shows the delegation of Chile and other Latin-American countries and Swiss advisors.

Program components

The concept for the Santiago de Chile DPF Program was elaborated in close cooperation between

- the environmental entity for the metropolitan area (Ministry of Environment),
- the Centre for Vehicle Control and Certification (3CV; which belongs to the Vice-Ministry of Transport),
- the Public Transport System of Santiago de Chile (Transantiago),
- and a Swiss Advisory Team (on behalf of SDC).

The Santiago de Chile DPF program consisted of three main components:

- DPF retrofit pilot program
- Local certification of DPF
- Implementation of DPF

In addition to these three main components, two other features were decisive for the success of the whole program:

- Capacity building and know-how transfer
- Public-private partnership with international manufacturers of DPF

An overview of the project components is given in the following table:

Component	Swiss cooperation	Chilean counterparts
Pilot program	• Know-how & technology transfer and capacity building • Leverage the participation of main DPF manufacturers	• Introduction and application of necessary facilities for the measurement of emissions of Heavy Duty Vehicles. • Prove the technical feasibility under local conditions • Define local certification requirements • Type approve (combinations of bus & DPF)
Local certification	• Know-how for the introduction of particle number as the best available measurement method for DPF quality evaluation • Know-how for the design of instruments for enforcement	• Introduce legal bases for local certification • Assure good operational conditions under local and specific application • Assure DPF manufacturers local capacity building • Establish basis for the introduction of instruments for enforcement
Implementation under the scheme of the transantiago concessions	• Support for the inclusion of DPF in the Transantiago framework • Support of massive implementation	• Assure and fine-tune the inclusion of DPF in the Transantiago framework
Implementation under the scheme of legally binding regulations	• Support for the development of institutional capacities for legal and institutional decrees and instruments for DPF policy, promotion and application	• Introduce a new emission standard, implying Euro III+DPF for all new buses (since January 2010)

Overview of project components

2 Program activities

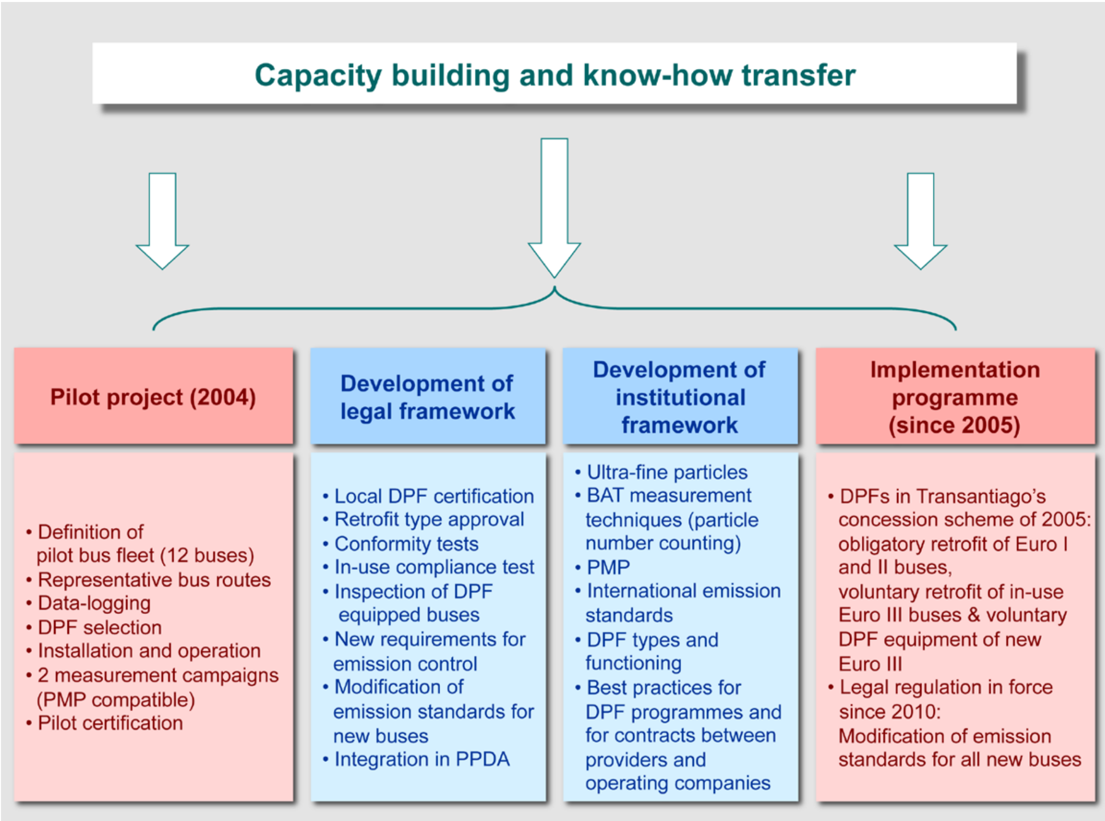
2.1 Capacity building and know-how transfer

The know-how transfer was designed to build-up and to strengthen the capacities of the Chilean counterpart institutions regarding DPF policies, technologies and applications with emphasis on retrofit. On behalf of SDC, the overall responsibility relied on a team of three experts (policy, technology, cooperation). Further specialists of the VERT network (an association of industry and science for the implementation of best available technology of after-treatment systems) were involved for specific work.

The main issues of know-how transfer were the following:

- Overall support for Program design and implementation,
- Best available know-how on diesel engine particle emissions and related measurement techniques (particle number counting instead of conventional gravimetric methods),
- Know-how on DPF technologies and certification, as well as on best practices in retrofit,
- Development of institutional capacities for legal and institutional decrees and instruments for DPF policy, promotion and application,
- Awareness raising and seminars for key personnel of institutions and bus operators.

Facets of the Santiago de Chile DPF program



2.2 Public-private partnership

Furthermore, the Swiss Advisory Team facilitated and leveraged the participation of international DPF manufacturers. From the very beginning they were invited to participate in the pilot activities. For that purpose, they provided manpower and filter systems free of cost and were urged to establish contacts with local firms in order to have their representatives on-site. The pilot project was a chance to promote their products and demonstrate performance and service quality. Finally, some of them successfully competed and achieved sales during the later DPF implementation phase.

In view of the announced requirement of the retrofit of in-use Euro-I and -II buses, local bus companies participated on a voluntary basis in the pilot tests of 2004. The participation allowed them to acquire experience and to improve their competiveness.

2.3 DPF retrofit pilot program

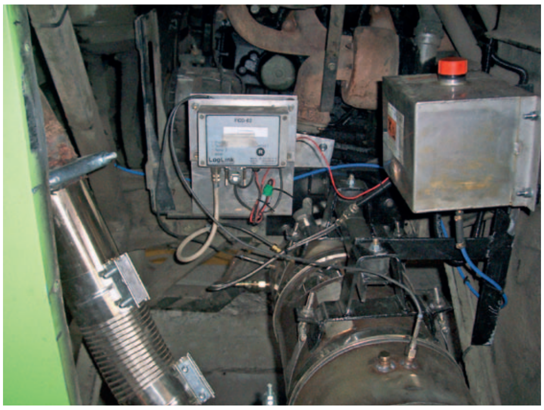
To demonstrate the functioning of the DPF systems in the local Chilean context with its bus types, operation mode, maintenance conditions and routes, in 2004 a pilot project was realized with twelve buses operating in representative conditions.

Nine buses were retrofitted with an internationally homologated DPF system (VERT- or CARB-certified), two buses with a non-homologated DPF system, and one bus was equipped with a diesel oxidative catalyst (DOC).

During two months these systems were evaluated to test filtration efficiency and endurance. The pilot fleet was monitored for operational factors, such as exhaust gas opacity, gas emissions, noise, lubricant and fuel consumptions. Exhaust gas temperature and DPF backpressure were recorded with dataloggers.

All DPF or DOC providers, participating in the pilot activity at their own cost, were informed of the evaluation criteria. Among others, filtration efficiency had to be over 70 % (in particle mass), and no deterioration of filtration efficiency should occur between the first measurement (at the beginning) and the second measurement (at the end of the two-month test-phase). Furthermore, no increment of noise was allowed due to retrofit and DPF operation; therefore also noise was measured with instruments according to the local law. All participants were aware that only those systems which meet these criteria would be locally certified to compete for sales in the subsequent retrofit implementation phase.

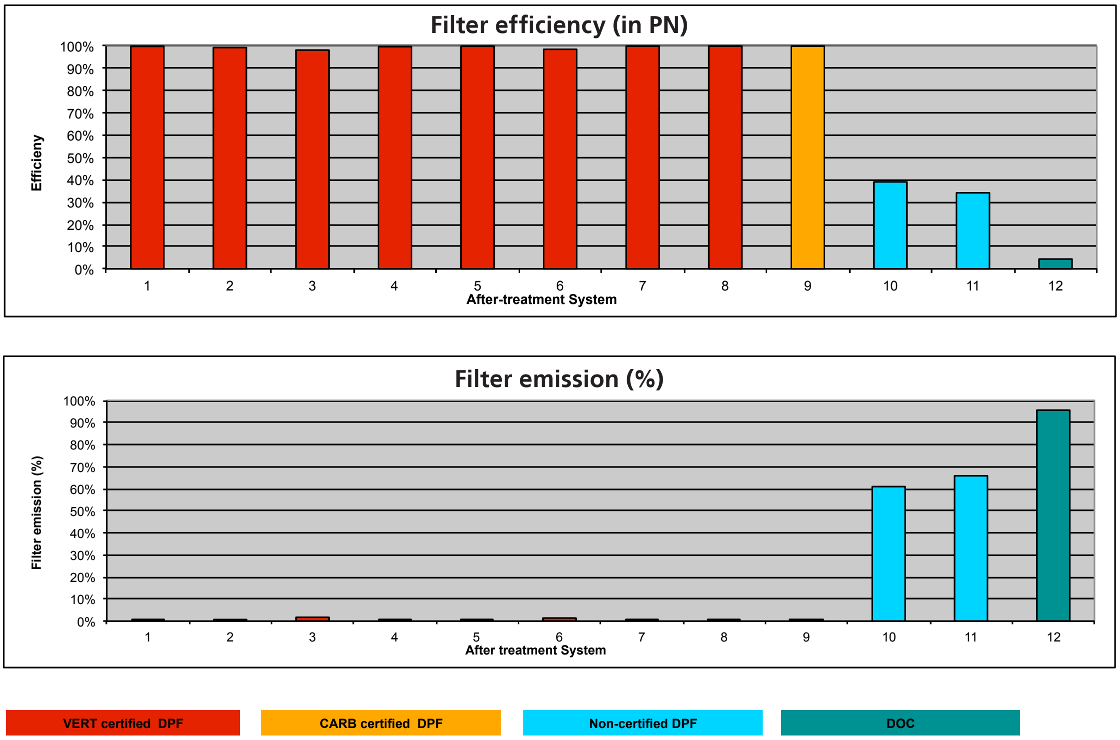
As a part of the pilot program, the best available technology (BAT) of measurement techniques for nanoparticles was introduced, using particle number measurement methods. These techniques were applied in parallel with the conventional gravimetric methods.



Data logger and DPF in a pilot bus (2004).

Measurements with NanoMet during pilot program (2004). Source: 3CV.

Results of the measurement campaign of 2004 with 8 VERT certified DPF, 1 CARB certified DPF and 2 internationally non-certified DPF systems and with 1 diesel oxidative catalyst (DOC). The 3 systems on the right side of the Graph did not get approval. Source 3CV.



The 2004 DPF retrofit pilot project in Santiago de Chile showed that good DPF, also in the local Chilean context, achieve filtration efficiencies of

- higher than 70 % (based on particle mass measurements) for coarse Diesel particles,
- higher than 97 % (based on particle number measurements) for ultrafine Diesel particles.

It also demonstrated that not every DPF is a good DPF and that diesel oxidative catalysts have a very low efficiency in particle emission reduction. This finding becomes most impressive if one looks not only at the filtration efficiency, but also at the remaining particle emission after the DPF, which is the relevant measure for air pollution. Based on particle number counting, the following average values resulted from the pilot program.

No.	System type	Certification	Filtration efficiency	Particle emission
1 – 9	Good DPF	certified	99.5 %	0.5 %
10 – 11	Poor DPF	not certified	37.0 %	73.0 %
12	DOC	not certified	4.4 %	95.6 %

The emissions of buses with a good DPF are about 150 times lower than the emissions of buses with a poor DPF, and about 200 times lower than the emissions of buses with a DOC.

Thus, the pilot project not only proved the technical feasibility of DPF retrofit under local Chilean conditions, but it also convinced the policy makers of the need to introduce a local certification scheme for retrofit devices to guarantee that only systems of top quality are applied.

2.4 Local certification of DPF

Based on its own pilot experience and measurement campaigns of 2004, the Chilean authorities felt encouraged and sufficiently supported to publish in August 2004 the Supreme Decree N° 65, which established the local certification scheme for DPFs and obliged DPFs foreseen for retrofit to undergo that procedure and demonstrate their performance locally. Only already internationally homologized DPFs (by VERT or CARB) are allowed to undertake the local certification.

Similar to the pilot tests, the systems have to demonstrate a filtration efficiency of at least 70 % (measured as particle mass), to be checked and met after installment of the DPF and again after 8000 km in operation. In July 2009 the Supreme Decree N° 130 of 2001 has been changed; thus a DPF filtration efficiency of at least 80 % (measured as particle mass) is now required.

Until 2010, fifteen DPF systems obtained the local certification and are published on the official filter list of 3CV, respectively of the Vice-Ministry of Transport.

2.5 Implementation of DPF

Original policy framework 2005–2008: Economic incentives and norms at the level of concessions

As mentioned before, the introduction of the Transantiago public transport system gave the opportunity to implement a DPF retrofit program as an 'incremental' element with a view to environmental benefits. But obviously, being only a complement of the overall Transantiago system, the DPF implementation program had to adapt its strategy to Transantiago, particularly to its concession scheme.

Originally the Transantiago concession scheme included:

- obligatory DPF retrofit of old Euro I and Euro II buses,
- voluntary DPF installation on newly acquired Euro III buses (to obtain an extension of the concession period (economic incentive).

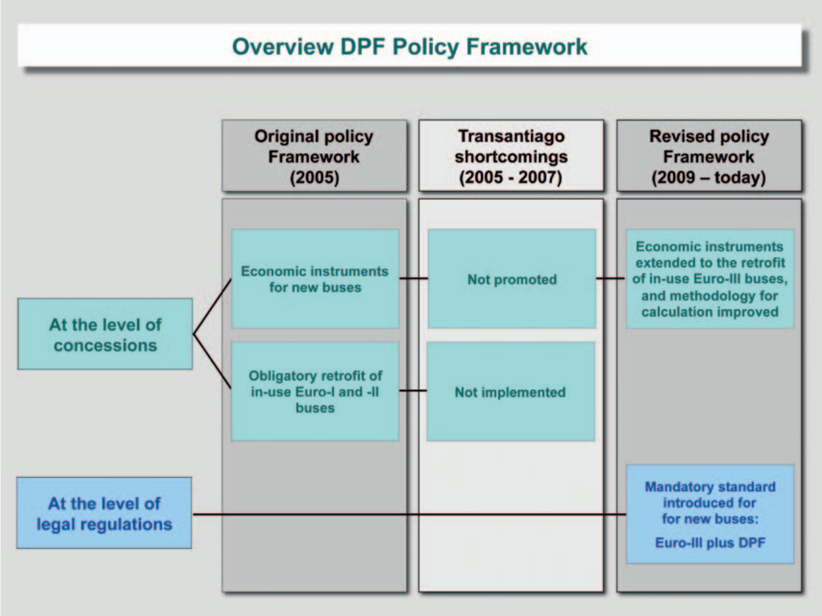
When started, the operation of the Transantiago system was confronted with serious problems (2005 – 2007). Transantiago's first priority was to recover the good and efficient operation of the overall transport system. So the DPF program could not proceed as foreseen. As a consequence of this, the retrofit of old in-use Euro I and Euro II buses suffered a delay, which made it very difficult to resume this activity later on. So, unfortunately, the planned retrofit of old Euro I and Euro II buses was in fact given up. Although the economic incentives for the voluntary installation of DPF were in force, they had not been attractive enough to the concessionaries to initiate a massive implementation of DPF on new Euro III buses.

Revised policy framework (since 2009): Fine-tuning of concessions and introduction of legally binding requirements

In 2009, considering a refreshed interest of the concessionaries for the Transantiago's scheme of granted extension of the concession period, it was further fine-tuned in order to facilitate the voluntary DPF retrofit. Basically, its methodology was improved and further specified, and the retrofit of in-use Euro-III buses was newly introduced into the scheme.

Moreover in September 2009 the Supreme Decree N° 130 of 2001 regarding the emission standards of new buses operating in the metropolitan area was modified. This implies in practice that all new buses must comply with Euro III plus a DPF system with a filtration efficiency of at least 80 % (measured as particle mass). Consequently, Transantiago revised the new concessions in that spirit.

Summary of evolution of policy framework and instruments



Evolution of policy framework and instruments

Basically two different options for implementation exist, and both played a role in the Santiago de Chile DPF Program:

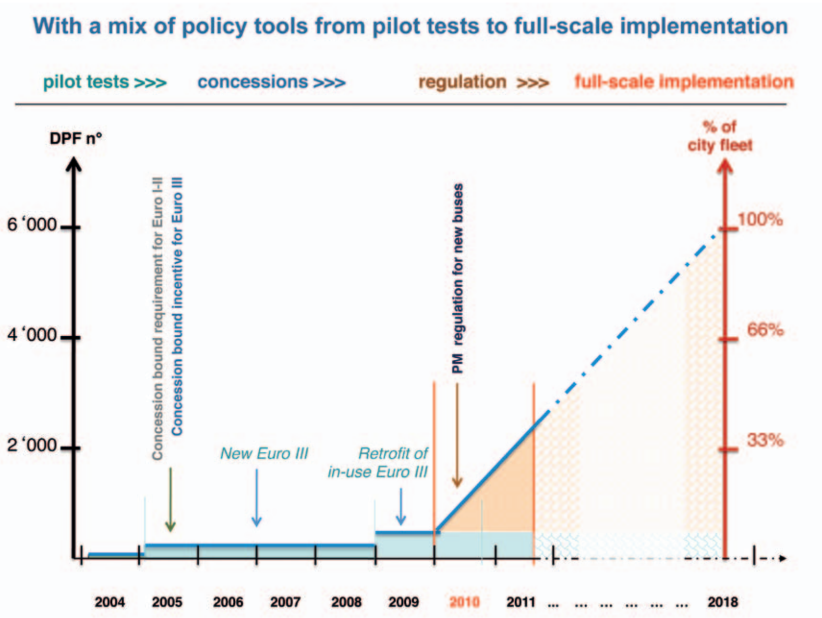
- Option 1: At the level of concessions, in the particular context of "Transantiago", thus of private (or semi-governmental) character
- Option 2: At the level of legal requirements (law, ordinance, decree, including clean air management plans), thus of governmental character.

Implementation results

The breakthrough of the DPF Program resulted first at the level of the voluntary measures. In 2005, one bus company (SUBUS S.A:) acquired 110 new DPF equipped Euro III buses. Encouraged by the very good operation of its after-treatment devices and attracted by the improved economic incentives, the company realized in early 2010 the retrofit of 564 in-use Euro III buses and obtained an additional extension of the concession period. No doubt, the successful experience of this company was a clear and positive signal for the authorities, as well as for Transantiago and all other bus companies.

A big step in DPF implementation was the entering into force in January 2010 of the mandatory legal requirement of the modified Supreme Decree N°130. Through this, up to the end of 2011, an additional 1329 buses have been equipped with DPF, bringing the total number of DPF equipped buses in Santiago de Chile to 2003 buses. This is equivalent to 31 percent of all public transport buses in Santiago metropolitan area.

Year	Increment of number of buses with DPF	Mode of installation	Reason for DPF installation
2005	110 Euro III	New buses, equipped in factory	Incentive
2010	+ 564 Euro III	Retrofit of in-use buses	Incentive
2010–2011	+ 1329 Euro III	New buses, equipped in factory	Mandatory standard



Overview of DPF test and implementation phase, policy tools applied and schematically the level of application achieved

Due to the programs of vehicle renovation, concession plans and the rule that an individual bus may operate for 1 million kilometers at maximum under the Transantiago regime, it is expected that at the latest by 2018 all Santiago buses will operate with DPF systems (according to a projection of current regulations)".

Summary of key assets of the 2009 modification of the Supreme Decree N° 130 of 2001 (regarding the emission standards of new buses operating in the metropolitan area of Santiago de Chile)

- The PM emissions of the bus have to be 80% below Euro III standard.
- The DPF system has to be one of the components which the bus manufacturer offers as the original equipment from the factory.
- The DPF has to fulfill at least one of the following 3 conditions:
  (a) the PM emissions of the combination engine & DPF system are at least 80% below Euro III standard,
  (b) the DPF system is accredited either by the Swiss Federal Office for Environment (Swiss FOEN) or by the Authority of the Californian State (CARB-USA),
  (c) local certification (in combination with a permitted engine type) by the Chilean Centre for Vehicle Control and Certification (3CV), demonstrating a 80 % emission reduction in reference to the engine standard.
- In force since January, 2010.

Box 1: Summary of key assets of Supreme Decree N°42 of 2009 (MTT) with its modification of Supreme Decree N° 130 of 2001 regarding the emission standards of buses operating in the metropolitan area of Santiago de Chile – Diario Oficial de la Re¬pública de Chile, 24 July 2009.

DPF equipped bus, acquired after coming into force of the modification of Supreme Decree N° 130.

2.6 Chronological table of program activities

The following chronological table gives an overview of the main DPF Program activities and achievements. At the same time it visualizes what occurred at the time in the Program's context.

Year	Santiago de Chile DPF Program milestones	Context milestones
2001		• For the Santiago metropolitan area, ENAP reduces sulfur content of diesel to 300 ppm and a further reduction to 50 ppm is decided by the Chilean authorities for 2004
2003	• Reconnaissance mission of key personnel of Chilean institutions to Switzerland	• Retrofit of in-use buses
2004	• Pilot Program with 12 DPF retrofitted buses and measurement campaigns • Requirement of DPF retrofit for all Euro I and II buses operating in the metropolitan area is integrated in Transantiago concession scheme • More explicit consideration of DPF applications using economic incentives by Transantiago	• Transantiago fine-tunes its scheme for new concessions and specifies DPF requirements • Call for tenders for all bus routes operating under the new Transantiago scheme and award of all new concessions of public transport • Sulfur content of diesel (in metropolitan area) is reduced to less than 50 ppm (parts per million) by ENAP
2005	• Based on pilot experience the decree on local certification of DPF applications for retrofit is approved and comes into force • 3 DPF applications are officially certified	• Transantiago starts operation in February • One of the bus companies (SUBUS S.A.) acquires on voluntary basis 110 new EURO III buses equipped with DPF (in order to get an extension of concession period)
2006–2007	• Further DPF applications are certified • Stand-by of assistance for the DPF retrofit implementation • Search for solutions and alternatives • Continuation of know-how transfer	• Due to problems of overall transport systems, the commitments regarding DPF retrofit are delayed • Problems are gradually overcome and Transantiago improves operation
2008	• Law modifying the emission standards is prepared. In practice it implies that all future buses (Euro III or better) need to be equipped with a DPF	• Transantiago develops further its concession scheme in accordance with new law modifying the emission standards • Law for further improvement of diesel quality is prepared
2009	• Law modifying the emission standards is approved and enters into force on January 2010 • SDC's formal cooperation with the Chilean counterparts ends	• One of the bus companies (SUBUS S.A.) realizes a retrofit process on voluntary basis for 564 Euro III buses (achieving further extension of concession period) • All new bus are ordered with DPFs
2010		• New buses equipped with DPFs start operation
2011–2018		• 2011: The 15 ppm Sulfur Content Standard for the metropolitan areas enters in force • 2011–2018: all operating buses without DPF will be replaced by new ones with DPF

Although the Swiss-Chilean bilateral cooperation ended in 2009, the Santiago DPF Program continues. By the end of 2018, all diesel buses under Transantiago will operate with DPFs.

3 Results and benefits

3.1 Number of buses with DPF

By the end of 2011, 2003 buses equipped with DPF operate under the Transantiago regime. As consequence of the modified PM emission standard for new buses (implying Euro III buses with DPF), the fleet renovations scheduled and the concessions expiring, it is estimated that by the end of 2018 all buses operating in Santiago metropolitan area will be equipped with DPF systems (according to a projection of current regulations).

Evolution of DPFs in bus operation in Santiago de Chile. Source Transantiago.

Note: A fleet of 6300 buses to the end of 2018 is a conservative estimation, because it doesn't consider the possible growth of demand and consequently of the Transantiago fleet. However, due to the instruments in force, the percentage of application will be 100% (according to a projection of current regulations).

Year	Description	Total n° of buses	Buses with DPF	% of DPF
2004	Before Transantiago	8169	0	0
2005	1st phase of Transantiago implementation	8169	110	1.3
2007	2nd phase of Transantiago implementation	6300	110	1.8
2009	Rev. econ. Incentive, incl. retrofit of in-use Euro III buses	6300	674	11
2010	Mandatory standard in force	6300	2003	32
(11–18)	New concessions (1)			
2018		6300	6300	100

3.2 PM emission reductions

Basic input data. Sources Transantiago, Ministry of Environment and PPDA – AGIES Report.
Note: PM emissions were calculated considering COPERT III, for urban bus emission factor, with 20 km/h of average speed.

Basic input data on bus fleet and baseline emissions without DPF	
Average lifetime of a bus in Transantiago regime, operating 1 million kilometers	156 months
Annual average distance of a bus operating under the Transantiago regime	75'000 km
Average PM emissions of a Euro III bus in Transantiago regime operating 1 million km	240.0 kg PM
Annual average PM emissions of Euro III bus (without DPF) in Transantiago regime	18.0 kg PM
Annual total PM emissions of Transantiago bus fleet (6300 buses without DPF)	113.4 tons PM

Each DPF on a bus reduces the emission of particulate matter (PM) of this bus by at least 80 percent (measured as particle mass).

Each DPF on a bus reduces the emission of particulate matter (PM) of this bus by at least 97 percent (measured as particle number). This reduction in particle number is most important because it concerns first and foremost ultrafine particles (nanoparticles) with a diameter of less than 300 nanometers. These ultrafine particles are the most harmful ones to human health.

The 2003 DPF equipped buses that operate in 2011 under the Transantiago regime achieve an annual PM emission reduction of approximately 36 tons.

By the end of 2018, when the whole Transantiago fleet of approximately 6300 buses will operate equipped with DPFs, the annual PM emission reduction will correspond to 113 tons.

Annual PM emission reduction (in tons) by DPF equipment of buses under Transantiago. N° of buses with DPF: Source Transantiago.

	2004	2005	2006	2007	2008	2009	2010	…	2018
Buses with DPF	0	110	110	110	110	674	2003	…	6300
Annual PM emission reduction by DPF (tons)	0	2	2	2	2	12	36	…	113

3.3 Health benefits due to PM emission reduction

Health effects attributable to buses in the pre-Transantiago situation (2000–2005)
In 2004 the environmental authority of the Santiago metropolitan region reformulated its Air Pollution Reduction and Prevention Plan for the Metropolitan Area. Its technical and scientific bases were the main environmental reference for the DPF Program design and reflect the air quality situation of the pre-Transantiago situation (2000–2005):

Relevant technical and scientific reference data	
Annual PM emission of buses (primary PM)	1’200 tons
Share of buses in PM concentrations (resulting from emissions of PM and precursor gases)	22%
Annual average of PM10 concentrations in metropolitan region (2000–2004)	> 50 µg/m3

Relevant technical and scientific reference data. Source Ministry of Environment (Decree N°58 of January 2004).

The environmental authority of the metropolitan region estimated at that time the health impact and cost per 1 µg/m3 PM 2.5 as follows:

	Health impact and cost per 1 µg/m3 PM 2.5	
	N° of cases	Cost in USD
Long-term mortality	170	118’580’000 USD
Short-term mortality	28	19’401’000 USD
Morbidity (Bronchitis long- and short-term, hospital admissions, asthma attacks, restricted activity days and work days lost)	Σ	12’120’000 USD
	Total Cost	**150’101’000 USD**

Synthesis of Table 6&7 of AGIES Ministry of Environment 2006, based on updated Study Cifuentes 2000 / 2005

Based on the data given in the upper table and with the non-published application of the WHO model (1999) to determine health costs due to road traffic-related air pollution, the DPF advisory team roughly estimated:

Annual mortality attributable to air pollution in general	≈ 3800
Annual mortality attributable to air pollution generated by buses	≈ 800

Remarks: As the PM10 concentrations levels of the Metropolitan Area are clearly above the “highest assessed level” of the WHO reference (50 µg/m3), the estimation followed the principle of cautionary assessment and used as model input data the concentration level of 50 µg/m3 (thus renounced to apply the probable linear extrapolation at concentrations over 50). This is a conservative way of model-application, so the health effects are most probably higher than estimated with this model-application. Please also note that in the WHO model, long-term effects of air pollution on mortality are more weighted than in the typically applied models in Chile.

Health benefits of the DPF program

The health benefits of the current (2010) and final status (2018) of the DPF Program have not been evaluated explicitly. However they can be qualitatively characterized as follows:

- The primary PM exhaust emissions of the Transantiago bus fleet are reduced by one third by 2010 and will be totally reduced by 2018. Thus, the corresponding health benefits are in the same proportion.
- From the point of view of health, ultrafine solid particles are the top concern, and therefore, the massive reduction of primary PM emissions is a major benefit for public health.

3.4 Benefits of PM / black carbon emission reduction in terms of climate mitigation

Worldwide there is an increasing concern on the part of scientific communities and of policy makers regarding on the global warming effects of black carbon. Although the radiative forcing equivalence ratio per unit mass of BC / CO2 is very elevated, the residence time of black carbon in the atmosphere is relatively short in comparison with CO2. Therefore the effective effect of black carbon on global warming is expressed by the Global Warming Potential, calculated typically for the 20-year or 100-year period.

The reduction of the yearly black carbon emissions of 2480 Euro III buses equipped with DPF (status end of 2010) may correspond in a rough estimation to a Global Warming Potential of 55'000 tons of CO2, calculated on a 20-year basis[1]. When by the end of 2018 approximately 6100 buses operate with DPF-equipment, it will be 2.5 times as much.

1 Following unpublished data of the 4th Assessment Report of IPCC, the GWP-20 of Black Carbon is estimated as 1600; and GWP-100 as 460. Please note that GWP is an index measuring the radiative forcing of a unit mass of a given greenhouse gas in the present-day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide.

Basic assumptions for calculation	
Proportion of BC in PM emissions (rough estimation for Santiago type buses)	75%
GWP-20 of Black Carbon	1600 x (unit CO2)
GWP-100 of Black Carbon	460 x (unit CO2)

Basic assumptions for calculation of BC emissions and effects.

Please note:

- the above indicated 75 % of the BC-proportion of PM is only a rough estimate for Santiago type buses. It is not based on a local analysis of the BC content,
- the above-indicated values for GWP-20 and GWP-100 of black carbon are following unpublished report of the 4th assessment of ICCP. Source ICCT Report 2009 (International Council on Clean Transport).

		BC emission reduction (in tons)	GWP – 20 (x 1600) (equiv. t CO2)
----	Total BC emission reduction of a DPF equipped bus operating 1 million kilometers under Transantiago	0.18	288
Year 2010	Annual average BC emission reduction of 2003 DPF equipped buses	27.0	43'265
Year 2018	Annual average BC emission reduction of 6300 DPF equipped buses	85.0	136'080
Total	**Total BC emission reduction of 6300 DPF equipped buses (operating 1 million km each)**	**1134**	**1'814'400**

Rough estimation of the annual and total BC emission reductions of DPF equipped Euro III buses operating under Transantiago and their corresponding Global Warming Potential for 20 years.

Please note:

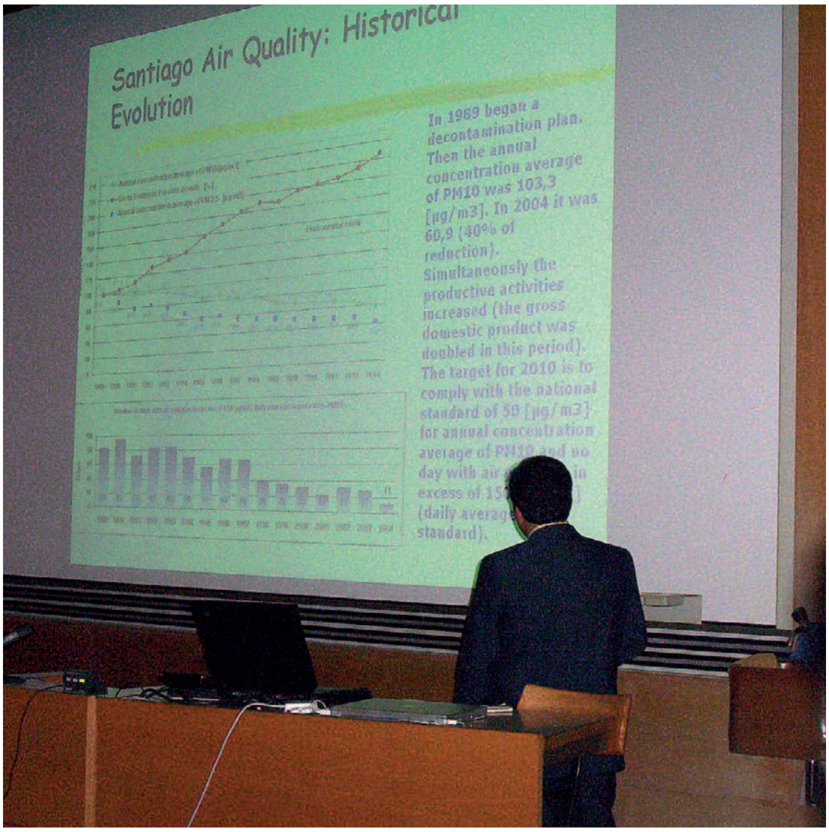
- The BC emission reduction is calculated on the basis of the data of table 3 (sources Transantiago and Ministry of Environment).

3.5 Capacity building and know-how transfer

Regarding ultrafine particles and DPF policy and technology, as a concrete result of know-how transfer, the institutional capacities of the main Chilean counterparts have been built up and strengthened, particularly:

- the environmental authority of the metropolitan region (Ministerial Secretariat of Environment of Metropolitan Region) has been strengthened in DPF policy and technology issues, and
- the Chilean Centre for Vehicle Control and Certification (3CV) has been strengthened in ultrafine particle emission measurement techniques, DPF certification and compliance testing, and has acquired a solid overview on existing DPF technologies.

The know-how transfer also enabled the Chilean counterpart institutions to participate actively in the international scientific and technical DPF community and to establish direct contacts with key experts, institutions and firms worldwide.



Chilean professional lecturing at the annual DPF conference in Zürich Switzerland. Source

3.6 Institutional aspects

The Program's main results at the institutional level are summarized as follows:

- Fine-tuning of incentives for DPFs in the Transantiago scheme,
- Introduction and consolidation of the local certification scheme for DPFs (retrofit and new acquisitions) [Decree N° 65 of 2005],
- Modification of emission standards for buses, implying in practice DPF applications for all new buses.

4 Key factors

- **Capacity building and know-how transfer were the basis for success**
  With the development of new measurement techniques (particularly number counting) and of DPF technologies, the attention given to particle emissions has evolved enormously in the last two decades. Regarding ultrafine particles, the best available technology is today far ahead of conventional understanding and ways of handling PM emissions. Therefore, to implement successfully a DPF program, capacity building is the basis for success. Access to top know-how and to recent progress is a prerequisite. Therefore in the Santiago de Chile case, know-how transfer played a major role in the construction of the local experience. It was never purely theoretical, but always thoroughly target-oriented and focused soundly on practice. Know-how transfer was done in teamwork and soundly combined policy, technology and cooperation. Despite the substantial influence of know-how transfer, the overall process was country-driven and always fully leaded by the competent Chilean institutions. Know-how transfer only played the role of facilitator and was developed with a spirit of dialogue.

- **Creation and consolidation of an inter-institutional network and alliance of motivated technicians and high-ranking professionals (decision-makers)**
  Of crucial importance on the Chilean side was the early establishment of an inter-institutional network of motivated professionals who formed an alliance. This network became the driving force, able to overcome barriers that existed at the level of the individual institutions. It not only consisted of technicians but included from the very beginning high-ranking professionals with decision-making competence.

- **One common vision to improve air quality and a subtle and well-coordinated pragmatic handling**
  All protagonists in the above-mentioned alliance shared the vision to improve air quality substantially by an extensive promotion of DPF applications. However the realization required from each protagonist a subtle and well-coordinated pragmatic handling, acting with several strategic options and steadily in search of politically acceptable solutions and alternative ways to achieve the goals.

- **Involving private DPF partners**
  The VERT association of DPF manufacturers was involved from the very beginning of the program, i.e. as early as the design stage. The participation of private partners brought proper dynamics into the program, which sometimes were not easy to follow from the point of view of the institutions, but which on the other hand were decisive for the program's link with the free market, and for scaling up from pilot activities to implementation. The international DPF manufacturers were requested to establish local networks, to foster local competence and to act through local representatives. Thus, their dialogue with Chilean authorities and bus companies became a subject of discussion among Chileans. In the same spirit, local competitors were involved from the very beginning.

- **Free market competition**
  The DPF program was developed with a clear primacy of free market competition and entrepreneurial decisions. They were guided by legal regulations (local certification of DPF systems, PM emission standard) and the Transantiago concession scheme (with economic instruments). Subsidies, however, were never considered and did not play any role in the DPF promotion in Santiago.

- **Initiative of one bus company**
  The readiness of one bus company in 2005 to acquire on a voluntary basis 110 new DPF equipped Euro III buses was an important step. The good operation of these buses became a strong signal for policymakers, the institutions involved and for other bus companies. It demonstrated that DPF applications in Santiago de Chile really work well under every day conditions.

- **Linkage of pilot project and implementation**
  The design of the pilot activities was embedded in and done in parallel with the design of the overall DPF implementation. This avoided the risks of so many successful pilot projects which after completion just end and never proceed to implementation.

- **Implementation strategy based on several options**
  The implementation scheme was not exclusively based on one pillar but on a mix of several strate-

gic options. This gave the program the necessary flexibility to adapt to the dynamics of its context. Each of the options played an important role during some period. (1) Although the concession-based DPF retrofit of Euro I and Euro II buses was finally uncompleted, in the retrospective, it played a crucial role for the overall success: In 2004 it was the asset to open the discus¬sion on DPF applications, to start and materialize capacity building activities and to raise awareness. (2) The concession-based incentive system for voluntary DPF applications in Euro III buses became somehow the breakthrough for the overall program, as the good operation of the first 110 DPF equipped buses demonstrated the practical feasibility in the local context and encouraged the parties involved to develop the program further. (3) And finally the most determinant result and impact was achieved with the legal regulation which set emission standards in such a way that in practice since September 2009 all new vehicles are acquired with DPF systems.

- **On-site demonstration and application**
  The on-site demonstration of DPF efficiency and the application of BAT nanoparticle measurement techniques by Chilean professionals became a major asset for the policy discussion, and made it very difficult for opponents to argue against the program. Although many international studies existed to demonstrate the performance of DPFs, the realization of tests in Chile and the presentation of own results were the basis of a new understanding and ownership in Chile. The professionals involved acquired new know-how and the policymakers gained in confidence from the locally achieved test results.

- **Clear criteria for pilot project participation and evaluation**
  All providers of diesel engine exhaust gas after-treatment devices, which participated in the local tests on the pilot fleet vehicles, were informed about the evaluation criteria, particularly the particle number criterion, before the tests were carried out. This facilitated the acceptance of the test results. Also, the voluntary participation of non-homologated systems in the pilot activities turned out to be very helpful, as it demonstrated their low performance.

- **Local certification scheme for DPF retrofit: a guarantee for quality and a symbol of Chilean ownership**
  Establishing a local certification scheme for DPF retrofit was decisive to assure the good quality of installed DPFs. Within the framework of locally certified DPF the market was open for free competition among filter manufacturers without the risk of installing poor filters.
  It also reflects a sound adaptation of the externally, Swiss-based VERT philosophy to the Chilean context, respecting fully local diversities and autonomy. The local certification scheme has become a symbol of Chilean ownership and embeds the international DPF homologations VERT and CARB harmonically in the Chilean political and legal framework.

Annex

List of Abbreviations

3CV	Centro de Control y Certificación Vehicular (MTT)
BAT	Best Available Technology
BC	Black Carbon (Soot)
CARB	California Air Resources Board
DOC	Diesel Oxidative Catalyst
DPF	Diesel Particle Filter
ENAP	Empresa Nacional del Petróleo
GWP	Global Warming Potential
MTT	Ministerio de Transportes y Telecomunicaciones
PM	Particulate Matter
PM10	Particulate Matter with particle size $< 10\ \mu m$
PN	Particle Number
PPDA	Plan de Prevención y Descontaminación Atmosférica
SDC	Swiss Agency for Development and Cooperation
Transantiago	Public Transport System of Santiago de Chile
VERT	Verification of Emission Reduction Technologies

Key institutions and professionals involved

Chilean institutions
- Ministry of Environment (former CONAMA).
- Vice-Ministry of Transport
- Centre for Vehicle Control and Certification (3CV)
- Coordination of Public Transport of Santiago
- Empresa Nacional del Petróleo (ENAP – state oil company)

International and Swiss institutions and organizations
- Swiss Agency for Development and Cooperation (SDC)
- Swiss Federal Office for the Environment (FOEN)
- University for Applied Sciences of Bienne / Berne (USASB)
- Swiss Federal Sciences for Materials Science and Technology (EMPA)

Private sector organizations, international DPF manufacturers and Swiss public and private transport entities
- VERT Association of DPF manufacturers (earlier AKPF)
- VERT-Forum
- Participating DPF manufacturers
- Public and private bus companies of Zürich, Winterthur, Berne, Bienne, Thun, …

Key personnel of Chilean institutions
- Alfonso Cádiz (3CV).
- Silvio Albarrán (former Coordination of Public Transport of Santiago, now UOCT).
- Nancy Manríquez (Ministry of Environment).
- Aliosha Reinoso (former 3CV, now head of Geasur).

Swiss advisory core team and further experts associated with cooperation
- Andreas Mayer (TTM): technology advice
- Gerhard Leutert (Air Consult): policy advice
- René Grossmann (Terra Consult): cooperation, coordinator Swiss Team
- Markus Kasper (Matter Engineering): BAT measurement techniques
- Peter Gehr (University of Berne): Health effects of ultrafine particles
- Gustav Benz (former VBZ, now retired): practical experience at company level

Imprint

Text:
Aliosha Reinoso (Geasur), Chile;
+56 (0)2 980 3658; aliosha.reinoso@geasur.cl

René Grossmann (Terra Consult), Switzerland;
+41 (0)31 352 4200; terraconsult@bluewin.ch

Gerhard Leutert (Air Consult), Switzerland

Andreas Mayer (TTM), Switzerland

Graphic design:
Visual Communication FDFA;
Federal Department of Foreign Affairs FDFA, Switzerland

Language revision:
Ann Greco, Switzerland