



SURVEY OF BEST PRACTICES IN REDUCING EMISSIONS THROUGH VEHICLE REPLACEMENT PROGRAMS

FRANCISCO POSADA, DAVID VANCE WAGNER, GAURAV BANSAL, AND ROCIO FERNANDEZ



www.theicct.org
communications@theicct.org

ACKNOWLEDGMENTS

Funding for this work was generously provided by the Climate and Clean Air Coalition (CCAC) and the William and Flora Hewlett Foundation. Special thanks to Anup Bandivadekar, Fanta Kamakate, Rachel Muncrief, and Zifei Yang for their contributions during the preparation of this paper and for their critical and helpful reviews.

© 2015 International Council on Clean Transportation

The International Council on Clean Transportation
1225 I Street NW, Suite 900
Washington DC 20005

www.theicct.org | communications@theicct.org

TABLE OF CONTENTS

| | |
|--|-----------|
| Executive Summary | 1 |
| Chapter 1. Introduction | 4 |
| Background..... | 4 |
| Motivation..... | 4 |
| Vehicle replacement vs. retrofitting or repowering..... | 5 |
| Voluntary vs. mandatory replacement programs..... | 6 |
| Identifying and defining high-emitting vehicles..... | 7 |
| Targeting different types of vehicles and pollutants..... | 7 |
| Economic impacts of vehicle replacement programs..... | 8 |
| Methodology..... | 8 |
| Chapter 2. Best practices in vehicle replacement | 9 |
| 1. For maximum environmental benefits, replacement vehicles should be as clean as possible..... | 9 |
| 2. Program implementation, management, and enforcement should ensure expected benefits are actually achieved..... | 9 |
| 3. Fiscal incentives should be carefully tailored to optimize both environmental benefits and cost-effectiveness..... | 10 |
| 4. Program design should carefully consider and balance the different roles of national, regional, and local-level policymakers..... | 11 |
| 5. Complement fiscal policies with additional incentives such as low emission zones and regulatory backstops..... | 12 |
| Chapter 3. Case Studies | 13 |
| California: Carl Moyer Program..... | 13 |
| United States: Consumer Assistance to Recycle and Save (CARS, a.k.a. Cash for Clunkers)..... | 15 |
| United States: National Clean Diesel Campaign (NCDC)..... | 18 |
| Germany: Scrappage Bonus..... | 20 |
| China: National scrappage programs..... | 22 |
| China: Local scrappage subsidies..... | 25 |
| Beijing's scrappage programs during the 12 th Five-Year Plan (2011-2015)..... | 26 |
| Mexico: National Program to Modernize Federal Road Transportation..... | 28 |
| Mexico City: Program to Replace Medium Capacity Buses with New Autobuses..... | 30 |
| Chile: Swap your Truck..... | 31 |
| Summary of Case Studies | 34 |
| Conclusions | 35 |
| References | 37 |

EXECUTIVE SUMMARY

In many regions of the world, older, high-emitting vehicles account for a small percentage of the overall vehicle fleet but a disproportionately large share of total emissions. It is estimated that these vehicles may be responsible for more than 50% of particulate matter (PM) and black carbon (BC) emissions by 2020 (Yan et al., 2011). There are a wide variety of emission control programs designed to reduce emissions from these legacy, high-emitting vehicles. Vehicle replacement, retrofit, and repower programs can have an immediate and positive environmental impact because they reduce emissions from older, gross emitting, and inefficient vehicles in the fleet within a short period of time. Positive environmental impacts can be achieved with the reduction of gaseous pollutants (CO, HC, NO_x), as well as of particulate matter. Greenhouse gas (GHG) emissions are also reduced, especially of short-lived climate pollutants (SLCPs) such as black carbon, one of the main components of PM emissions. While a region considering one or more of these types of programs should fully assess which would be most cost-effective based on the region's specific capabilities and needs, this report focuses primarily on vehicle replacement programs.

Vehicle replacement programs seek to entirely replace older and gross emitting vehicles with newer, more efficient, and environmentally friendly vehicles. This report evaluates vehicle replacement programs worldwide and suggests five best practices that serve as guidelines for policymakers seeking to design and implement these programs in their jurisdictions.

1. For maximum environmental benefits, replacement vehicles should be as clean as possible

The largest emission reductions are achieved when the replacement vehicles are significantly cleaner than those they replace. For the benefits to be realized, policymakers must ensure that replacement vehicles have much lower pollutant emissions for the full range of operating conditions encountered by the vehicle during its useful life ("real-world" operation).

2. Program implementation, management, and enforcement should ensure expected benefits are actually achieved

It is key that policymakers be cautious that subsidies are not provided for vehicles already abandoned and not in regular operation. In addition, replacement programs ideally include strong oversight and guarantees on the fate (e.g., destruction and recycling) of the replaced vehicles. These measures should ensure that high emitting vehicles do not continue to operate even after subsidies for their retirement have been issued.

3. Fiscal incentives should be carefully tailored to optimize both environmental benefits and cost-effectiveness

The level of fiscal support necessary for a specific program will vary based in part on the severity of the regional air pollution, as well as the targeted vehicle types and resources available. Generally speaking, fiscal incentives should be sufficient to guarantee enough program participation to warrant investment in the program. In the long term, the economic benefits of cleaner or more fuel-efficient vehicles as a result of the program should exceed the fiscal incentives given.

4. Program design should carefully consider and balance the different roles of national, regional, and local-level policymakers

Initially, a large-scale vehicle replacement program may need to be established and funded by a central authority. However, program implementation and especially individual project grant determinations may be best handled by local policymakers who have a detailed understanding of local needs and conditions.

5. Complement fiscal policies with additional incentives such as low emission zones and regulatory backstops

Complementary, non-fiscal measures could include regulatory backstops, low emission zones, mandatory age limits for vehicles, or operation restrictions. These complementary measures not only incentivize increased participation in the voluntary vehicle replacement program, but each measure will also have its own distinct emissions benefits as well.

Eight vehicle replacement programs from around the world were reviewed in the context of the five best practices identified above. The case studies are discussed in detail in the main text. Table ES-1 summarizes some key elements of each case study. Table ES-2 summarizes how each program met the requirements of each best practice.

While policymakers can learn from the experiences of vehicle replacement programs around the world and the best practices discussed in this report, these should not be interpreted to be strict rules. The success of a vehicle replacement program often depends on the specific environmental concerns of a region as well as what features would best complement the local culture. It is therefore key that policymakers keep in mind the specific situation of the region to which the policy is being applied. Likewise, as reflected in Best Practice #5, vehicle replacement programs work best when they are implemented in tandem with other policies to reduce vehicle emissions. Vehicle replacement programs should not be used as an alternative to things like new vehicle emission standards, fuel sulfur reduction strategies, and well-designed inspection and maintenance (I/M) programs. Rather, vehicle replacement programs would ideally be considered as one tool of many to reduce the health and climate impacts of a region's transportation sector.

Table ES-1. Summary of characteristics of vehicle replacement programs analyzed in this report

| Program | Vehicles targeted | Approximate average subsidy offered | Complimentary policies used |
|--|--|--|--|
| US: California: Carl Moyer Program | Multiple types, including on-road and off-road | ~\$28,000 per vehicle | Mandatory upgrades of high polluting vehicles (regulatory backstops) |
| US: Consumer Assistance to Recycle and Save (CARS) | Light-duty vehicles | \$3,500-\$4,500 | None |
| US: National Clean Diesel Campaign (NCDC) | Heavy-duty vehicles | ~\$9,400 per vehicle spent for the program | None |
| Germany: Scrappage Bonus | Light-duty vehicles | \$3,500 | Low emission zones |
| China: National Vehicle Scrappage Program | Light- and heavy-duty vehicles | Varies by vehicle type; between \$980 and \$2,940 | Mandatory vehicle age limits |
| China: Local Vehicle Scrappage Program | Light- and heavy-duty vehicles | Varies by vehicle type; LDVs: \$410-2410 HDVs: \$1,330-\$2,100 | Mandatory vehicle age limits and low emission zones |
| Mexico: Program to Modernize Federal Road Transportation | Heavy-duty vehicles on federal highways | Up to 15% of the cost of the replacement vehicle | None |
| Mexico: Mexico City: Program to Replace Microbuses with New Autobuses | City buses | Up to \$7,700 | None |
| Chile: Swap your Truck | Heavy-duty trucks | From \$8,000 to \$24,000 depending on vehicle category | Partial: there is a ministerial decree to implement a low emission zone, but it has not been executed. |

Table ES-2. Analysis of vehicle replacement programs in the context of the five best practices defined in this report

| Vehicle Replacement Program | Best Practice | | | | |
|--|---------------|-----------|-----------|-----|-----|
| | #1 | #2 | #3 | #4 | #5 |
| US: California: Carl Moyer Program | Yes | Yes | Yes | Yes | Yes |
| US: Consumer Assistance to Recycle and Save (CARS) | No | Partially | Partially | No | No |
| US: National Clean Diesel Campaign (NCDC) | Yes | Yes | Yes | Yes | No |
| Germany: Scrappage Bonus | Yes | No | No | No | Yes |
| China: National Vehicle Scrappage Program | Yes | Yes | No | Yes | Yes |
| China: Local Vehicle Scrappage Program | Yes | Partially | No | Yes | Yes |
| Mexico: Program to Modernize Federal Road Transportation | Yes | Yes | Yes | No | No |
| Mexico: Mexico City: Program to Replace Microbuses with New Autobuses | Yes | Yes | Yes | Yes | No |
| Chile: Swap Your Truck | Yes | Yes | No | No | No |

CHAPTER 1. INTRODUCTION

BACKGROUND

Vehicle emissions have long been known to have harmful effects on human health and the environment (HEI, 2010; Chambliss et al., 2013). Many countries and regions—especially those with mature vehicle markets—have taken actions to mitigate vehicle emissions. As technology has developed and policymakers have learned from past experience and from each other, vehicle emission control programs have been strengthened. Successful experience in both developed and developing countries has confirmed that a comprehensive, mature program to maximize emission reductions and air quality benefits must widely target all types of vehicles with control programs affecting both new and legacy fleets. These programs include establishing progressively more stringent vehicle emission limits for new vehicles, implementing stepwise improvements in fuel quality, mandating inspection and maintenance (I/M) programs to prevent gross emitters, implementing vehicle replacement and retrofit programs for older or high-emitting vehicles, and more.

Without diminishing the importance of other types of vehicle regulations, this report focuses on one particular strategy to control emissions from in-use vehicles: vehicle replacement programs (sometimes called “scrappage” programs). In such programs, governments encourage vehicle owners to upgrade their vehicles to newer, cleaner models, even if the existing vehicles still have remaining useful life. These programs can be very effective in regions in which many old, high-emitting vehicles are still in operation.

MOTIVATION

Older vehicles often emit a disproportionately large share of total emissions, especially in regions that have rapidly implemented new tailpipe emission standards. For example, China’s Ministry of Environmental Protection estimated that in 2011, ten-year old and older vehicles (Euro 0 and Euro I equivalent) constituted just 15% of the total vehicle fleet, but emitted 61% of NO_x and 76% of PM (MEP, 2012). Measurements carried out by Wang et al. (2011) in Beijing show that around 50% of PM and black carbon emissions come from high-emitter vehicles. The story is similar in India, where the International Council on Clean Transportation (ICCT) estimated that pre-2003 vehicles constituted less than 20% of the total vehicle fleet but accounted for nearly half of all vehicular PM emissions and a third of NO_x emissions in 2011 (Bansal and Bandivadekar, 2013). In the US, where new vehicles are using diesel particulate filters since 2007, the impact of high emitters becomes more evident. According to measurements of BC emissions performed by Ban-Weiss et al. (2009) on 251 trucks in California, 45% of BC emissions come from a small share of high-emitter trucks (13%). It is not surprising that global modeling of PM emissions by vehicle model and technology performed by Yan et al. (2011) show that high-emitter vehicles could become the largest contributors of PM emissions by 2020, especially from Asia, Africa and Latin America. Moreover, the 2011 UNEP Integrated Assessment of Black Carbon and Tropospheric Ozone identified elimination of high-emitting vehicles for road and off-road engines as one of two key measures for mitigation of international emissions of black carbon in the transport sector (Shindell et al. 2011). Removing these vehicles from the fleet is clearly a high priority for policymakers wishing to achieve rapid environmental benefits.

Older vehicles are also fitted with outdated and inefficient powertrain technologies, which has a negative impact on fuel consumption and CO₂ emissions. Some countries have adopted vehicle replacement programs and complementary policy measures that promote the removal of those vehicles and the purchase of newer, fuel efficient ones. The US and Germany are examples of countries that have implemented vehicle replacement programs targeting fuel and CO₂ savings, with the added benefit of stimulating the auto industry (Lensky et al., 2010).

This report aims to be a guide for regions developing and implementing vehicle replacement programs. The report first establishes five best practice principles in designing and implementing a vehicle replacement program. It then analyzes various vehicle replacement programs that have been implemented around the world on the basis of these five principles. While not a complete list of replacement programs around the world, the case studies intentionally cover a wide variety of regions and programs targeting different types of vehicles. The successes and shortcomings of each program are discussed.

It is important to note that vehicle fleets and socioeconomic conditions may vary dramatically from one region to another. Therefore, while this report establishes basic principles for vehicle replacement programs, it does not make detailed recommendations for any one particular country or region. It is imperative that policymakers fully consider local needs and conditions while designing a vehicle replacement program.

VEHICLE REPLACEMENT VS. RETROFITTING OR REPOWERING

Vehicle replacement programs seek to eliminate older or high-emitting vehicles from the fleet altogether. In contrast, retrofit or repower programs upgrade older or high-emitting vehicles so they may continue to operate while emitting lower levels of pollution. Table 1 briefly compares replacement, retrofit, and repower programs.

Table 1. Comparison of replacement, retrofit, and repower programs

| Program Type | Description | Advantages | Disadvantages |
|--------------------|--|---|--|
| Replacement | Eliminate full vehicles from the fleet and replace them with newer, lower emitting ones | <ul style="list-style-type: none"> • Simple and straightforward program design • May have economic co-benefits • Can increase safety and reduce noise pollution in parallel | <ul style="list-style-type: none"> • May not be as cost-effective as retrofitting or repowering for some vehicle types • May be higher upfront cost per vehicle than retrofitting or repowering |
| Retrofit | Install additional pollution control equipment (e.g., diesel particulate filter (DPF) or selective catalytic reduction (SCR) or both) on existing vehicles | <ul style="list-style-type: none"> • Allows complete vehicles with remaining useful life to continue operating • May be cheaper and more cost-effective solution for some vehicles than full vehicle replacement • Well-suited for municipal fleets (e.g. buses, refuse trucks) operating over fixed duty-cycles and under common management | <ul style="list-style-type: none"> • Technologically complex • Requires very careful matching of equipment to vehicles based on duty cycle, engine configuration, and more • Requires very careful monitoring to ensure continued effectiveness |
| Repower | Replace the engine and emission control equipment of existing vehicles; may include changing fuel type as well (e.g., converting a diesel vehicle to CNG) | <ul style="list-style-type: none"> • Well-suited for specialized vehicles with expensive, custom equipment (e.g., refuse trucks, fire trucks) | <ul style="list-style-type: none"> • Technologically complex • May be challenging or impossible to link new engine with existing control systems |

In some regions, vehicle replacement, retrofit, and repower programs are designed and implemented simultaneously, especially since they may target the same vehicles in the fleet. For example, California’s Carl Moyer Program, described in further detail later in this report, provides grants for all three types under a single program. This provides flexibility to fleet owner/operators in reducing emissions, allowing for the optimization of cost-effectiveness as reflected in cost per ton of pollution reduction.

VOLUNTARY VS. MANDATORY REPLACEMENT PROGRAMS

Vehicle replacement programs can either require mandatory removal of a vehicle from the fleet or provide subsidies to encourage voluntary retirement of a vehicle. Mandatory vehicle replacement programs force the retirement of a vehicle from the fleet even if it has useful life remaining. Retirement is usually based on a vehicle’s age or mileage and may be linked to vocation. This is the case in China, as described in detail later in this report. Mandatory vehicle replacement programs are not very common and, without additional incentives (fiscal or otherwise), may become unpopular.

More commonly, vehicle replacement programs are voluntary and supported by some form of policy incentives. These are usually fiscal incentives, such as direct subsidies or fees to eliminate or discourage the use of older vehicles. They may also include other incentive policies such as restrictions on when and where high-emitting vehicles may operate. The effective use of non-fiscal policy incentives to complement subsidies or other fiscal incentives is one of the important best practices described below.

IDENTIFYING AND DEFINING HIGH-EMITTING VEHICLES

The definition of “high-emitting vehicles” varies from region to region depending on fleet characteristics, history of emission control programs, and specific air pollution or climate change mitigation goals. In most of the examples described in this report, high-emitting vehicles are defined according to their age or certified emission standard. In India and China, for example, replacement programs consider only the original standard to which the vehicle was certified as opposed to the vehicle’s current emissions performance.

The use of current, real-world emissions performance to identify high-emitting (or “gross-emitting”) vehicles is the goal of I/M and remote sensing programs. Such programs may include a form of retirement mandate. One example is the prohibition of registration of vehicles that do not pass I/M. However, the forced retirement of vehicles failing in-use testing is beyond the scope of this paper.

Before identifying which vehicles to target for vehicle replacement, a country or region must first characterize its fleet. The availability of good fleet data and emissions inventories are key in accomplishing this. Policymakers and researchers typically rely on vehicle emissions inventory models to identify high-emitting vehicles and predict the potential impact of a vehicle replacement program. This is described further in Best Practice #1.

TARGETING DIFFERENT TYPES OF VEHICLES AND POLLUTANTS

Vehicle replacement programs can target any group of vehicles in the fleet, even non-road vehicles and engines (e.g., construction equipment, locomotives, marine vessels, etc.). For heavy-duty vehicles (HDVs)—buses, freight trucks, and large vocational vehicles—vehicle replacement programs traditionally have sought to reduce emissions

of conventional pollutants and greenhouse gases. The conventional pollutants reduced with vehicle replacement programs are nitrogen oxides, carbon monoxide, hydrocarbons, and particulate matter. GHG emission reductions can be achieved for black carbon, as it is the main component of PM in older vehicles (Ruehl, 2014). This is because HDVs often account for a disproportionately large amount of conventional pollutant emissions from a region’s vehicle fleet, especially in developing countries. Plus, these vehicles often have longer useful lifetimes than light-duty vehicles.

For light-duty vehicles (LDVs), several countries have implemented vehicle replacement programs that target reductions in emissions of both conventional pollutants and greenhouse gases (GHGs), especially carbon dioxide (CO₂). Many countries have implemented regulations over the last decade that have strongly decreased GHG emissions of new LDVs, making the retirement of older vehicles an attractive way to accelerate the benefits of the new standards (ICCT, 2013). Reducing GHG emissions also reduces fuel consumption, which can yield additional economic benefits and reduce dependence on imported oil.

Vehicle replacement programs for two- and three-wheelers have not been as common as those for HDVs and LDVs. But in regions where these vehicles dominate sales and the vehicle fleet—such as in many Asian countries—vehicle replacement programs designed for two-stroke two- and three-wheelers, for example, could potentially be very effective in reducing emissions. As mentioned earlier, a representative emissions inventory is instrumental in identifying priority vehicles for replacement programs.

ECONOMIC IMPACTS OF VEHICLE REPLACEMENT PROGRAMS

Aside from the environmental benefits of air pollution reduction and climate change mitigation, vehicle replacement programs may also be a form of economic stimulus for a region. Replacement programs usually link vehicle retirement fiscal incentives with the required purchasing of new (or newer used) vehicles. Such programs commonly are promoted by governments not just as environmentally beneficial, but simultaneously as a form of short-term economic stimulus.

Following the start of the global economic recession in late 2008, during which automobile sales plummeted, many regions of the world implemented some sort of vehicle replacement fiscal program to stimulate consumer spending. For example, the economic benefits of the 2009 Car Allowance Rebate System in the United States (popularly known as Cash for Clunkers, described in detail later in this report) were highlighted over the environmental benefits of the program. Mexico also implemented a vehicle renewal program in 2009, with economic stimulus as the leading motive after a drastic 26.4% reduction in sales that year. However, it should be noted that although aggressive replacement subsidies may result in short-term economic boosts, the long-term value of these programs is debatable, since the programs may merely shift future spending to the present as opposed to driving new or additional spending (Li et al., 2011; Copeland and Kahn, 2011; Mian and Sufi, 2010). In Mexico's case, the low fiscal incentives did not get the expected results, and the program was terminated before being fully implemented.¹

As with the environmental reasons for developing a vehicle replacement program, each individual region ideally will carefully consider the economic implications of such a program. The economic benefits—or lack thereof—of vehicle replacement programs will vary from region to region.

METHODOLOGY

In order to determine the best practices for vehicle replacement programs a detailed review of programs around the world was conducted. The review included investigation of the structure, implementation, and results of multiple existing scrappage and replacement programs. The review took into account the overall success of each program on a number of metrics, specifically cost effectiveness, quantity of emissions reduction, and program participation. Although the features and specific goals of each program under investigation vary widely, a few commonalities among strong programs emerged in our analysis. These commonalities were boiled down into five best practices that are outlined in the next chapter.

¹ Sales attributable to the subsidy totaled 12,848 vehicles, but 77% of the budget planned was spent in the first period of the program. After that, the government decided not to continue the program.

CHAPTER 2. BEST PRACTICES IN VEHICLE REPLACEMENT

In this chapter, we outline five best practices (BP) for vehicle replacement programs with respect to mitigating both criteria pollutant and GHG vehicle emissions. Ideally policymakers should consider these guidelines when developing a vehicle replacement program.

1. FOR MAXIMUM ENVIRONMENTAL BENEFITS, REPLACEMENT VEHICLES SHOULD BE AS CLEAN AS POSSIBLE

Newer vehicles that will replace older vehicles would ideally meet much more stringent emission standards, especially for NO_x and PM. Vehicle replacement programs are most effective when replacement vehicles are as clean as possible. For maximum benefit, replacement vehicles should be certified to state-of-the-art emission standards (e.g., U.S. 2010 or Euro VI for HDVs). For reduction of black carbon and the most dangerous ultrafine particles, it is essential that replacement vehicles be equipped with diesel particulate filters (DPFs). Before a vehicle replacement program is implemented, policymakers would ideally conduct a thorough analysis to ensure the environmental benefits they are seeking will be achieved by the program. This is commonly done through emissions inventory modeling to determine the relative contribution of older vehicles to fleetwide emissions.

Additionally, replacement vehicles should be shown to have much lower pollutant emissions for the full range of operating conditions encountered by the vehicle during its useful life (“real-world” operation). Experience in Europe and China has shown that real-world NO_x emissions from HDVs operating at low speeds in urban environments have not decreased even with the successive introduction of emission standards through Euro V (Lowell and Kamakaté, 2012). Some local authorities have reacted by employing supplemental or alternative test procedures for replacement buses. For example, Transport for London (TfL), as part of a program to replace all Euro II buses with Euro V buses by 2015, is requiring that replacement vehicles demonstrate proper NO_x controls on a supplemental London bus-specific drive cycle. In China, the Ministry of Environmental Protection and the Beijing Environmental Protection Bureau have issued supplemental testing requirements for new Euro IV/V HDVs sold and registered (ICCT, 2014). Without such supplemental testing, local governments risk implementing costly replacement programs that do not deliver any significant reduction in NO_x emissions.

In the case that vehicle replacement programs seek to reduce GHG emissions or improve fuel economy, the replacement vehicles should have significantly better fuel efficiency than the vehicles they replace. As with reducing conventional pollution, the fuel efficiency gains should occur in the real world as well as during testing.

2. PROGRAM IMPLEMENTATION, MANAGEMENT, AND ENFORCEMENT SHOULD ENSURE EXPECTED BENEFITS ARE ACTUALLY ACHIEVED

Replacement program implementation, management, and enforcement should be carefully designed to ensure that expected environmental benefits (i.e., benefits predicted by modeling) are actually achieved. Program implementation and oversight are the keys to ensuring these benefits are actually realized. As an example of this

design philosophy, California's Carl Moyer Program establishes four core principles driving program developing and implementation: emission reductions must be "real, surplus, quantifiable, and enforceable" (CARB, 2011).

As part of program implementation design, policymakers should consider the usage profiles (e.g., vehicle miles traveled) and rated power of both the legacy vehicle and the replacement vehicle. Policymakers should be cautious that subsidies are not provided for vehicles already abandoned and not in regular operation; otherwise, there are no benefits for scrapping the older vehicle. A robust program establishes clear requirements for the performance and operation of both the old and replacement vehicle. Policymakers can verify usage profiles by checking insurance, registration, inspection, maintenance, and odometer records, for example.

In some programs, it may be appropriate to set usage limits on vehicle rated power, gross vehicle weight, in the case of goods transport, or seating capacity, in the case of passenger transport. The main objective of this type of usage limit is to keep control over the final application or vocation of the vehicle. For example, in California's Carl Moyer Program the replacement vehicle cannot have a rated power more than 15% higher than the one being replaced. This is a percentage that also coincides with typical engine family definitions, which include variations of 15% on engine displacement and rated power.

It may not always be appropriate to limit the power or usage of the new vehicle. New vehicles are consistently driven more per year than older ones; a strong replacement program should account for this by requiring the cleanest and most efficient vehicle replacement possible to balance out the increase in driving. If the increase in driving is not accounted for during program design and cost/benefit analysis, the benefits of the vehicle replacement program could be much smaller than initially anticipated.

On the other hand, a replacement program in the commercial vehicle space sometimes can take advantage of the additional power and capability of new vehicles. For example, in Mexico City's replacement program, each new, high capacity, clean bus replaced two older, smaller, high-emitting minibuses.

Finally, enforcement programs must also consider the fate of the scrapped vehicle. Unless strong regulations force and require the destruction or dismantling and recycling of the vehicle/engine, the replaced vehicle is at risk of being transferred to another region where it will continue to pollute even after retirement subsidies have been issued.

3. FISCAL INCENTIVES SHOULD BE CAREFULLY TAILORED TO OPTIMIZE BOTH ENVIRONMENTAL BENEFITS AND COST-EFFECTIVENESS

Due to the large variation in international vehicle replacement program experience, it is impossible to establish a simple rule of thumb for the amount of subsidy that should be offered to owners of high-emitting vehicles. The level of fiscal support necessary will vary from one region to another as well as according to the targeted vehicle types or budgets available. Generally speaking, the fiscal incentive should be higher than the current market value of the vehicle to be replaced, in order to incentivize owners to scrap their vehicle instead of selling it to another person. Moreover, the incentive has to sufficiently assist with the purchase of a newer replacement vehicle.

Policymakers should attempt to find the “tipping point” at which owners of the targeted number of older vehicles to be removed actually participate in the vehicle replacement program, without offering subsidies that are too high, thereby reducing cost-effectiveness. A GIZ-sponsored research report for Mexico (TSTES and ITP, 2013) estimated this tipping point to be 70% of the cost of a new vehicle, though it is unclear how widely this would apply. In contrast, the Carl Moyer Program in California provides replacement subsidies between 4% and 18% of the price of the new vehicle, depending on vehicle type (CARB, 2007).

Successful experience suggests that policymakers should be prepared to offer a variety of different subsidies for different types of vehicles/vocations or owners, and that the subsidies should be revised periodically to optimize participation. Some regions, such as California and Beijing, have had success at offering fiscal subsidies that decrease over time, encouraging owners of high-emitting vehicles to replace their vehicles as early as possible and therefore result in the largest possible environmental benefit.

Furthermore, the use of a cost-effectiveness metric may provide some guidance to help policymakers prioritize grants. A cost-effectiveness estimation, meaning the total cost per ton of pollutant emissions reduction, allows for the direct comparison of various types of vehicles or even program types, for example, whether to replace, retrofit, or repower a specific vehicle. In addition to benefiting policymakers, such a scheme provides vehicle owners the flexibility to choose the most cost-effective route for themselves.

Even when subsidies are optimized for maximum economic and environmental considerations, policymakers may need to offer support to owner/operators in the form of low-interest loans or other financing assistance. Because many commercial vehicles operate with slim profit margins, a capital equipment purchase—even one that is subsidized and could potentially have a payback period of just a few years—may be challenging. An example of such a program is the California Air Resources Board’s Providing Loan Assistance for California’s Equipment (PLACE) program, which provides loan guarantees and competitive financing for owners upgrading their vehicles to comply with state regulations.

Finally, in cases where subsidies are not enough to convince owners to participate in the program for purely economic reasons, supporting policies can further drive success of the program, as described in Best Practice #5.

4. PROGRAM DESIGN SHOULD CAREFULLY CONSIDER AND BALANCE THE DIFFERENT ROLES OF NATIONAL, REGIONAL, AND LOCAL-LEVEL POLICYMAKERS

The roles of policymakers at various levels (local to national) should be considered logically and should be well defined at the program’s inception. Initially, a large-scale vehicle replacement program may need to be established and funded by a central authority. However, program implementation and especially individual project grant determinations ideally should be handled by local policymakers who have a detailed understanding of local needs and conditions. Local policymakers will be better suited to estimate expected emissions reduction (for maximizing cost-effectiveness) as well as to ensure that vehicles are properly retired.

5. COMPLEMENT FISCAL POLICIES WITH ADDITIONAL INCENTIVES SUCH AS LOW EMISSION ZONES AND REGULATORY BACKSTOPS

Complementary policies and programs can encourage owners to take advantage of fiscal subsidies for vehicle replacement, especially in cases where subsidy amounts alone are not enough to result in widespread participation. Complementary, non-fiscal incentives could include regulatory backstops, low emission zones, mandatory age limits for vehicles, or operation exclusions.

Regulatory backstops are mandatory policies which take effect for a given vehicle fleet after a set time period. Prior to the regulation taking mandatory effect, a government may offer subsidies to encourage early compliance with the program. For example, California has strong mandatory regulations ultimately requiring the upgrading of nearly every in-use diesel engine in the state to world-class emission standards. Fiscal incentives offered through programs like the Carl Moyer Program help offset the cost of upgrading and encourage owners to take early action. Owners that do not take advantage of the early action subsidies lose the opportunity to have their costs offset but ultimately are still required to comply with the regulation.

Low emission zones are regions in which high-emitting vehicles are either prohibited from operating or charged a fee for entering. The establishment of such zones can provide strong additional incentives to owners of high-emitting vehicles to take advantage of fiscal subsidies and replace their vehicles. In China, the city of Beijing offered subsidies for the replacement of older vehicles while simultaneously banning those vehicles from traveling in the city center, strongly incentivizing truck owners to take advantage of the subsidies and upgrade their vehicles. Somewhat similarly, in California the twin ports of Los Angeles and Long Beach banned high-emitting drayage, thereby incentivizing truck owners who wished to do business in the port to upgrade. In some cases, especially in Europe, fees for entering the low emission zone are differentiated based on vehicle emissions, with higher emitting vehicles being charged more.

CHAPTER 3. CASE STUDIES

This chapter describes and analyzes selected vehicle replacement programs that have been implemented in different regions around the world. It does not provide an exhaustive list of all precedent vehicle replacement programs, but rather focuses on a diverse array of vehicle replacement programs that could have implications for policymakers seeking to do the same in their respective regions. The successes and shortcomings of these programs are discussed in the context of each of the best practices outlined in the previous chapter.

CALIFORNIA: CARL MOYER PROGRAM

The California State Legislature created the Carl Moyer Program in 1998. It initially focused on reducing NO_x emissions from HDVs in order to help the state meet ambient air quality standards for ozone (CARB, 2011). Since its inception, the program has been expanded and has received much public support.

Funding was allocated for the initial four years of the Carl Moyer Program by the Legislature's budget appropriations. Voters approved continued funding for the program for the subsequent two years. Since 2004, additional smog check, tire, and vehicle registration fees have funded the program. These fees have brought in an average of about \$141 million per year, and they are expected to continue to do so through 2015 (Wagner and Rutherford, 2013; CARB, 2011).

The California Air Resources Board (CARB)—the managing entity of the program—makes grants to individual air districts, which in turn distribute funds to local public and private entities to cover new purchases, fleet modernization (vehicle replacement), repowers, and retrofits for both on-road and off-road vehicles. In this sense, the program is not purely a vehicle replacement program. Maximizing cost-effectiveness (money spent per ton of pollution reduction) is a key goal in determining which types of vehicles and projects are funded.

Since its inception, provisions for LDVs and off-road equipment have been included in addition to HDVs. The Carl Moyer Program now funds two types of vehicle replacement programs. The first offers fiscal incentives for the replacement of older HDVs or off-road equipment that still have useful life left with newer equipment that meets more stringent emission standards. The second offers fiscal incentives to LDV owners to voluntarily scrap their higher polluting older vehicles earlier than they otherwise would have. In both cases, there are specific rules establishing the eligibility of vehicles to participate in the program and the amount of funding for which they are eligible. (CARB, 2011).

Several other parallel state- and local-level programs offering replacement grants complement the Carl Moyer Program. These include Prop 1B and the Voucher Incentive Program (VIP).

Best Practice #1 (Replacement vehicles should be as clean as possible)

The Carl Moyer Program is a good example of a vehicle replacement program that meets the criteria for BP#1. The latest program guidelines state that only HDVs with both engines and chassis of model year 1990 or older are eligible for vehicle replacement funding. The replacement vehicle must be a much cleaner model year 2007 or later vehicle, though it can be either new or used. These replacement vehicles reduce emissions of PM and NO_x by more than 95%.

Eligible LDVs in the Carl Moyer Program are categorized in one of two groups: voluntary accelerated vehicle retirement (VAVR) and voluntary repair of vehicles (VRV). VAVR is a vehicle replacement plan, while VRV allows for retrofits to lower vehicle emissions. In both cases, program participants must prove that their old vehicle is still operational and receive funds linked to the estimated amount of emission reductions resulting from their vehicle replacement or retrofit.

Best Practice #2 (Ensure expected benefits are actually achieved)

The Carl Moyer Program is a good example of a vehicle replacement program that meets the criteria for BP#2. The program calculates, via inventories, the annual benefits accrued and reports both the environmental benefits and costs of the program. In its first 12 years, the benefits achieved through replacing more than 24,000 vehicles include reducing emissions of ozone precursor pollutants—primarily NO_x and reactive organic gases—by about 100,000 tons and PM emissions by 6,000 tons.

To maintain program accountability, vehicle owners must show official tags or get dynamometer test certificates—at their own expense—displaying the old vehicle's engine power and characteristics. The engine power of the replacement vehicle cannot be more than 20% greater than that of the old vehicle. Regular auditing of the new vehicle throughout the life of a specific replacement project ensures that these requirements are met.

Additionally, replacement vehicles must be in the same weight class and have the same body and axle configuration as old vehicles. In some cases individual districts can allow for changes to these regulations due to technology developments. Replacement vehicles must operate in the same vocation as the old vehicle for a minimum of 85% of the miles during the replacement project life. If for some reason a change of vocation is required, a written explanation must be provided to the district and approved by CARB (CARB, 2011).

Best Practice #3 (Maximize cost-effectiveness)

The Carl Moyer Program is a good example of a vehicle replacement program that meets the criteria for BP#3. Applicants must estimate in detail the expected emission reductions resulting from each replaced vehicle based on standardized emission factors and verified estimations of vehicle kilometers traveled (VKT). The cost-effectiveness of the project is then calculated based on the cost of the new vehicle purchase and a weighted estimation of surplus reductions of NO_x, reactive organic gases, and PM. During the first 12 years of operation, the total cost of the Carl Moyer Program was \$680 million, which amounts to an average grant per vehicle of a little more than \$28,000 and a cost per ton (short ton) of ozone precursor and PM emission reductions of about \$6,800 and \$113,000, respectively (Wagner and Rutherford, 2013; CARB, 2011).

If repairs to the old vehicle are required, their costs are subtracted from the fiscal incentives paid for replacement vehicles. Grants are awarded competitively, with a cap on cost-effectiveness. Individual districts within California may set stricter cost-effectiveness caps.

Best Practice #4 (Balance national and local-level roles)

The Carl Moyer Program is a good example of a vehicle replacement program that meets the criteria for BP#4. While CARB oversees the overall program, funds are given to individual California districts to distribute and implement the program. In some instances, district officials have leeway in modifying program rules according to their needs. Compliance efforts for the program are undertaken by both CARB and district governments. District liaisons are required to submit all necessary documents and compliance checks to CARB, which then conducts its own audits of the program (CARB, 2011).

Best Practice #5 (Employ complementary policies)

The Carl Moyer Program is a good example of a vehicle replacement program that meets the criteria for BP#5. CARB officials attribute much of the recent success of the Carl Moyer Program to the strong, mandatory regulatory backstops California has established to progressively tighten vehicle emission standards for all diesel engines in the state. CARB's current regulations include phase-in requirements that every on-road diesel engine meet the US2010 emission standards by 2023. Selected vehicle categories and model years must meet the US2010 standards much earlier. The Carl Moyer grants are made available only to vehicle owners who wish to upgrade their vehicles earlier than the mandatory compliance dates.

Additionally, all owners of old vehicles seeking to participate in the program must show numerous documents to prove that they, their businesses, and their vehicles are in compliance with all California and US laws to be eligible. This interaction between the Carl Moyer Program and other regulations ensures that compliance on a variety of issues is enforced.

UNITED STATES: CONSUMER ASSISTANCE TO RECYCLE AND SAVE (CARS, A.K.A. CASH FOR CLUNKERS)

The Consumer Assistance to Recycle and Save (CARS) Act of 2009 was a vehicle replacement program that sought to improve LDV fuel economy throughout the United States. The program, popularly called Cash for Clunkers, was implemented through the United States National Highway Traffic Safety Administration (NHTSA).

The motivation for the CARS Act was twofold: to increase the fuel efficiency of the United States' passenger car fleet and to provide economic stimulus to the auto industry during a time of economic recession. While conventional pollution was not targeted, there was likely a drop in conventional pollutant emissions as well from the program.

Vehicles in operational condition and less than 25 years old at the time of replacement were eligible under the CARS program. Replacement vehicles had to have a retail price of not more than \$45,000. The program gave a one-time payment of either \$3,500 or \$4,500 to vehicle owners, depending on the official combined fuel economy gap between the replacement and old vehicles. In the case of the heaviest LDVs, the incentive was not defined by fuel economy improvement but rather by a reduction in vehicle weight. Table 2 shows the CARS program fiscal incentives (NHTSA, 2009).

Table 2. Eligibility requirements and fiscal incentives under the CARS program

| Type of Replacement Vehicle | Minimum combined fuel economy of Replacement Vehicle (mpg) ^a | Type of Old Vehicle ^b | Amount of Incentive | |
|--|---|--|---|------------------|
| | | | Fuel economy difference, Replacement vs Old (mpg) | Incentive amount |
| Passenger car | 22 | Passenger car Category 1 or 2 truck | 4-9 | \$3,500 |
| | | | > 10 | \$4,500 |
| Category 1 Truck^c SUV, GVWR ≤ 10,000 lbs Pick up, GVWR < 8,500 lbs and wheelbase ≤ 115 inches Passenger and cargo vans, GVWR < 8,500 lbs and wheelbase ≤ 124 inches | 18 | Passenger car Category 1 or 2 truck | 2-4 | \$3,500 |
| | | | > 5 | \$4,500 |
| Category 2 Truck^c Pick up, GVWR < 8,500 lbs and wheelbase > 115 inches Passenger and cargo vans, GVWR < 8,500 lbs and wheelbase > 124 inches | 15 | Category 2 truck | 1 | \$3,500 |
| | | | > 2 | \$4,500 |
| | | Category 3 truck | N/A | \$3,500 |
| Category 3 Truck^c Pick up, GVWR < 8,500 lbs and wheelbase > 115 inches Passenger and cargo vans, GVWR < 8,500 lbs and wheelbase > 124 inches | N/A | Category 3 truck | N/A however replacement vehicle must have GVWR equal or less than old vehicle | \$3,500 |

a) miles per gallon (mpg)—requirements based on EPA’s combined city/hwy rating
 b) all old passenger cars, category 1, category 2 trucks must have a combined mpg of 18 or less
 c) GVWR: gross vehicle weight rating

A total of nearly 680,000 vehicles were scrapped and replaced under the CARS program. The program cost was about \$2.85 billion. The average fuel economy of the scrapped vehicles was 15.8 miles per gallon (mpg), while the average fuel economy of the replacement vehicles was 24.9 mpg. NHTSA estimated in 2009 that over the next 25 years, 824 million gallons of fuel use and 9 million metric tons of GHG emissions would be avoided. The monetized benefit of this was estimated to be \$278 million in 2008 dollars. NHTSA also estimated that the program resulted in a \$3.8 billion to \$6.8 billion increase in United States GDP (NHTSA, 2009). Upon program completion, a number of studies found that not only were the environmental benefits of the CARS program grossly overstated, but the program also did not provide for the long-term economic gains it was initially estimated to have (Li et al., 2011; Copeland, 2011; Mian et al., 2010).

Best Practice #1 (Replacement vehicles should be as clean as possible)

The CARS program met BP#1 to some extent, but hurt environmental progress on other fronts. In 2009, the United States Secretary of Transportation, Ray LaHood, declared the CARS program to be “wildly successful.” The program did indeed have a significant impact in reducing GHG emissions and fuel use by the United States LDV fleet. It also improved air quality because replacement vehicles likely met stricter emission standards than the older vehicles (Li et al., 2011).

Although there were initial indications that the program was a success, studies conducted upon the completion of the program found the overall environmental benefits of the CARS program were significantly overstated. While the program did increase LDV fuel economy while it was active, the net effect was not as great because vehicle sales were depressed in the subsequent months (Li et al., 2011).

Best Practice #2 (Ensure expected benefits are actually achieved)

The CARS program did establish guidelines that were in accordance with BP#2. Program rules required vehicle owners to purchase vehicles that were generally in the same category as the old ones they were scrapping. However, an unintended long-term environmental consequence of the CARS program was that many vehicles in working condition were not recycled. While outdated vehicles can generally be fully recycled, the requirement of the CARS program that the engines of scrapped vehicles be destroyed meant that many parts of the vehicles could not be reused for other purposes. This hurt the non-air quality and non-GHG emissions aspects of the environment (Santisi, 2013).

Best Practice #3 (Maximize cost-effectiveness)

The CARS program was wildly popular due to its fiscal incentives. Its initial budget of \$1 billion was exhausted during the first week of implementation, and the US government had to allocate more funds for the program (Li et al., 2011). The program also gave greater fiscal incentives for the purchase of replacement vehicles for which the gap in fuel economy between the replacement vehicle and old vehicle was larger, but the fiscal incentives were not tiered to maximize fuel economy gains. Instead, vehicle owners were eligible for just a single lump sum payment of either \$3,500 or \$4,500.

The other motivation for the CARS program was economic stimulus. A 2009 NHTSA report estimated that more than 60,000 jobs would be saved as a result of the program and that it would result in a gross domestic product (GDP) increase of \$3.8-6.8 billion (NHTSA, 2009). But other studies found that while vehicle sales increased during the months in which the program was active, they went down in subsequent months. These studies found the effect of the program on vehicle sales over a one-year period to be essentially zero (Li et al., 2011; Copeland, 2011).

The initial popularity of the program faced a backlash in later times, as many citizens felt the money was an unnecessary handout that did not truly achieve cost-effective environmental progress or sufficiently stimulate the economy. Furthermore, the cost per gallon of fuel use reduction was found to be quite high under the CARS program relative to other government initiatives that discourage fuel consumption (Li et al., 2011).

Best Practice #4 (Balance national and local-level roles)

The CARS program did not do a good job with respect to BP#4. The program was developed and implemented entirely at the national level. There was no variation in the program across different states or regions, and there was little, if any, input from regional, state, or local governments in the development or implementation of the program. Compliance with the CARS program was entirely the responsibility of the NHTSA (NHTSA, 2009).

Involving states and municipalities in the development and implementation of the CARS program could have had many benefits. For example, the federal government only thought of the climate benefits and reduced fuel consumption when developing the environmental side of the program. Had input from local policymakers been taken into

account, the environmental problem of completely scrapping old vehicles rather than recycling them could have been avoided.

On the economic side, an estimated 45% of program expenditure was for consumers who would have bought a new vehicle even in the absence of fiscal incentives (Li et al., 2011).

Best Practice #5 (Employ complementary policies)

The CARS program was not developed in tandem with other complementary programs that reduced vehicle emissions. While the United States had tightened vehicle emission regulations over the previous few decades, the CARS program did not explicitly take advantage of these developments.

The CARS program primarily sought to improve the fuel economy of the United States' LDV fleet, but it was not implemented in tandem with new vehicle fuel economy standards. If the program were to be implemented after a period of mandatory new vehicle fuel economy improvements, it would have had a much larger positive impact on overall fuel economy improvement.

The CARS program was largely rushed through based on economic needs. The United States was in the middle of a serious recession in 2009, and the CARS program was part of a larger stimulus the government implemented to uplift the economy. In that regard, it was part of a larger economic plan to lift the United States out of recession.

UNITED STATES: NATIONAL CLEAN DIESEL CAMPAIGN (NCDC)

The National Clean Diesel Campaign was initiated in 2007 under the directive of the Diesel Emissions Reduction Act (DERA), which is a part of the Energy Policy Act of 2005. DERA allocated up to \$200 million in annual funding from fiscal year (FY) 2007 to FY 2011. In 2010, DERA was reauthorized and up to \$100 million in annual funds were allocated for FY 2012 through FY 2016 for the program. Though these are the maximum amounts allocated by the US Congress, the actual fiscal incentives issued have been considerably lower (OTAQ, 2013).

The NCDC awards competitive grants to projects that aim to reduce conventional pollutant emissions, especially PM and NO_x, from in-use diesel vehicles. The program is geared toward HDVs and non-road vehicles and equipment. The NCDC is somewhat similar to the Carl Moyer Program, but focused on the entire nation instead of just California.

Under the NCDC, specific projects must make competitive bids for funding. Project proposals are then reviewed and those determined to be the most cost-effective are funded. From 2008 through 2010, only about 22% of proposal were approved, representing 13.5% of the requested funding (OTAQ, 2012).

NCDC funding is allocated into four subprograms, three of which are federal and one of which allocates funds to state governments. Seventy percent of the funds are given to the federal subprograms. A diagram of the NCDC funding structure is shown in Figure 1.

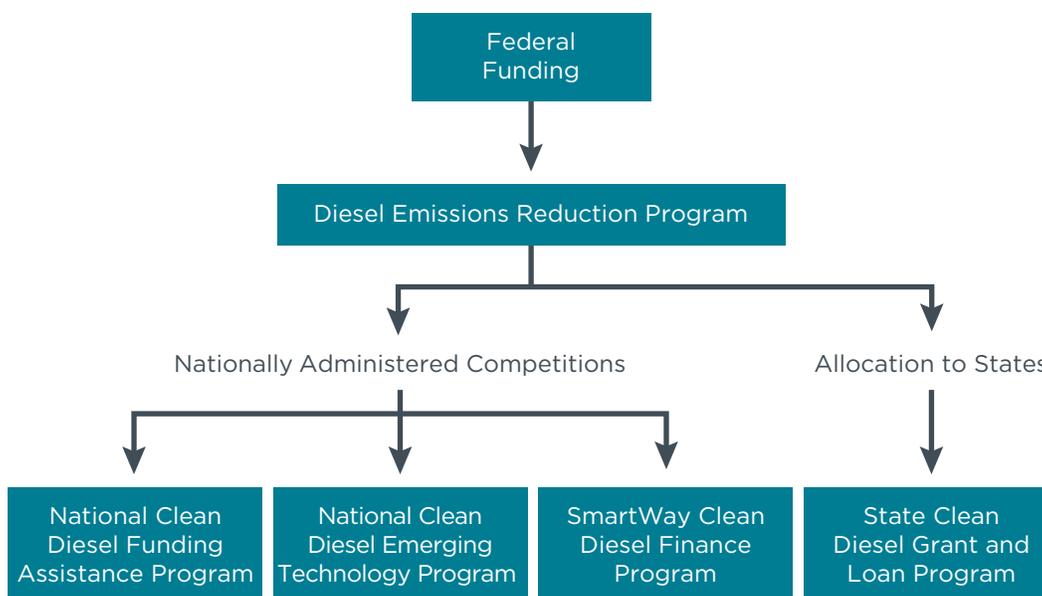


Figure 1. NCDC funding recipients (EPA, 2009).

In late 2010, the EPA awarded \$120 million worth of grants under the NCDC to 84 projects. The grants resulted in lifetime emission reductions of 50,600 tons of NO_x, 26,000 tons of PM, 3,600 tons of HC, 9,300 tons of CO, and 706,000 tons of CO₂. Lifetime fuel savings were estimated to be 63 million gallons (240 million liters). Lifetime health benefits were estimated to be between \$728 million and \$1.8 billion (OTAQ, 2012).

It should be noted that the NCDC is not purely a vehicle replacement program. The bulk of its funds have gone toward non-vehicle replacement measures, such as retrofits, engine rebuilding and repowering, operational changes, and cleaner fuels. In 2009 and 2010, vehicle replacement programs accounted for only 10% of NCDC funding grants.

Best Practice #1 (Replacement vehicles should be as clean as possible)

The NCDC does a good job of meeting BP#1. Individual projects must apply for grants under the program, and grants are issued based on competitive bidding. This allows for a review of proposals in advance, and only those with the greatest and most cost-effective environmental impacts receive money.

Best Practice #2 (Ensure expected benefits are actually achieved)

The NCDC does a good job of meeting BP#2, albeit in a different manner than many traditional vehicle replacement programs. While the program does not have strict guidelines defining which vehicles are eligible for vehicle replacement and what characteristics replacement vehicles must have, prospective program participants must give details about which vehicles they seek to replace and estimate reductions in overall emissions over a period of time. This, in effect, ensures that replacement vehicles will not have more power or higher emissions than old vehicles, because prospective participants are less likely to receive money if they do not prove that overall, real-world emissions will not go down.

In addition, the NCDC program has developed a tool to evaluate the expected benefits of retrofits projects carried out under this program. The Diesel Emissions Quantifier (DEQ) is an interactive tool for evaluating clean diesel projects and options for medium-heavy- and heavy-heavy-duty diesel engines. It estimates emission reductions, cost effectiveness, and health benefits of the projects.²

Best Practice #3 (Maximize cost-effectiveness)

The NCDC does a very good job of meeting BP#3. Instead of establishing grant amounts in advance, the process of having projects solicit funds allows them to seek appropriate project-specific fiscal incentives. At the same time, because projects compete for funds, they are incentivized to seek the least amount of funds that will achieve the largest reductions in emissions.

Best Practice #4 (Balance national and local-level roles)

The NCDC does a good job of meeting BP#4. Thirty percent of funds are allocated to state governments to make decisions that are best for them. Furthermore, much input from local policymakers and regulators is taken into consideration when a project applies for a grant. This ensures that there is some consensus at all levels before any fiscal incentives are issued.

Best Practice #5 (Employ complementary policies)

The NCDC is not specifically linked to any complementary policies such as low emission zones, mandatory age limits, or regulatory backstops.

GERMANY: SCRAPPAGE BONUS

Germany's Umweltprämie ("Environmental Bonus," a.k.a. Abwrackprämie, "Scrappage Bonus," or Cash for Clunkers) program was implemented in 2009. The primary aim of the program was to provide economic stimulus for the auto industry following the 2008 world economic crisis. The second goal of the program was to reduce emissions of all air pollutants. The Umweltprämie was the model for the United States' CARS program discussed earlier in this report and similar scrappage programs in other European countries.

Under the Umweltprämie program, light-duty vehicle owners were eligible for a one-time bonus of €2,500 (\$3,500) for the purchase of a new vehicle to replace an old one. To qualify for the bonus, the old vehicle had to have been first registered at least nine years before the time of application for the bonus, and the replacement vehicle had to be less than a year old and meet at least Euro 4 emission standards (BAFA, 2009). The Euro 4 emission requirement had strong synergy with Germany's low emission zones.

Although the program was scheduled to last until December 2009, its entire budget of €5 billion (\$7 billion) was exhausted by September 2009, having subsidized the purchase of two million vehicles (Kaul et al., 2012).

Despite the popularity of the program and initial declarations of success, there were later doubts about whether it truly contributed to long-term economic recovery. At least one study concluded that the vast majority of bonuses went to people who would have bought new vehicles even without them (Kaul et al., 2012).

² Diesel Emission Quantifier tool <http://www.epa.gov/cleandiesel/quantifier/>

On the environmental side, there were definite air quality benefits. A late 2009 study found that, on average, replacement vehicles emitted 99% less PM, 87% less NO_x, and 74% less CO than old vehicles (IFEU, 2009). Replacement vehicles were about 20% more fuel efficient, but much of the potential fuel economy gains were offset by the fact that many replacement vehicles were heavier and more powerful than the vehicles they replaced (IFEU, 2009).

Best Practice #1 (Replacement vehicles should be as clean as possible)

Overall, the Umweltprämie program met BP#1. Emissions of harmful air pollutants fell significantly, while reductions in CO₂ emissions were less significant but palpable.

The program did take advantage of the gradual tightening of emission standards in the EU over time. Old vehicles all met Euro 2 and earlier standards, while replacement vehicles had to meet Euro 4 or later standards. Still, if the program had been implemented just one year later, replacement vehicles could have been required to meet Euro 5 standards, which first went into effect in September 2009. During emissions certification testing Euro 5 vehicles have to meet emission limits that are 80% more stringent for PM and 25% more stringent for NO_x than for Euro 4 vehicles.

Best Practice #2 (Ensure expected benefits are actually achieved)

There were no rules regarding the characteristics of replacement vehicles with respect to old vehicles. One reason CO₂ emission reductions were not as great as they could have been was because replacement vehicles were often heavier and more powerful than old vehicles. In addition, there was an unexpected twist in the implementation of the program that negated some of its environmental benefits. Although the program required old vehicles to be delivered to scrapyards, regulations requiring and verifying actual scrapping were either unclear or loosely enforced. As a result, many old vehicles were simply resold to Africa or Eastern Europe. In a few instances, the vehicles even returned to Germany (Dougherty, 2009).

Best Practice #3 (Maximize cost-effectiveness)

Despite its environmental benefits, the program was very expensive. Furthermore, the bonuses issued under the program were set at a constant €2,500 (\$3,500) for all replacement vehicle purchases, regardless of their impacts relative to old vehicles. This did not incentivize vehicle owners to replace their old vehicles with the least polluting and most fuel-efficient vehicles.

Best Practice #4 (Balance national and local-level roles)

The program was carried out entirely by Germany's Federal Office of Economics and Export Control. There was no inclusion of state or local authorities in implementing the program.

Best Practice #5 (Employ complementary policies)

Germany has widespread experience at the municipal level with the implementation of low emission zones, which become increasingly stringent over time. For example, Berlin has a restricted zone based on emissions performance since 2008; current regulations have prohibited gasoline vehicles not meeting the Euro 1 and diesels not meeting Euro 4 emission standards from entering the city centers since 2010. Other cities have similar programs (Umweltbundesamt, 2013). Although the national Umweltprämie was not explicitly linked to cities' low emission zones, it is conceivable that the local LEZ policies provided additional motivation to consumers to take advantage of the replacement subsidies in 2009.

CHINA: NATIONAL SCRAPPAGE PROGRAMS

China is currently implementing one of the world's most ambitious voluntary scrappage programs. The main vehicles targeted for early retirement are Euro 0 gasoline vehicles (pre-2000) and Euro 0, I, and II diesel vehicles (pre-2008). These vehicles, which are known in China as “yellow-label vehicles”—because there is a parallel effort to affix yellow environmental labels to their windshields—emit a disproportionately large share of total emissions. In 2011, China's Ministry of Environmental Protection (MEP) estimated that the 15.6 million yellow-label vehicles on the roads accounted for just 16% of the fleet, but produced 64% of NO_x, 60% of HC, 56% of CO, and 87% of PM emitted from all vehicles nationwide (MEP, 2012). Accordingly, eliminating these vehicles is seen as a high priority for the Chinese government in achieving rapid urban air quality improvements.

In addition to improving air quality, the national government also has promoted the economic benefits of a scrappage/replacement program to promote domestic consumption and stable growth of the automotive market. A 2009 State Council document also touted the energy saving benefits, estimating that new vehicles are on average 30% more efficient than the yellow-label vehicles they replace (State Council, 2009).

The Chinese government has initiated multiple programs to encourage the voluntary scrappage of these vehicles: national scrappage subsidies, local scrappage subsidies, and supporting policies including mandatory vehicle age limits and vehicle activity restrictions.

China's first national scrappage subsidy program was jointly initiated by eight ministries, including the Ministry of Commerce, Ministry of Finance, and Ministry of Environmental Protection, in mid-2009. The year-long program offered subsidies ranging from 3,000 to 6,000 RMB (\$490 to \$980) per scrapped vehicle (MOF et al., 2009). Subsidies varied by vehicle type and targeted both LDVs and HDVs. However, initial consumer response to the program was low. At the end of 2009, the government revised the subsidies upward to 6,000 to 18,000 RMB (\$980 to \$2,940) and extended the program to the end of 2010 (MOF et al., 2010a, 2010b). The 2009-2010 subsidy amounts by vehicle type are shown in Table 3.

Table 3. China’s 2009-2010 national-level scrappage subsidies (\$USD)

| Vehicle Type | Vehicle Type | June – December 2009 | January – December 2010 |
|-------------------|-------------------------------|----------------------|-------------------------|
| Passenger | Light passenger | <1.0 l | \$980 |
| | | 1-1.25 l | \$1,633 |
| | | >1.35 l | \$2,940 |
| | Micro bus | \$490 | \$817 |
| | Small bus | \$653 | \$1,143 |
| | Medium passenger (urban) bus* | \$817 | \$1,797 |
| | Large passenger bus (coach) | \$980 | \$2,940 |
| Freight | Micro truck* | \$653 | \$980 |
| | Light truck* | \$817 | \$1,470 |
| | Medium truck* | \$980 | \$2,123 |
| | Heavy truck | \$980 | \$2,940 |
| Specialty vehicle | | \$980 | |

* Subsidies also paid for scrappage of green-label vehicles

The increased subsidies were effective at encouraging greater participation in the program. From 2009 to 2010, the Ministry of Commerce (MOC) reported a twelve-fold increase in the daily average number of vehicles receiving subsidies (MOC, 2011). Over the course of 2010, the government spent a total of 6.41 billion RMB (\$1.04 billion) on subsidies for 459,000 vehicles—equivalent to an average subsidy of about 14,000 RMB/vehicle (\$2,270). MOC reported that the most subsidies were given to passenger cars (46.4%), then large/medium buses (20.7%) and small/micro trucks (17.2%) (MOC, 2011).

The national program ended at the end of 2010. Although no national-level scrappage subsidy program has been run since then, the Chinese national government has repeatedly mentioned wide-scale scrappage of yellow-label vehicles as an important near-term goal. For example, in June 2013, China’s highest executive body, the State Council, mentioned scrappage of yellow-label vehicles in the first of ten major new air pollution control measures (State Council, 2013a). In September 2013, a more detailed plan from the State Council established three concrete goals (State Council, 2013b):

1. Scrap all pre-2005 operational yellow-label vehicles by 2015;
2. Scrap five million yellow-label vehicles in the three key regions (greater Beijing region, greater Shanghai region, and greater Guangzhou region) by 2015;
3. Scrap all yellow-label vehicles nationwide by 2017.

The plan calls for the use of fiscal policies as well as the use of driving restrictions (e.g., low emission zones) to encourage scrappage.

Best Practice #1 (Replacement vehicles should be as clean as possible)

China’s programs do a good job of meeting BP#1. At the national level, the China IV (equivalent to Euro IV) emission standard went into effect on July 1, 2013. One reason national-level scrappage programs were not pushed more aggressively after 2010 was that the national government wanted to wait until the China IV emission standard went into force to ensure maximum emission reductions.

Best Practice #2 (Ensure expected benefits are actually achieved)

Emissions inventory modeling is regularly used in China to estimate expected emission reductions from vehicle replacement programs. However, it is unclear how much the modeling considers real-world performance, especially for off-cycle emissions. China has established explicit emissions reduction targets for each province, with local-level officials receiving “credit” towards these emissions reduction goals with each vehicle scrapped. China’s programs do not have strict regulations regarding the power and operation of the new vehicles compared to the vehicles they replace. The national scrappage program requires vehicles to be dismantled.

Best Practice #3 (Maximize cost-effectiveness)

China’s programs do not yet employ cost-effectiveness as a parameter for prioritizing grants. China also does not yet have any integrated programs that support replacement in parallel with other emissions reductions programs such as retrofitting or repowering.

Best Practice #4 (Balance national and local-level roles)

Experience in China is positive as related to BP#4. National-level and local-level programs historically have been run independently in China. Local-level programs, which are self-initiated, have been more successfully than exclusively national-level programs. As China prepares to implement its aggressive 2017 scrappage goals, it is unclear whether the national government will continue to operate the program itself or allocate funding to local governments.

Best Practice #5 (Employ complementary policies)

On a national level, the Chinese national government has set mandatory age and activity limits for nearly all categories of vehicles since 1997. The most recent revisions to the age limits and activity (i.e., maximum vehicle kilometers traveled, VKT) limits were implemented in May 2013. Table 4 highlights age and activity limits for some selected vehicle classes (MOF, 2009; MOC, 2013). Once a vehicle reaches the maximum age or activity limit, it can no longer be legally registered or operated. When China’s national scrappage program was initiated in 2009, the State Council announced that only a vehicle whose age was at least one year younger than its mandatory age limit would be eligible to receive a scrappage subsidy (State Council, 2009). This policy strongly encouraged owners to take advantage of the fiscal incentives prior to mandatory scrappage (at which point no financial subsidy would be given). Over time, the mandatory age limits have been slowly extended for some vehicle classes, and removed entirely for private passenger cars.

Table 4. Age limits for selected motor vehicles in China

| Vehicle Type | | Age Limits when national subsidies first implemented (2009-2010) | Current Age Limit | Current VKT Limit |
|--------------|-----------------------|--|-------------------|-------------------|
| Passenger | Taxi | 8 | 8 | 600,000 |
| | Private Passenger Car | 15 | none | 600,000 |
| | Public Bus | 10–15* | 13 | 400,000 |
| | Long-distance Bus | 10–15* | 15 | 800,000 |
| Freight | Light / Medium Trucks | 10–15* | 15 | 600,000 |
| | Heavy Trucks | | 15 | 700,000 |

* Basic age limit was 10 years, extendable by 5 more years.

CHINA: LOCAL SCRAPPAGE SUBSIDIES

Many local municipalities in China have developed their own scrappage subsidy programs above and beyond the national subsidies. The State Council's September 2013 air quality improvement plan specifically encourages local governments to strengthen their policy support for early scrappage of yellow-label vehicles (State Council, 2013b). To date, Beijing has been most the successful city in China at encouraging the voluntary early retirement of older vehicles.

Beijing's vehicle retirement programs during the 11th Five-Year Plan (2006-2010)

During the 11th Five-Year Plan (2006-2010), Beijing's municipal government began efforts to eliminate yellow-label vehicles from the city. At first, the city offered two rounds of subsidies to vehicle owners who agreed to either scrap their vehicles or transfer them outside of Beijing. From September 2008 to June 2009, subsidies ranged from 800 to 25,000 RMB/vehicle (\$131 to \$4,086) depending on vehicle age and type. These subsidies were subsequently reduced slightly in the second half of 2009 to 500 to 22,000 RMB/vehicle (\$82 to \$3,595). Both sets of subsidies were announced at the beginning of the program; the planned reductions were designed to encourage owners to take early advantage of the program (BJEPB, 2008). In 2010, the Beijing municipal government extended the subsidies and revised them again to be slightly higher (Beijing municipal government, 2010). Beijing's 2008-2009 subsidies are shown in Table 5.

Table 5. Beijing's 2008-2009 vehicle elimination subsidies (\$USD)

| Vehicle type | Vehicle Model Year | | | | | | |
|--|--------------------|-----------------|-----------------|-----------------|-----------------|-----------------|------------------|
| | 2004+ | 2002-2003 | 2000-2001 | 1998-1999 | 1996-1997 | 1994-1995 | 1993 and earlier |
| Small passenger | \$1500 / \$1160 | \$1330 / \$1000 | \$1160 / \$830 | \$830 / \$660 | \$580 / \$500 | \$330 / \$250 | \$160 / \$130 |
| Medium passenger or Medium trucks | \$1660 / \$1330 | \$1500 / \$1160 | \$1330 / \$1000 | \$1000 / \$830 | \$660 / \$580 | \$500 / \$330 | \$330 / \$250 |
| Large passenger | \$4160 / \$3660 | \$3830 / \$3330 | \$3500 / \$3000 | \$3000 / \$2500 | \$2330 / \$1830 | \$1500 / \$1160 | — |
| Small/micro trucks | \$1000 / \$830 | \$830 / \$660 | \$660 / \$500 | \$500 / \$330 | \$330 / \$160 | \$160 / \$130 | \$130 / \$80 |
| Heavy trucks | \$2500 / \$2160 | \$2330 / \$2000 | \$2160 / \$1830 | \$1660 / \$1330 | \$1160 / \$1000 | \$830 / \$750 | — |

Note: in each case, the first number is the Phase I subsidy (September 2008—June 2009); the second number is the Phase II subsidy (July—December 2009).

The average per-vehicle subsidy given in 2010 was 7,347 RMB (\$1,225).³ The Beijing EPB reported that, over 2009 and 2010, over 50,000 yellow-label vehicles were eliminated from the city. It calculated that the elimination of these vehicles resulted in daily reductions of 245 tons of CO, 35 tons of HC, 32 tons of NO_x, and 3 tons of PM in the city (BJEPB, 2011b).

³ Beijing EPB reported total spending of 85,749,600 RMB in 2010 on the elimination of 11,670 vehicles (BJEPB, 2011b).

BEIJING'S SCRAPPAGE PROGRAMS DURING THE 12TH FIVE-YEAR PLAN (2011-2015)

Beginning in the 12th Five-Year Plan (2011-2015), Beijing stopped giving subsidies for the elimination of yellow-label vehicles, because these vehicles had largely already been altogether eliminated from the fleet. Beijing continued offering subsidies to eliminate older, green-label vehicles from the fleet. The city's initial goal was to eliminate 400,000 vehicles over the period 2011-2015, but by the end of 2012 the city had already succeeded in retiring more than 500,000. Later, the goal was revised up to 700,000 (BJEPB 2011a, 2012). In August 2013, Beijing announced a new plan to further scrap one million older vehicles by 2017 (Beijing municipal government, 2013).

In 2011 and 2012, subsidies offered ranged from 2500 to 14,500 RMB/vehicle (\$409-\$2370), with an average of 4000 RMB/vehicle (\$654) (BEPB, 2011a). From 2011-2012, the government spent 1.05 billion RMB (\$172 million) in subsidies for 254,000 vehicles (BPEB, 2012). In 2013 and 2014, the maximum subsidy was increased to 16,500 RMB (\$2700), and the average offered was 4500 RMB (\$735) (BEPB, 2012). Beijing's 2011-2014 vehicle elimination subsidies are summarized in Table 6 (Beijing municipal government, 2012).

It is important to note that although the Beijing's program requires the destruction of the vehicle, it also allows for the vehicle to be sold outside Beijing. Of the approximately 50,000 yellow-label vehicles eliminated from the city in 2010, about 7,000 were simply transferred to another part of China (BJEPB, 2011b; BMEP, 2010), where they will continue to pollute. As shown in Table 6, since 2011, two different types of subsidies have been offered: subsidies for scrappage (*i.e.* vehicle destruction) and subsidies for transferring the vehicle outside the city. For each vehicle type, the scrappage subsidies were 500 RMB (\$82) higher from 2011-2012 and 2500 RMB (\$409) higher from 2013-2014 than the transfer subsidies.

Table 6. Beijing's 2011-2014 vehicle elimination subsidies in \$USD

| Vehicle type | Size | 2011-2014 subsidies for transferring vehicle outside Beijing | | 2011-2012 subsidies for scrappage | | 2013-2014 subsidies for scrappage | |
|--------------|--------|--|--------|-----------------------------------|--------|-----------------------------------|--------|
| | | Vehicle age in years | | | | | |
| | | 6-8 | 8+ | 6-8 | 8+ | 6-10 | 10+ |
| Passenger | Micro | \$500 | \$410 | \$580 | \$500 | \$580 | \$500 |
| | Small | \$750 | \$750 | \$830 | \$750 | \$1160 | \$1080 |
| | Medium | \$660 | \$580 | \$750 | \$660 | \$1080 | \$1000 |
| | Large | \$2330 | \$2000 | \$2410 | \$2080 | \$2700 | \$2410 |
| Freight | Micro | \$410 | — | \$500 | — | \$500 | — |
| | Light | \$500 | \$410 | \$580 | \$500 | \$910 | \$830 |
| | Medium | \$1160 | \$830 | \$1250 | \$910 | \$1580 | \$1250 |
| | Heavy | \$1660 | \$1330 | \$1750 | \$1410 | \$2100 | \$1750 |

Best Practice #1 (Replacement vehicles should be as clean as possible)

The replacement programs require that the replacement vehicle meet the latest, most stringent emission standard. This is reinforced via explicit emissions reduction targets for each province, with local-level officials receiving “credit” towards these emissions reduction goals with each vehicle scrapped.

Best Practice #2 (Ensure expected benefits are actually achieved)

The Beijing scrappage program partially complies with BP#2. Modeling is performed, and the local program managers have incentives to successfully run the program and accomplish the replacement goals. According to recent information posted on the Vehicle Emission Control Center Website (VECC, 2014) during the months from January through September Beijing has successfully removed more than 75% of the 2014 scrappage target of 390,000 vehicles. However, the local program encourages yellow label vehicles to be transferred to regions outside the city, as shown in Table 6.

Best Practice #3 (Maximize cost-effectiveness)

As mentioned before, China’s programs do not yet employ cost-effectiveness as a parameter for prioritizing grants. Thus, Beijing’s program does not comply with BP#3.

Best Practice #4 (Balance national and local-level roles)

Local-level programs have been very successful, as evidenced by the sheer number of replacements accomplished by the two phases of the Beijing plan. During the first phase more than 12,000 vehicles from the city were replaced; during the second phase, more than 254,000 vehicles were replaced.

Best Practice #5 (Employ complementary policies)

China has done an excellent job of employing complementary policies, especially national mandatory age/activity limits and local vehicle travel restrictions. In 2010, the Beijing EPB reported a total of more than 50,000 vehicles eliminated from the city, though it only gave subsidies to owners of fewer than 12,000 vehicles. From 2011-2012, the government claimed the elimination of over 500,000 vehicles, but issued subsidies to only 254,000 vehicle owners (BJEPB, 2012). Clearly, there has been significant vehicle retirement well exceeding what the subsidy programs have directly incentivized. While detailed statistics are not available on the precise reasons for retirement of the vehicles that did not receive subsidies, some of this retirement was doubtless bolstered by China’s additional policies including national mandatory age limits and local vehicle travel restrictions.

At the local level, scrappage programs are further bolstered by restrictions on where and when yellow-label vehicles can travel. Beijing was the pioneer of such restrictions, limiting yellow-label vehicle activity in certain parts of the city as early as 2003. Beginning in 2009, nearly all yellow-label vehicles were prohibited from traveling on or inside the 5th Ring Road around the city (approximately 10km from the city center). As of October 2009, the area was expanded to the 6th Ring Road (15-20km from the city center) (Beijing municipal government, 2008). Many other cities around China, including Shanghai and Guangzhou, have subsequently implemented yellow-label vehicle travel restrictions.

MEXICO: NATIONAL PROGRAM TO MODERNIZE FEDERAL ROAD TRANSPORTATION

In 2003, Mexico's Transport and Treasury Ministries launched the Programa de Modernización del Autotransporte de Carga y Pasaje (Program to Modernize Federal Road Transportation) with the objective of renewing the freight and bus fleets in order to increase competitiveness and access to regional and international markets. Other goals of the program were to reduce fuel consumption, accident rates, and environmental impacts.

Currently, truck owners with vehicles over ten years in age can exchange their old vehicle for a down payment or reduced costs for the purchase of a new or semi-new (less than 5 years old) vehicle. Vehicles that may be candidates for the bonus are required to be operating in good condition for one year before program participation and be registered as part of the federal highway fleet.⁴

The incentive amount is the lowest one of the following three: the value of the old vehicle, 15% of the cost of the replacement vehicle, or the bonus according to the vehicle categories shown in Table 7. If the owner is replacing two or more vehicles with one vehicle, the bonus becomes 15% of the cost of the replacement vehicle.

Table 7. Economic incentive amounts under Mexico's Program to Modernize Federal Road Transportation

| Vehicle categories | Incentive |
|--|-----------|
| 5th wheels tractor-trailers | \$12,400 |
| Three-axle trucks (14,500 kg minimum GVW) | \$8,000 |
| Two-axle trucks (11,794 kg minimum GVW) | \$5,350 |
| Integral buses | \$10,650 |
| Conventional buses | \$6,200 |

By January 2012, the program resulted in the scrappage of 20,974 vehicles. The number of vehicles participating in the program increased after the economic crisis in 2009, with 4,107 vehicles participating in 2010 and 6,183 vehicles in 2011. Between 2004 and 2011, an average of 2,621 vehicles per year have participated in the program.

The program has been complemented with other financial options. For example, through National Financing (NAFIN), vehicle owners get the option to pay for the replacement vehicle in one or five years, have guaranties of credit worth 1.5 times the price of the replacement vehicle, and get preferential interest rates. In order to do this, the owner has to be paying taxes (as oppose to be working as an informal unregistered transport operator) and show enough cash flow for credit access.

Although the program has delivered emission reductions, there are many concerns regarding future success and, thus, the continuation of the program in its current form. There is a low participation rate in the program because most old vehicles are in the hands of small family businesses with fewer than five vehicles. These vehicles compose 29% of the share of the federal freight and bus fleets, even though small family businesses make up 83% of all transport businesses (Transport Ministry, 2012). Most of these smaller

⁴ The freight and passenger bus fleets which travel on highways and roads managed by the federal government have to be registered as federal highway fleet and carry federal plates

business owners do not have good access to credit because they have seasonal incomes and some of them do not pay taxes. Lastly, according to the National Association of Truck and Bus Producers, owners of old vehicles have little incentive to scrap and replace their vehicles because the non-existence of heavy-duty in-use emission norms provides no disincentive for keeping old vehicles running (ANPACT, 2012).

Best Practice #1 (Replacement vehicles should be as clean as possible)

The principal accomplishment of the program was to reduce the average age of the federal transport fleet from 13.3 to 11.39 years between 2007 and 2012 (SCT, 2008). Vehicle emission standards have evolved since the start of the program. Because of this, many new replacement vehicles comply with much more stringent (EPA 2004 or Euro IV) emission standards compared to those of the older vehicles to be replaced (EPA 1994 or EPA 1998). In 2010, the National Institute of Ecology and Climate Change estimated the reductions in HC, CO, NO_x, and PM_{2.5} emissions from 2004 to 2010 as a result of the program. Their findings are presented in Table 8.

Table 8. Avoided emissions from 2004 to 2010 under Mexico’s Program to Modernize Federal Road Transportation. Source: INECC, 2010.

| Pollutant | Tons of pollutant emissions avoided, 2004-2010 |
|------------------------------------|--|
| Hydrocarbons (HC) | 31,410 |
| Carbon Monoxide (CO) | 152,663 |
| Nitrogen Oxides (NO _x) | 77,547 |
| Particles (PM _{2.5}) | 7,543 |

Best Practice #2 (Ensure expected benefits are actually achieved)

The program complies with BP#2. The program requires that the vehicle should be removed from circulation and that the vehicle should have been in circulation at least one year before requesting the incentive. The program just considers that the replacement vehicle should be in the same vehicle category, but there are no checks on differences in terms of rated power or activity.

Best Practice #3 (Maximize cost-effectiveness)

The fiscal cost by the program in the period of 2004-2010 was around \$2,207 million MXN (\$166 million USD). Although the program did not seek to reduce emissions, estimates have been made as to the cost-effectiveness of the resulting pollutant emission reductions. Table 9 gives the cost per ton reduced, by pollutant. It should be noted, by comparison, that the Carl Moyer Program shows a cost-effectiveness between \$1,500 and \$5,100 per ton of NO_x reduced.

Table 9. Cost per ton of emissions reduced from 2004 to 2010 under Mexico’s Program to Modernize Federal Road Transportation. Source: INECC, 2010

| Pollutant | USD/ton |
|------------------------------------|----------|
| Hydrocarbons (HC) | \$5,308 |
| Carbon Monoxide (CO) | \$1,092 |
| Nitrogen Oxides (NO _x) | \$2,150 |
| Particles (PM _{2.5}) | \$22,103 |

Best Practice #4 (Balance national and local-level roles)

The program was national in scope and does not apply to vehicles that operate primarily in cities, but rather to long-haul truck fleet owners.

Best Practice #5 (Employ complementary policies)

There are no complementary policies that enforce vehicle age limits under the federal law.

MEXICO CITY: PROGRAM TO REPLACE MEDIUM CAPACITY BUSES WITH NEW AUTOBUSES

Mexico City launched a program in 2001 to renew public transportation buses called Programa de Sustitución de Microbuses por Autobuses Nuevos. In that year, 90% of microbuses were model year 1993 or older, without any emission control systems. Emissions from these microbuses and buses composed 11.7% of total emissions from the transport sector (CAM, 2011).

The program gives owners of pre-1995 buses up to \$100,000 MXN (around \$7,700 USD) as a down payment for the purchase of an EPA 2004 certified replacement vehicle. In order to qualify for the fiscal bonus, vehicle owners provide all legal documents for the vehicle in good standing and must prove the economic solvency of their business. Furthermore, vehicle owners must submit their old vehicles to a certified scrapyards to be destroyed (SETRAVI, 2013).

Through this program and the introduction of diesel particle filters in some new vehicles, Mexico City government planned to reduce bus NO_x, CO, PM₁₀ and PM_{2.5} emissions by 10, 90, 90, and 90%, respectively in 13,000 buses. Annual microbus replacements under this program are shown in Table 10.

Table 10. Microbuses replaced under the Mexico City program. Source: Mexico City Government, 2013

| Fiscal Year | Microbuses Replaced | Program Expenditure (USD millions) |
|--------------|---------------------|------------------------------------|
| 2001 | 384 | \$2.90 |
| 2002 | 451 | \$3.41 |
| 2003 | 344 | \$2.60 |
| 2004 | 555 | \$4.19 |
| 2005 | 355 | \$2.68 |
| 2006 | 203 | \$1.53 |
| 2007 | 250 | \$1.89 |
| 2008 | 553 | \$4.18 |
| 2009 | 876 | \$6.62 |
| 2010 | 424 | \$3.20 |
| 2011 | 181 | \$1.37 |
| Total | 4576 | \$34.56 |

Best Practice #1 (Replacement vehicles should be as clean as possible)

The program meets BP#1 as the replacement vehicle is certified to EPA 2004, a much cleaner technology than the uncontrolled pre-1995 vehicles being replaced.

Best Practice #2 (Ensure expected benefits are actually achieved)

The program ensures the desired benefits are accruing in several ways. First, the older vehicle (pre-1995) is replaced with a new one, certified to EPA 2004. The second benefit is a reduction in the total number of older vehicles on the road as the program allows the substitution of one high-capacity cleaner bus for two medium- or low-capacity buses (microbuses). In addition, the annual distance traveled remains controlled as transit authorities set the routes of the buses; this means that the new bus replaces an old one and runs under approximately the same duty cycle.

Best Practice #3 (Maximize cost-effectiveness)

The costs and benefits of the vehicle replacement program have been evaluated by the Program to Improve the Air Quality in the Metropolitan Zone (PROAIRE). This program covers not only the local microbus replacement program, but also additional air-quality improvement programs for the transport sector. The microbus replacement program and other programs covered by PROAIRE are presented in Table 11 for comparison. This shows that vehicle replacement programs are one of the most cost effective for NO_x control, while repowering and retrofitting are much better for PM reductions.

Table 11. Cost-effectiveness of various interventions to reduce transportation emissions in Mexico City. Source: CAM for PROAIRE program 2011-2020, 2011

| | Cost per year (USD, millions) | USD/ton PM ₁₀ | USD/ton PM _{2.5} | USD/ton CO | USD/ton NO _x |
|---|-------------------------------|--------------------------|---------------------------|------------|-------------------------|
| Diesel vehicle renovation with engine substitution (repowering) and emission control incorporation (retrofitting). | 3.19 | 49,797 | 59,019 | 5,722 | 57,946 |
| Public transport vehicle fleet renovation for low, medium and high capacity. | 120.08 | 2,001,329 | 3,078,968 | 1,643 | 11,157 |

Best Practice #4 (Balance national and local-level roles)

The program for microbus replacement is a local program, managed by local authorities.

Best Practice #5 (Employ complimentary policies)

Currently there are no low emission zones defined in Mexico City. New bus procurements are not defined for microbuses, but there are precedents in this area from Mexico City's bus rapid transit (BRT) system experience. The BRT Metrobus System establishes a maximum of 10 years useful life for a bus operating in the system (Gaceta 2005). BRT buses that have reached the peak useful life are contractually required to be removed from circulation, and replaced with a new one.

CHILE: SWAP YOUR TRUCK

The Cambia tu Camión (Swap Your Truck) program in Chile targeted the renewal of trucks that have been in service for more than 25 years. The program was developed

by the Chilean Energy Efficiency Agency (AChEE) and introduced in 2009 as a subsidy with the amount dependent on the vehicle weight. The program targeted micro and small business owners with revenue below a minimum threshold of roughly USD\$25,000 per year.

Payments were dependent on vehicle weight as follows:

- » 3.86 ton < GVW < 9 ton: USD\$8,000,
- » 9 ton < GVW < 17 ton: USD\$16,000, and
- » GVW > 17 ton: USD\$24,000

The program was managed by the Technical Cooperation Service (SERCOTEC). The Ministry of Energy provided 50% of the resources, and the remaining 50% was divided among the private sector. The payments represented between 1.2-2.0 times the resale value of the old truck, and about one-third of the price of the new one (TSTES and ITP, 2013)

Detailed requirements of the program included:

- » The business owner had to provide proof of a preapproved loan from a financing institution for the remainder of the replacement vehicle price;
- » The replacement vehicle had to be selected in advance;
- » The replacement vehicle was required to be new or no more than 10 years old.
- » The vehicle to be scrapped had to be 20 years old or older and in good working condition;
- » The vehicle's working condition was demonstrated with annual safety and emission verification documents.

Best Practice #1 (Replacement vehicles should be as clean as possible)

The program led to the removal of just under 5% of the pre-1984 trucks in the country. Vehicles were required to be replaced by Euro III certified models. In addition, eco-driving technique instructions were provided.

This program made significant efforts to achieve reductions in emissions and fuel consumption. Besides specific emission standard requirements, the program carried out a series of tests for the evaluation of improvements. The tests involved both the old and new vehicles being driven by the owner on the same route and comparing fuel consumption. This evaluation showed an 89% reduction in PM and an estimated reduction of more than 100,000 tons of CO₂ (TSTES and ITP, 2013).

Chile has had Euro III HD vehicle standards and access to 50 ppm sulfur diesel in the metropolitan area since 2005. Ultra low sulfur diesel has been available since 2011. The program pilot started in 2009 and has been running since then. This vehicle replacement program has benefitted due to the availability of low and ultra low sulfur diesel programs. This allows for the adoption of diesel particulate filters and other advanced control technologies in replacement vehicles.

Best Practice #2 (Ensure expected benefits are actually achieved)

Removal of the replaced vehicle from the fleet is required. It is unclear whether replacement vehicles were required to be of similar power. However, the program clearly required proof that the vehicles to be retired were in fact in regular operation.

Best Practice #3 (Maximize cost-effectiveness)

No information on cost-benefits analysis was available from the government agencies involved in developing and implementing this program.

Although the amount offered as subsidy was considered generous, access to credit for small fleet operators was challenging (TSTES and ITP, 2013). The difficulty accessing credit lines particularly affected the small operators who have a family business, or unregistered low-income operators. These vehicle owners typically lack financial documents, complete tax information and have little credit history. No additional funding opportunities were set up through government financing offices.

Best Practice #4 (Balance national and local-level roles)

The program was national in scope and carried out entirely by SERCOTEC. Potential program applicants had to apply through their regional or provincial SERCOTEC office, meaning there was some level of input in decision-making by more regional or local authorities.

Best Practice #5 (Employ complementary policies)

In addition to vehicle replacement, the program included eco-driving classes for vehicle owners and drivers. Eco-driving is designed to engage the driver in obtaining the best fuel consumption possible from a vehicle, and may include better shifting techniques, keeping steady speeds and anticipating traffic flow. Eco-driving techniques allowed for a 13% to 20% improvement in fuel consumption (AChEE, 2014).

Establishment of a LEZ for heavy-duty trucks in the region was part of the strategy for improving air-quality in the metropolitan region of Santiago, Chile (Ministerio Secretaria General de la Presidencia, 2010). However, the law has yet to be implemented for numerous reasons, such as failing to successfully agree upon the perimeter, emission criteria, and identification methods.

SUMMARY OF CASE STUDIES

The Table below summarizes the vehicle replacement programs presented in this report.

Table 12. Summary of characteristics of vehicle replacement programs analyzed in this report

| Program | Years covered by program | Vehicles targeted | Approximate average subsidy offered | Complementary policies used |
|--|--------------------------|--|--|---|
| US: California: Carl Moyer | 1999-present | Multiple types, including on-road and off-road | ~\$28,000 per vehicle | Mandatory upgrades of high polluting vehicles (regulatory backstops) |
| US: Cash for Clunkers | Limited to 2009 | Light-duty vehicles | \$3,500-\$4,500 | None |
| US: National Clean Diesel Campaign | 2007-2011 and 2012-2016 | Heavy-duty vehicles | ~\$9,400 per vehicle spent for the program | None |
| Germany: Scrappage Bonus | Limited to 2009 | Light-duty vehicles | \$3,500 | Low emission zones |
| China: National Scrappage Program | Nationwide, 2009-2010 | Light- and heavy-duty vehicles | Varied by vehicle type, between \$980 and \$2940 | Mandatory vehicle age limits |
| China: Local Scrappage Program | In Beijing, 2008-present | Light and heavy-duty vehicles | Varies by vehicle type: LDVs: \$410-2410 HDVs: \$1330-\$2100 | Mandatory vehicle age limits and low emission zones |
| Mexico: Program to Modernize Federal Road Transportation | 2003—present | Heavy-duty vehicles on federal highways | Up to 15% of the cost of the replacement vehicle | None |
| Mexico City: Program to Replace Microbuses with New Autobuses | 2001-present | City buses | Up to \$7,700 | None |
| Chile: Swap Your Truck | 2009-present | Heavy-duty trucks | From \$8,000 to \$24,000 depending on vehicle category | Potential: there is a ministerial decree to implement a low emission zone, but it has not been executed |

CONCLUSIONS

This report presented a number of vehicle replacement programs that have been implemented around the world, and evaluated them on the basis of five identified best practices. The best practices and experience presented here are intended to serve as guidelines for policymakers to consider when developing vehicle replacement programs. The five best practices for vehicle replacement programs identified in this report are:

1. For maximum environmental benefits, replacement vehicles should be as clean as possible.
2. Program implementation, management, and enforcement should ensure expected benefits are actually achieved.
3. Fiscal incentives should be carefully tailored to maximize both environmental benefits and cost-effectiveness.
4. Program design should carefully consider and balance the different roles of national, regional, and local-level policymakers.
5. Complement fiscal policies with additional incentives such as low emission zones and regulatory backstops.

Table 13 summarizes whether each program analyzed in this report met each of the five best practices.

Table 13. Analysis of vehicle replacement programs in the context of the five best practices defined in this report

| Vehicle Replacement Program | Best Practice | | | | |
|--|---------------|-----------|-----------|-----|-----|
| | #1 | #2 | #3 | #4 | #5 |
| US: California: Carl Moyer Program | Yes | Yes | Yes | Yes | Yes |
| US: Consumer Assistance to Recycle and Save (CARS) | No | Partially | Partially | No | No |
| US: National Clean Diesel Campaign (NCDC) | Yes | Yes | Yes | Yes | No |
| Germany: Scrappage Bonus | Yes | No | No | No | Yes |
| China: National Vehicle Scrappage Program | Yes | Yes | No | Yes | Yes |
| China: Local Vehicle Scrappage Program | Yes | Partially | No | Yes | Yes |
| Mexico: Program to Modernize Federal Road Transportation | Yes | Yes | Yes | No | No |
| Mexico: Mexico City: Program to Replace Microbuses with New Autobuses | Yes | Yes | Yes | Yes | No |
| Chile: Swap Your Truck | Yes | Yes | No | No | No |

While policymakers should learn from the experiences of vehicle replacement programs around the world and the best practices discussed in this report, these should not be interpreted to be strict rules. The success of a vehicle replacement program often depends on the specific environmental concerns of a region as well as what features would best complement the local culture. It is therefore key that policymakers keep in mind the specific situation of the region to which the policy is being applied. Likewise,

as reflected in Best Practice #5, vehicle replacement programs work best when they are implemented in tandem with other policies to reduce vehicle emissions. Vehicle replacement programs should not be used as an *alternative* to things like new vehicle emission standards, fuel sulfur reduction strategies, and well-designed I/M programs. Rather, vehicle replacement programs should be considered as one tool of many to reduce the impacts of a region's transportation sector on the climate and human health.

REFERENCES

- Agencia Chilena de Eficiencia Energetica (ACHEE) 2014. Website: *Bienvenido a la Conduccion Eficiente*. Oct 2014. Available at <http://www.conduccioneficiente.cl/index.php?s=consejos&t=carga&p=22>
- Asociación Nacional de Productores de Autobuses, Camiones y Tractocamiones (ANPACT), 2012. Structural Changes, Modernization and Professionalization of Federal Freight and Passengers Transport in Mexico.
- Bansal, G., and Bandivadekar, A., 2013. *Overview of India's Vehicle Emissions Control Program: Past Successes and Future Prospects*. The International Council on Clean Transportation. November 2013. Available at <http://theicct.org/indias-vehicle-emissions-control-program>
- Ban-Weiss, G.A., Lunden, M.M., Kirchstetter, T.W., Harley, R.A., 2009. *Measurement of black carbon and particle number emission factors from individual heavy-duty trucks*. Environmental Science and Technology 43, 1419-1424.
- Beijing Environmental Protection Bureau (BEPB), 2008. <http://www.bjepb.gov.cn/portal0/tab189/info6749.htm>
- BEPB, 2010. *Over 40,000 high pollution emissions yellow cars removed from the city in 2010*. Available at <http://zhengwu.beijing.gov.cn/zfjd/hj/t1141575.htm>
- BEPB, 2011a. *Municipal government issues new policy encouraging scrappage of older vehicles* (in Chinese). Retrieved September 5, 2013, from <http://www.bjepb.gov.cn/portal0/tab189/info6306.htm>
- BEPB, 2011b. *2010 State of the Environment in Beijing*, <http://www.bjepb.gov.cn/bjepb/323474/331443/331616/331634/444594/index.html>
- BEPB, 2012. <http://www.bjepb.gov.cn/portal0/tab189/info9608.htm>
- Beijing municipal government, 2008. http://www.gov.cn/gzdt/2008-09/28/content_1108399.htm
- Beijing municipal government, 2010. <http://www.bjepb.gov.cn/portal0/tab189/info2509.htm>
- Beijing municipal government, 2012. <http://bjtgc.cbeex.com.cn/face/xgxx/20130110.pdf>
- Beijing municipal government, 2013. <http://zhengwu.beijing.gov.cn/gzdt/gggs/t1322955.htm>
- California Air Resources Board, 2007. *The Carl Moyer Program 2006 Status Report*. January, 2007. Available at http://www.arb.ca.gov/msprog/moyer/status/2006status_report.pdf
- California Air Resources Board, 2011. *The Carl Moyer Program Guidelines*. April 28, 2011. Available at http://www.arb.ca.gov/msprog/moyer/guidelines/2011gl/2011cmpgl_10_30_13.pdf
- Chambliss, S., Miller, J., Façanha, C., Minjares, R., and Blumberg, K., 2013. *The impact of vehicle and fuel standards on premature mortality and emissions*. The International Council on Clean Transportation. November 2013. Available at <http://theicct.org/global-health-roadmap>
- Comisión Ambiental Metropolitana (CAM), 2001. Programa para mejorar la calidad del aire de la Zona Metropolitana del Valle de México 2001-2010.

- Comisión Ambiental Metropolitana (CAM), 2011. Programa para mejorar la calidad del aire de la Zona Metropolitana del Valle de México 2011-2020.
- Copeland, A., Kahn, J., 2011. *The Production Impact of “Cash-for-Clunkers”: Implications for Stabilization Policy*. Federal Reserve Bank of New York. July 2011. Available at http://www.newyorkfed.org/research/staff_reports/sr503.pdf
- Diario Oficial de la Federación, 2003. National Decree that gives fiscal stimulus to taxpayers. Oct 30, 2003. Available at http://dof.gob.mx/nota_detalle.php?codigo=689441&fecha=30/10/2003
- Dougherty, C., 2009. *Driving Out of Germany, to Pollute Another Day*. August 7, 2009. Available at <http://www.nytimes.com/2009/08/08/world/europe/08germany.html?hpw&r=0>
- Environmental Protection Agency (EPA), 2013. Last updated June 26, 2013. Retrieved from <http://www.epa.gov/cleandiesel/index.htm>
- Federal Office of Economics and Export Control (BAFA), 2009. *Richtlinie zur Förderung des Absatzes von Personenkraftwagen*. January 2009. Available at http://www.bafa.de/bafa/de/wirtschaftsfoerderung/umweltpraemie/dokumente/foederrichtlinie_umweltpraemie.pdf
- Gaceta Oficial de Distrito Federal, 2005. Autorización para la Prestación del Servicio Público de Transporte de Pasajeros. June 24, 2005. Available at <http://www.metrobus.df.gob.mx/transparencia/documentos/art14/XVIII/01%20permisos/Autorizacion%20RTP.pdf>
- Government of Chile, 2013. *Nuevo programa “Cambia tu camión” permitirá renovar máquinas en todo Chile* Website <http://www.gob.cl/informa/2013/09/16/nuevo-programa-cambia-tu-camion-permitira-renovar-maquinas-en-todo-chile.htm>
- Health Effects Institute (HEI), 2010. Panel on the Health Effects of Traffic-Related Air Pollution. *Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects*. Special Report 17. Health Effects Institute. January 2010. Available at <http://pubs.healtheffects.org/getfile.php?u=553>
- Institute for Energy and Environmental Research (IFEU), 2009. *Abwrackprämie und Umwelt—eine erste Bilanz*. August 31, 2009. Available at http://www.bmu.de/fileadmin/bmu-import/files/pdfs/allgemein/application/pdf/ifeu_abwrackpraemie_bf.pdf
- International Council on Clean Transportation, 2013. *Global passenger vehicle standards*. Accessed November 5, 2013. Available at <http://www.theicct.org/info-tools/global-passenger-vehicle-standards>
- International Council on Clean Transportation, 2013. *California: Heavy-duty: Emissions*. Last updated July 31, 2013. Retrieved from http://transportpolicy.net/index.php?title=California:_Heavy-duty:_Emissions
- International Council on Clean Transportation, 2013. *US: Heavy-duty: Emissions*. Last updated August 6, 2013. Retrieved from http://transportpolicy.net/index.php?title=US:_Heavy-duty:_Emissions
- International Council on Clean Transportation, 2014. *Supplemental WHTC testing for Euro IV/V heavy-duty vehicles in China*. Accessed August 27, 2014. Retrieved from <http://www.theicct.org/supplemental-whtc-testing-hdvs-china>
- Instituto Nacional de Ecología y Cambio Climático (INECC) and Secretaría del Medio Ambiente y Recursos Naturales (SEMARNAT), 2011. Economics valuation of environmental benefits for a federal transport scrapping program.

- Kaul, A., Pfeifer, G., and Witte, S., 2012. *The Incidence of Cash for Clunkers—An Analysis of the 2009 Car Scrappage Scheme in Germany*. April 5, 2012. Available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2034394
- Lenski, S. M.; Keoleian, G. A.; Bolon, K. M. 2010. *The impact of “Cash for Clunkers” on 504 greenhouse gas emissions: a life cycle perspective*. Environ. Res. Lett. 2010, 5, 044003
- Li, S., Linn, J., and Spiller, E., 2012. *Evaluating “Cash-for-Clunkers.”* Resources for the Future. October 2011. Available at <http://www.rff.org/RFF/Documents/RFF-DP-10-39-REV.pdf>
- Lowell, D., and Kamakate, F., 2012. *Urban off-cycle NO_x emissions from Euro IV/V trucks and buses*. International Council on Clean Transportation. March 2012. Available at <http://www.theicct.org/urban-cycle-nox-emissions-euro-ivv-trucks-and-buses>
- México City Government, 2013. Personal communications.
- Mian, A., and Sufi, A., 2009. *The Effects of Fiscal Stimulus: Evidence from the 2009 ‘Cash-for-Clunkers’ Program*. National Bureau of Economic Research. September 2010. Available at <http://www.nber.org/papers/w16351>
- Ministry of Environmental Protection of China. 2012 China Vehicle Emission Control Annual Report (in Chinese). Available at: http://www.mep.gov.cn/gkml/hbb/qt/201212/t20121227_244340.htm
- Ministry of Commerce of China (MOC), 2011. <http://www.mofcom.gov.cn/aarticle/ae/ai/201101/20110107349567.html>
- MOC, 2013. The current limits (in Chinese) are available at <http://www.mofcom.gov.cn/article/b/d/201301/20130100003957.shtml>
- Ministry of Finance et al., 2009. *Notice about issuing of implementation methods for vehicle scrappage and replacement* (in Chinese). Retrieved September 2, 2012, from http://www.vecc-mep.org.cn/news/news_detail.jsp?newsid=33844
- Ministry of Finance and Ministry of Commerce, 2010. *Notice about adjusting subsidy standards and related matters for vehicle scrappage and replacement* (in Chinese). Retrieved September 2, 2012, from http://www.vecc-mep.org.cn/news/news_detail.jsp?newsid=36388
- Ministerio Secretaria General de la Presidencia, 2010. *Revisa, Reformula y Actualiza Plna de Prevencion y Descontaminacion Atmosferica para la Region Metropolitana (PPDA)*. 2010. Available at http://www.cavem.cl/sitio_socios/PPDA_2010/PPDA-2010.pdf
- MOF et al., 2010. <http://scjss.mofcom.gov.cn/aarticle/cx/201006/20100606987758.html>
- National Highway Traffic Safety Administration, 2009. *Consumer Assistance to Recycle and Save Act of 2009: Report to the House Committee on Energy and Commerce, the Senate Committee on Commerce, Science, and Transportation, and the House and Senate Committees on Appropriations*. December 2009. Available at <http://icsw.nhtsa.gov/cars-archive/official-information/CARS-Report-to-Congress.pdf>
- Office of Transportation and Air Quality, 2009. *Report to Congress: Highlights of the Diesel Emissions Reduction Program*. Environmental Protection Agency. August 2009. Available at <http://epa.gov/cleandiesel/documents/42Or09006.pdf>
- Office of Transportation and Air Quality, 2012. *Second Report to Congress: Highlights of the Diesel Emissions Reduction Program*. Environmental Protection Agency. December 2012. Available at <http://www.epa.gov/cleandiesel/documents/42Or12031.pdf>

- Ruehl, C., Herner, J. D., Yoon, S., Collins, J. F., Misra, C., Na, K., ... & Ayala, A., 2014. Similarities and Differences Between “Traditional” and “Clean” Diesel PM. *Emission Control Science and Technology*, 1-7.
- Santisi, J., 2013. *The Cash for Clunkers Conundrum*. The Environmental Magazine. January 2, 2013. Available at <http://www.emagazine.com/blog/the-cash-for-clunkers-conundrum>
- Secretaría de Comunicaciones y Transportes México (SCT), 2008. *Decreto por el que se aprueba el Programa Sectorial de Comunicaciones y Transportes 2007-2012*. Diario Oficial de la Federación. 18-01-2008.
- Secretaría de Transportes y Vialidad (SETRAVI), 2013. *Programa de Sustitución de Microbuses por Autobuses Nuevos*. Accessed November 12, 2013. Available at http://www.setravi.df.gob.mx/wb/stv/programa_de_sustitucion_de_microbuses
- Shindell, D., Ramanathan, V., Raes, F., Cifuentes, L., & Kim Oanh, N. T. (2011). *Integrated assessment of black carbon and tropospheric ozone (pp. 1–285)*. Nairobi: UNEP and WMO. Retrieved from <http://www.unep.org/dewa/Assessments/Ecosystems/ClimateChange/tabid/7002/Default.aspx>
- State Council of China, 2009. http://www.gov.cn/zwgk/2009-06/03/content_1331210.htm
- State Council of China, 2013a http://www.gov.cn/ldhd/2013-06/14/content_2426237.htm
- State Council of China, 2013b http://www.gov.cn/zwgk/2013-09/12/content_2486773.htm
- Transport Ministry, 2012. Basic statistics of the federal transport 2012. <http://www.sct.gob.mx/transporte-y-medicina-preventiva/autotransporte-federal/estadistica-basica-del-autotransporte-federal/>
- TranSantiago. 2013. *Who are we?* (Description in English). Retrieved September 26, 2013 from <http://www.transantiago.cl/QUIENESSOMOS/DESCRIPCION/INGLES/index.htm>
- TSTES and Integrated Transport Planning (ITP), 2013., Mexico International Freight Study. Research into GHG Mitigation Measures in the Small Carrier Freight Sector. By Robin Kaenzig, Prepared for Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). August, 2013.
- Umweltbundesamt, 2103. *Low emission zones and air quality plans in Germany*. December 17, 2013. Available at http://gis.uba.de/website/umweltzonen_en/index.htm
- Vehicle Emission Control Center (VECC), 2014. Department of Environmental Protection Bulletin on Yellow and Old Cars. October, 2014. Available at: http://www.vecc-mep.org.cn/news/news_detail.jsp?newsid=64059
- Wagner, D.V., and Rutherford, D., 2013. *Survey of Best Practices in Emission Control of In-Use Heavy-Duty Diesel Vehicles*. International Council on Clean Transportation. August 2013. Available at <http://theicct.org/best-practices-emission-control-in-use-hdvs>
- Wang, X., Westerdahl, D., Wu, Y., Pan, X., Zhang, K.M., 2011. On-road emission factor distribution of individual diesel vehicles in and around Beijing, China. *Atmospheric Environment* 45, 503-513
- Yan, F., Winijkul, E., Jung, S., Bond, T. C., & Streets, D. G., 2011. *Global emission projections of particulate matter (PM): I. Exhaust emissions from on-road vehicles*. *Atmospheric Environment*, 45(28), 4830–4844