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REVIEW AND COMPARATIVE ANALYSIS OF IN-USE VEHICLE EMISSION CONTROL PROGRAMS IN GUANGDONG PROVINCE

Zifei Yang, Yin Qiu, and Rachel Muncrief

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

www.theicct.org

communications@theicct.org

BERLIN | BRUSSELS | SAN FRANCISCO | WASHINGTON

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1225 I Street NW, Suite 900
Washington DC 20005 USA

communications@theicct.org | www.theicct.org

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Controlling emissions from the in-use fleet, particularly from high emitters and older vehicles, can immediately alleviate urban air pollution. This is complementary to the implementation of new vehicle emission and low-sulfur fuels standards that can generate significant long-term benefits. Under the increasing pressure to improve air quality and reduce environmental impacts of vehicle use, Guangdong Province in China has taken various approaches to reduce emissions from the existing stock of in-use vehicles.

With authorization and guidance from the national and provincial governments, cities in Guangdong have established programs based on their specific capabilities and needs. The most common in-use emission control practices in Guangdong include enforcing in-use compliance to identify high emitters, such as inspection and maintenance, remote sensing, spot-checking, public spotter programs; cleaner fuel program; eliminating high emitters and older vehicles from the road, through programs such as scrappage and replacement as well as retrofit and repower; establishing low emission zones; and vapor recovery at fueling stations, referred to as Stage II vapor recovery.

This report summarizes best practices of each in-use control program that serve as guidelines for policymakers seeking to design, implement, and improve their programs at the local level. In addition, the report evaluates in-use vehicle emission control programs in four cities in Guangdong's Pearl River Delta region: Guangzhou, Shenzhen, Foshan, and Dongguan. Table ES-1 summarizes how each city's program meets the requirements of each best practice of the different programs.

Table ES-1. Evaluation of in-use vehicle emission control programs in Guangzhou (GZ), Shenzhen (SZ), Foshan (FS), and Dongguan (DG)

In-use compliance	GZ	SZ	FS	DG
Inspection and Maintenance (I/M) program				
1. Design a comprehensive institutional structure for I/M management				
2. Base I/M program technical design on studies and improve over time				
3. Promote I/M program compliance and enforcement				
4. Obtain and manage resources				
5. Build up maintenance capacity in I/M programs				
Remote sensing program				
1. Choose good locations to collect useful data				
2. Establish enough remote sensing systems to prevent cheating				
3. Set on-road emission standards properly and take corrective action				
4. Use remote sensing results to effectively reduce emissions				
5. Ensure adequate enforcement for effective pollution control				
Spot-checking program				
1. Choose good locations to target possible high-emitting vehicles				
2. Establish test procedures and train inspectors to conduct testing				
3. Ensure adequate enforcement for effective pollution control				
Public spotter program				
1. Promote the program to encourage public support				
2. Provide the public easy reporting methods when identifying smoking vehicles				
3. Ensure follow-up with vehicle owners who are reported				
Cleaner fuel program	**GZ**	**SZ**	**FS**	**DG**
1. Adopt a systematic approach				
2. Build a solid and flexible regulatory mechanism				
3. Adopt progressive pricing to encourage cleaner fuels				
4. Implement an effective compliance program	N/A	N/A	N/A	N/A
5. Use captive fleets to create demand for cleaner fuels				
Eliminating high emitters and older vehicles from the road	**GZ**	**SZ**	**FS**	**DG**
Scrappage and replacement program				
1. Replace scrapped vehicles with vehicles that are as clean as possible				
2. Ensure expected benefits are actually achieved				
3. Maximize both environmental benefits and cost-effectiveness				
4. Balance national and local-level roles				
5. Employ complementary policies				
Low emission zone	**GZ**	**SZ**	**FS**	**DG**
1. Receive political support				
2. Reduce emissions from gross-emitting vehicles effectively in the city				
3. Educate operators affected by the scheme changes				
4. Establish cost-effective enforcement mechanism				
Stage II vapor recovery	**GZ**	**SZ**	**FS**	**DG**
1. Maximize program coverage to improve control efficiency				
2. Ensure strong local oversight of system installations				
3. Monitor and maintain the Stage II vapor recovery system consistently	N/A	N/A	N/A	N/A
4. Evaluate the cost-effectiveness of the program	N/A	N/A	N/A	N/A

Meets Partially meets Does not meet

The best practices discussed in this report are experiences that policymakers can learn from rather than strict rules for implementation. Effective in-use vehicle emission control is a collective result from various programs. For instance, the I/M program works best when it is complemented by other programs to reduce vehicle emissions, such as remote sensing, spot-checking, or public spotter programs. Moreover, the success of these programs often depends on the specific local environmental concern and available resources to which the policy is being applied. The report concludes by suggesting detailed actions that Guangdong or its cities can undertake to enhance each of the in-use vehicle emission control programs at the local level.

BACKGROUND

Guangdong Province's vehicle population has significantly increased in recent years and Guangdong has become the province with largest vehicle population in China. With more than 50% of the province's population, the Pearl River Delta (PRD) region has 80% of the on-road vehicles in the province. The four cities selected in this paper—Guangzhou, Shenzhen, Dongguan, and Foshan—account for 80% of the vehicle population in PRD area. Table 1 summarizes key data about Guangdong and the Pearl River Delta.

Table 1. Population and vehicle stock in 2012

Region	Permanent Population (millions)	Motor Vehicle Population (thousands)
Guangzhou	12.9	2,148
Shenzhen	10.6	2,584
Dongguan	8.3	1,389
Foshan	7.3	1,358
Zhuhai	1.6	312
Zhongshan	3.2	554
Huizhou	4.7	414
Jiangmen	4.5	411
Zhaoqing	4.0	236
Rest of Guangdong	49.3	2,332
Guangdong Province (all)	106.4	11,785

Source: Guangdong Statistical Yearbook (2014)

These millions of motor vehicles subsequently impose an increasingly large burden on air quality. As a result, local regulators are under increasing pressure to act. In 2013, none of the cities in the Pearl River Delta completely met China's new ambient air quality standards (GB 3095-2012), which evaluate SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, and O_3 (MEP, 2014). Reducing vehicle pollutant emissions yields corresponding improvements in ambient air quality, which has broad positive effects on public health. Therefore, local governments are making great efforts to control emissions from on-road vehicles.

In-use vehicle emission control programs are used to identify and control high-emitting vehicles and mitigate their environmental effects. High-emitting vehicles are those whose pollutant levels are significantly greater than expected based on the vehicle's technology, certified emission standard, and age. In China, local governments set the definition of "high emitter" following national guidelines. Vehicle programs like I/M, remote sensing, and spot-checking can identify and reduce emissions from high-emitting vehicles.

Besides high emitters, China also pays special attention to older vehicles. Unlike vehicles that become high emitters through improper maintenance and operation or tampering, older vehicles could maintain emission rates close to the design emission standards with proper and regular maintenance. But even so, older vehicles are a large contributor to the local emission inventory and difficult to keep well maintained, compared to newer additions to the fleet. Due to vehicles' long lifespans, even accounting for the fact that Guangdong province has an aggressive timeline for implementing new vehicle emission standards, it typically takes decades before the oldest, highest-emitting vehicles are retired from use. As shown in Figure 1, there is a large population of on-road vehicles

certified under less stringent standards. Some vehicles are even pre-China 1/I. Vehicle management programs like scrappage, retrofitting and repowering, complemented with transit measures such as low emission zones, can reduce the impact of emissions from older vehicles while also controlling emissions from other vehicles in use to achieve rapid improvement in regional air quality.

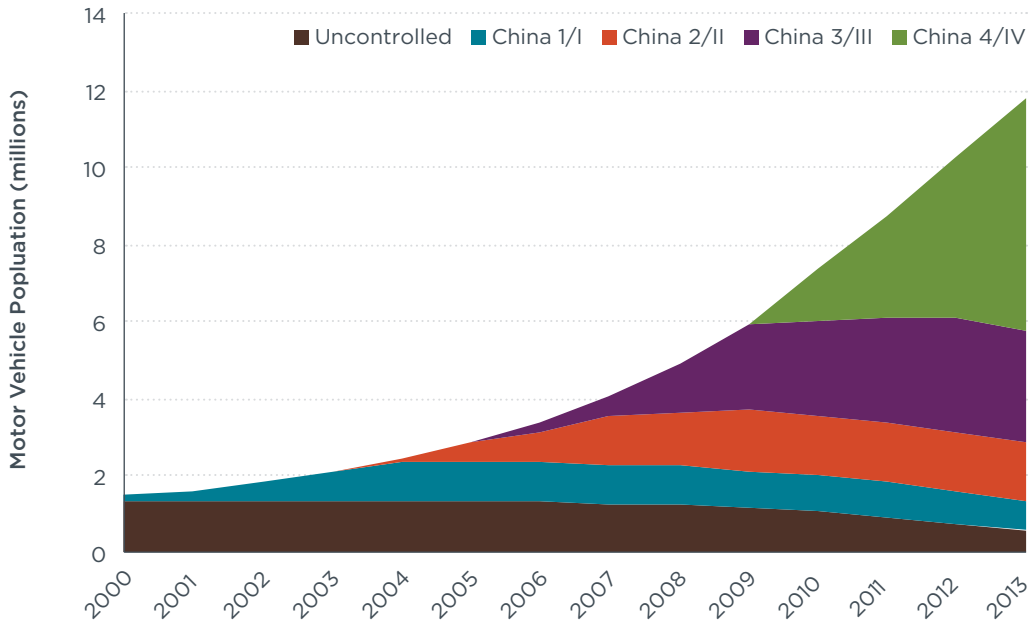

Figure 1. Guangdong vehicle stock by emission standards. Source: ICCT Roadmap, 2014

Vehicles in Guangdong are overwhelmingly light-duty vehicles (LDVs). Heavy-duty vehicles (HDVs), although accounting for a small percentage of vehicle fleet, emit a significant share of total emissions from on-road vehicles, especially NO_x and $PM_{2.5}$ (Figure 2). This means high-emitting HDVs make a proportionately larger impact on the environment. Therefore, managing emission from heavy-duty in-use fleets is a key focus of in-use vehicle emission control programs.

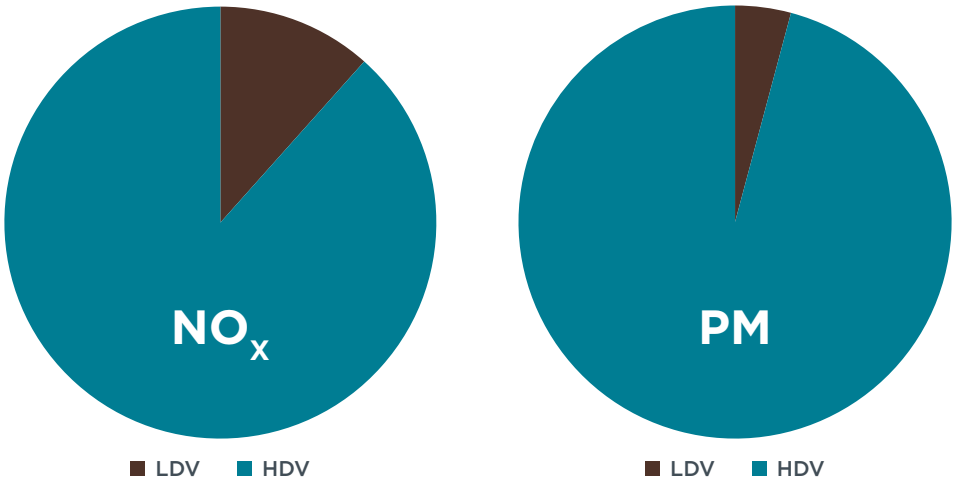

Figure 2. 2010-2013 NO_x and PM emissions by vehicle category[1]. Source: ICCT Roadmap, 2014

1 HDVs include all vehicles heavier than 3.5 tons. The NO_x and PM emissions from medium/heavy-HDVs accounted for 62% and 69% respectively of 2014 on-road transportation emissions.

Under national and provincial guidance, local governments are establishing various in-use vehicle control programs, including in-use vehicle emission compliance (e.g., I/M programs, remote sensing, spotter programs), cleaner fuel, eliminating high-emitter and older vehicles (e.g., scrappage and replacement, retrofit and repower), low emission zones, and vapor recovery.

This paper summarizes international best practices on in-use vehicle emission control of specific programs. It includes a review of China's legislative authorities and roles of national, provincial and city agencies in in-use vehicle emission control. The paper also evaluates the strengths and weaknesses of the in-use vehicle emission control programs in Guangdong Province and four cities in the PRD region (Guangzhou, Shenzhen, Dongguan, Foshan). Recommendations are provided for improving local in-use vehicle emission control practices in the future.

BEST PRACTICES FOR LOCAL IN-USE VEHICLE EMISSION CONTROL PROGRAMS

There are a variety of strategies for controlling emissions from an in-use vehicle fleet. According to international practices, a combination of multiple strategies will achieve the most effective and rapid emission reductions. This section summarizes best practices from across the world of in-use vehicle emission control programs, including programs that ensure in-use vehicle emission compliance, promote cleaner fuels, eliminate high emitters and older vehicles through scrappage and replacement or retrofit and repower, and improve evaporative emission control efficacy.

IN-USE COMPLIANCE

In-use compliance programs ensure in-use vehicles perform at or below given certification emission limits for their useful life. Strong in-use compliance programs at the local level can effectively identify and reduce the prevalence of high-emitting vehicles with limited resources. Various methods have demonstrated success in monitoring in-use vehicle emission levels and identifying different types of high-emitting vehicles. The methods most commonly adopted in China include mandatory periodic inspection and maintenance (I/M) and programs that monitor vehicles' on-road emissions, including on-site inspection, remote sensing, and spotter programs. Policymakers have other options, such as a Portable Equipment Measurement System, for measuring individual vehicle emissions under real-world driving for specific purposes[2]. These are not discussed in this paper.

Inspection and maintenance program

I/M programs require vehicle owners to regularly subject their vehicles to a certified emissions test. Vehicles that fail the test, either due to emissions that are over a regulated threshold or emission control component malfunctions, are required to undergo repair or maintenance. Experience suggests that I/M programs need to be carefully planned and implemented to be cost-effective and receive public support (USAID, 2004). Five best practices for running such a program are summarized as (Posada, Yang, & Muncrief, 2015):

1. *Design a comprehensive institutional structure for I/M management*. This includes:
    a. Developing the general I/M program framework at the national level, which could suffice for the majority of cities/regions across the country, and improving the general program to meet specific local air quality challenges.
    b. Designing the program around specialized test-only facilities to conduct vehicle technical and emission inspections.
    c. An I/M program design that accounts for adequate testing equipment and staff training, with close oversight, independent of public or private inspection operation.
    d. A strong, independent, oversight and quality assurance program.
    e. Allowing a phase-in period for learning, adaptation, and capacity building.
    f. Coordination with environmental officials at the national and local levels on complementary policies.

2 A Portable Equipment Measurement System is usually used for manufacturer compliance.

2. *Base I/M program technical design on local impact assessment studies and make it subject to improvement over time*.
    a. The I/M programs ideally should be redesigned around a local impact assessment study, which determines the type of vehicles in the fleet, vehicle use patterns, pollutants monitored, I/M emission pass/fail levels, and costs and benefits of I/M programs.
    b. As new vehicle emission standards become more stringent over time, the I/M programs should evolve to take into account the penetration rates of new technologies and cleaner vehicles in the fleet.
    c. A cost and benefit or cost-effectiveness analysis would be required to determine at what cost a range of benefits in terms of air quality and health improvements can be secured.
    d. I/M testing protocols should achieve a balance between accuracy, testing time, and cost.
    e. The periodicity of inspections should be designed based on vehicle age and contribution to emission inventory.
3. *Promote I/M program compliance and enforcement*. Enforce I/M requirements with an effective, periodic vehicle registration system that can accurately track the status of vehicles and restrict the operation of noncompliant ones.
4. *Obtain and manage resources*. Policymakers should set inspection fees at levels that will support the cost of a well-designed I/M program and cover equipment and facility upgrades.
5. *Build up maintenance capacity in I/M programs*. Regulators need to pay special attention to the 'M' in I/M and improve capacity of the vehicle service sector to provide adequate maintenance and repairs for vehicles that fail I/M tests. It is important to ensure that repairs are not "fixing to pass the test" but actually result in reasonably long-lived on-road emission reductions.

Remote sensing program

Remote sensing tests on-road vehicle emission levels during normal street operations. Although remote sensing is currently not accurate enough to determine discrete emission factors for individual vehicles, it complements I/M programs by identifying high emitters and requiring prompt vehicle repair. These five best practices relate to remote sensing (Wagner and Rutherford, 2013, Borken-Kleefeld, 2013):

1. *Choose good locations to collect useful data.* The remote sensing system must be positioned to detect the exhaust plume of a single vehicle operating under load, such as those accelerating on a freeway on-ramp.
2. *Establish enough remote sensing systems to prevent cheating.* Drivers may intentionally not accelerate as they pass remote sensing stations. As a result, enough remote sensing systems are needed to establish coverage adequate to ensure accurate data.
3. *Set the on-road emission standards (i.e., cutoff thresholds) properly and take corrective action once high emitters are detected*. There is a trade-off between an accurate identification of high-emitting vehicles and the avoidance of false detection. Therefore policymakers need to find a balance between the two when setting cutoff thresholds for remote sensing tests. Furthermore, additional measures need to be taken even if vehicles are detected with emissions above the thresholds; for instance, sending a vehicle back for I/M testing.

4. *Use remote sensing testing results to effectively reduce emissions.* A remote sensing program can
    a. Detect high emitters and notify vehicle owners for testing and repair, either voluntary or mandatory
    b. Detect clean vehicles and waive I/M tests for a longer period
    c. Develop an emission profile of a given vehicle fleet
    d. Cross-check I/M performance (Fung & Suen, 2014)
5. *Ensure adequate enforcement for effective pollution control.* Local authorities need to make sure the detected high emitters are sent for further testing and get repaired if they fail the formal inspection.

Spot-checking program

Spot-checking programs in China test primarily on-road vehicles with high emission potential. Under the program, local authorities create checkpoints for conducting emission tests along the roadside or in parking lots. This program complements the I/M programs and remote sensing programs. However, the results of on-site inspection are more accurate than remote sensing. Three best practices are summarized as:

1. *Choose good locations that target possible high-emitting vehicles.* Unlike remote sensing, a spot-checking program requires more labor investment and a longer time commitment from drivers. Thus, the selected locations should allow the inspectors to better identify possible high emitters, such as company parking lots of firms with large vehicle fleets or highway exits where potential high-emitting long-haul vehicles may pass.

2. *Establish test procedures and train inspectors to conduct testing.* The inspectors must follow the test procedures when performing the testing to obtain reliable results.

3. *Ensure adequate enforcement for effective pollution control.* Detection of high-emitting vehicles does not mean repair will follow. Local authorities should not only notify the vehicle owners of the failing inspection, but also ensure the problem gets fixed before the vehicle gets back on the road.

Public spotter program

Public spotter programs primarily aim to eliminate vehicles emitting visible smoke from their tailpipes. Under the program, local authorities encourage and empower citizens to voluntarily report the license plate numbers of smoky vehicles. The program has its limitations because it is only effective at reducing visible smoke, but because of its low cost of operation it is highly cost-effective. Three best practices are summarized below to maximize participation from the general populace for the best outcome:

1. *Promote the program to encourage public support*. Local authorities should advertise to increase public awareness of the program. This could include training the public or rewarding participants if the reported vehicles are confirmed as gross emitters.

2. *Provide the public with easy reporting methods when they identify smoking vehicles.* One common practice is to set up a telephone number for people to call and report the license plate numbers of vehicles that visibly emit smoke from their tailpipes.

3. *Ensure follow-up with the vehicle owners who are reported.* Once a vehicle is reported, the authorities should identify the type of noncompliance of reported vehicles, follow up with vehicle owners, and make sure the vehicles no longer emit smoke if they are eligible to get back on the road.

USE OF CLEANER FUELS

Improving conventional fuel quality can ensure the stable and efficient performance of aftertreatment technologies and maximum emission reduction from in-use vehicles. Introducing alternative fuels (e.g., gaseous fuels and biofuels) at the local level can improve local air quality as well as reduce greenhouse gas emissions in some cases. For the in-use fleet, the use of low-fraction biofuel blends (e.g., 5% or 10%) does not require engine modifications. It is also possible to convert a conventional vehicle to run on a gaseous fuel (e.g., CNG or LNG) by replacing or retrofitting the engine and fuel system (Wagner and Rutherford, 2013). In China, the national government plays a critical role in establishing stricter fuel quality standards and promoting alternative fuels. Local agencies can support efforts to adopt nationwide fuel standards early or implement alternative fuel pilot projects using local captive fleets.

The Wagner and Rutherford report (2013) summarizes five best practices in using cleaner fuels. These practices require coordination among multiple regulatory agencies at both the national and local levels.

1. *Adopt a systematic approach*. Fuel quality standards should match vehicle tailpipe emission standards to ensure functionality of advanced vehicle technologies.

2. *Build a solid and flexible regulatory mechanism.* Grant environmental agencies authority to regulate fuel quality and allow local agencies leeway to set higher standards.

3. *Adopt progressive pricing to encourage cleaner fuels*. Combined with mandatory regulations, regulatory agencies can provide fiscal incentives or subsidies to encourage production of higher-quality fuel. Differential pricing for alternative-fuel vehicles can also accelerate fuel switching.

4. *Implement an effective compliance program*. Regulatory agencies should establish a robust policy framework that includes mandatory standards, regular testing, and strong penalties for noncompliance.

5. *Use captive fleets to create demand for cleaner fuels*. Local governments can use public fleets that are large enough (e.g., bus or taxi fleets) to create an early market for cleaner or alternative fuels. The fueling infrastructure created to support the public fleets would then be available for private consumers.

ELIMINATING HIGH EMITTERS AND OLDER VEHICLES FROM THE ROAD

Scrappage and replacement

The most direct method for reducing emissions from older and high-emitting vehicles is to scrap them from the fleet and, to maximize environmental benefits, replace them with cleaner vehicles. Scrappage programs can be mandatory or voluntary. Because the owner/operators of older vehicles are typically economically disadvantaged, mandatory vehicle scrappage programs usually are combined with additional fiscal or other policy incentives. Based on international experience, five best practices are summarized for the implementation of successful scrappage and replacement programs (Posada et al., 2015).

1. *Replace scrapped vehicles with others that are as clean as possible*. For maximum environmental benefits, regulators 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.

2. *Ensure program implementation, management, and enforcement actually achieve expected benefits*. Regulators need to be cautious not to provide subsidies for vehicles already abandoned and not in regular operation. Strong oversight is also necessary to ensure that the scrapped vehicles do not continue to pollute. In other words, vehicles and engines that are being scrapped must be destroyed, not resold for use elsewhere.

3. *Tailor fiscal incentives to optimize both environmental benefits and cost-effectiveness.* The fiscal incentives should be sufficient to attract enough participation to warrant investment in the program.

4. *Design a program that carefully considers and balances the different roles of national, regional, and local policymakers.* While the national authority establishes large-scale scrappage programs, local regulators should determine program implementation and manage individual grants that meet local needs and conditions.

5. *Complement fiscal policies with additional incentives such as low emission zones and regulatory backstops*. Supporting policies are necessary when fiscal incentives are not enough to convince owners to participate in the scrappage and replacement program for purely economic reasons.

Retrofit and repower

Retrofit and repower programs can have an immediate and positive environmental impact for older and high-emitting vehicles with enough remaining useful life that they are not cost-effective scrappage and replacement targets. Retrofitting refers to the addition of an emission control device, typically an emission aftertreatment catalyst, to the existing engine. Repowering refers to replacement of the existing engine with a new engine while keeping the existing chassis. There are voluntary programs with fiscal incentives and, less frequently, mandatory programs where retrofits or repower are required of a certain type of vehicles. Retrofitting and repowering vehicles can be a very complex and engineering-intensive process. Thus, the program must be designed and implemented carefully to ensure its efficacy and durability, and to prevent potential damage to the vehicle or the retrofit equipment. Below are six best practices for retrofit and repower programs learned from international case studies (Wagner and Rutherford, 2013):

1. *Establish rigorous verification systems to ensure effectiveness.* Regulatory agencies must verify the efficacy of retrofit technologies and match those technologies with engines, applications, and duty cycles to ensure appropriate suitability.

2. *Conduct pilot projects to build capacity and test the suitability of off-the-shelf technologies for local conditions*. This helps educate stakeholders in the retrofit process while providing an opportunity for early course corrections.

3. *Match domestic supply to local demand.* The national government, and in some cases large local governments, should aim at promoting vehicle retrofits that can foster domestic manufacturing capacity of retrofit technologies.

4. *Provide retrofit subsidies.* Complementary fiscal incentives can encourage participation in voluntary programs while lessening the impact of mandatory programs on economically vulnerable populations.

5. *Improve fuel quality and ensure fuel supply to facilitate use of best available retrofit technologies*. Certain retrofit and engine technologies will require a level of fuel quality that might be higher than the fuel quality used prior to the retrofit or repower.

6. *Ensure enforcement and follow-up*. Regulatory agencies should periodically contact operators and manufactures to verify that the retrofits remain installed and continue to work properly throughout the vehicle's useful life.

LOW EMISSION ZONE PROGRAM

The establishment of low emission zones (LEZ) discourages heavily polluting vehicles from entering main city areas. This can immediately alleviate vehicle pollution in cities. It also complements other in-use vehicle emission control programs by increasing high-emitting vehicle operation cost, encouraging the most polluting vehicles to become cleaner. Establishing an efficient LEZ program should:

1. *Receive political support*. Political backing is essential to promote the LEZ program and get sufficient support for policy-making and enforcement.

2. *Establish a scheme that effectively reduces emissions from gross-emitting vehicles in the city*. The program should set the LEZ to be influential enough to encourage polluting vehicles driving in the city area to become cleaner, including areas and locations of the restricted zones, restricted vehicle categories, and restricted time of day. Setting penalties for unauthorized entry into the zone is also necessary to maximize effectiveness of the program.

3. *Educate operators affected by the scheme changes.* To ensure the compliance options and intentions are well understood, and to gain public support, the program needs to engage key external stakeholders in the decision-making process. This is in addition to widely advertising the program as it is phased in.

4. *Establish a cost-effective enforcement mechanism*. The LEZ program needs a strong enforcement net to ensure high-emitting vehicles stay out of the LEZ. Local agencies can choose the most cost-effective support system based on available resources and existing programs, such as environment labeling, plate number recognition cameras, remote sensing, spot checks, and other techniques.

STAGE II VAPOR RECOVERY

Vehicle evaporative emissions contribute a significant fraction of overall mobile source VOC emissions. Ninety percent of the evaporative emissions come from diurnal parking, running loss, and refueling. For in-use vehicles, one widely adopted measure is controlling evaporative emissions when vehicle owners refill their fuel tanks at dispensing facilities, which is known as Stage II recovery. For Stage II recovery, gasoline dispensing facilities are required to install vacuum-assist nozzles that recover vapor escaping from the fuel tank and circulate it back to the underground oil storage tank. Stage II control can be implemented quickly, thus the program is usually used to focus on regional implementation in areas of most need. The efficiency of Stage II systems can be designed to be as high as 95%, but real-world efficiency is usually much lower due to deterioration, lack of maintenance, and insufficient inspection and enforcement. To ensure that Stage II controls achieve their designed efficiency, regulators need to:

1. *Maximize program coverage to improve control efficiency.* Ideally, Stage II controls should be required for all service stations in the regulated region. Area-wide efficiency drops if compliance waivers are granted for small throughput service stations.

2. *Ensure strong local oversight of system installations.* The program needs to get support from local governments to ensure the installation of vapor recovery

equipment at refueling stations. Because the program requires a high capital cost investment in the beginning, local government sometimes provides subsidies for system installations.

3. *Monitor and maintain the Stage II vapor recovery system consistently to continue to achieve high vapor recovery efficiency.* The components at the refueling interface (nozzles, nozzle boots, and hoses) are subject to deterioration in use. This process will accelerate if the system is not maintained frequently, reducing vapor recovery efficiency. While the design capability of efficiency can be as high as 95%, the actual efficiency range can be 62% to 92% depending upon the degree of oversight. Local government needs to train staff and regularly test Stage II systems. System testing includes monitoring the vapor recovery effectiveness at the dispenser and the vapor containment in the underground storage tank, the pipe work, and the fittings.

4. *Evaluate the cost-effectiveness of the program.* The retrofit advantage comes at a high capital cost investment plus continued maintenance costs for the refueling stations. Achieving ideal vapor recovery efficiency also needs significant monitoring from local government. Thus, it is essential to evaluate the cost-effectiveness of the program before deciding upon its implementation.

A potential alternative to Stage II vapor recovery systems is the adoption of on-board refueling vapor recovery (ORVR) systems on new vehicles, which could achieve efficiency as high as 95% to 98% per vehicle. However, ORVR is not a strategy that can be used for the in-use fleet and is therefore beyond the scope of this report.

LEGISLATIVE AUTHORITIES AND ROLES OF GOVERNMENT FOR IN-USE VEHICLE EMISSION CONTROL

The authority and roles of different levels of government determine the actions that local government can take to manage and improve their in-use vehicle emission control programs. China's current legislative structure has the distinctive characteristic of strong centralization, but with some power allocated to certain specific classes of regions. Multiple legislative authorities exist at several levels of government, each subject to different institutional authority. The principle legislative authority lies at the national level, where the legislation of Constitution and state law belongs to the National People's Congress (NPC) and its Standing Committee. No administrative and local law or regulation is allowed to contravene the Constitution or state law.

There are different types of legislation and regulations. China's national-level laws are generally quite short, broad in scope, and infrequently updated. Statute (i.e., *tiaoli*) is a common type of regulatory document that has legislative force similar to laws. Most implementation details are left to regulatory action. The lack of clarity of national-level laws has been identified as an impediment to stronger regulatory action with regard to automotive emissions.

While most regions are subject exclusively to national-level laws, exceptions are given to three categories of regions: ethnic autonomous regions, special economic zones, and special administrative regions. These types of regions are afforded additional authority to formulate laws or statutes *(i.e., lifa quanli*). Shenzhen, a special economic zone in the PRD region, is the only region in Guangdong with this special legislative authority. The unique position of special economic zones is described separately in further detail (see sidebar, China's Special Economic Zones).

CHINA'S SPECIAL ECONOMIC ZONES

Ever since the Chinese Reform and Opening-up Policy, China has established five areas called special economic zones where special policies are designed to develop foreign trade, economic cooperation, technical exchanges and foreign investment and technology. In July 1992, the Standing Committee of the National People's Congress (NPC) passed *the Decision on Authorizing the People's Congress and Its Standing Committee of Shenzhen and the People's Government of Shenzhen to Separately Make Laws, Rules and Regulations for Implementation in Shenzhen Special Economic Zone*. In this sense, the people's congresses and their standing committees in the special economic zones can exercise a part of the legislative right of the national legislative institution while keeping conformity with the basic principles of the Constitution and the relevant administrative regulations.

Compared with ordinary local legislation, the legislation in special economic zones is authorized by the highest organ of state power or its standing committee, and is supposed to be implemented only within the boundaries of its zone. The level of effectiveness and scope of readjustments of the standard legal documents introduced in the special economic zones are generally lower than those introduced by NPC, but exceed the scope of regulation making in local and ethnic autonomous areas.

From 1992 through June 2007, the People's Congress and government in Shenzhen special economic zone passed 296 regulations specific to Shenzhen. A third of the regulations were put forward before national laws and regulations were available to address the same issues, drawing on the experience of Hong Kong and other developed countries. Another third consisted of the necessary amendments, supplements and refinements to existing national laws and administrative regulations to meet to the development needs of Shenzhen. The last third were designed to facilitate environmental protection, urban management and other important issues.

With special authority to formulate laws or statutes, regulation making in the special economic zones can be groundbreaking and serves an experimental role in the country. Among the PRD regions, Shenzhen enjoys the most distinguished advantage, as a special economic zone, to design creative policies to address new or pressing challenges, especially at the local level.

There are some beneficial examples of laws or regulation-making in Shenzhen that deal with special issues in transportation. Shenzhen issued its *Shenzhen Special Economic Zone Environmental Protection Statute* far ahead of Guangdong Province. Its automotive emission prevention and control statute also was promulgated earlier than Guangzhou, whose legislative regulation must be approved by provincial authorities. Smaller cities, like Foshan and Dongguan, don't have the same level of legislative authority and therefore comply with provincial statute. Appendix I summarizes existing legislation and regulatory documents that have major impacts on vehicle emission control, including national and local level policies that provide guidance regarding in-use vehicle emission management.

The regulatory documents (i.e., *guifanxing wenjian*) made by provincial and city governments, such as measures or plans (i.e., *fangan, tiaoli, guanli banfa*) do not have a legislative base, but provide guidance, framework, or implementation measures to achieve assigned targets. Guangdong Environmental Protection Bureau's (EPB) role is to

provide guidance and supervise local implementation rather than carrying out the actual work. Environmental protection agencies at the city level make their own work plans based on national and provincial guidance. Nevertheless, the upper level authorities sometimes are vague about detailed issues in the regulation, which may jeopardize the robustness and effectiveness of local legislative systems.

Table 2 summarizes the roles of national, provincial, and local agencies in in-use vehicle emission control. Within the legislative framework from upper level government, the local government could be innovative and aggressive in local vehicle emission management through localized regulatory policies.

Table 2. Roles of national, provincial, and city level agencies in in-use vehicle emission control management

	National	Guangdong	City
In-use compliance	• Mandate I/M inspection • Decide on applicable vehicles and frequency • Set I/M noncompliance penalty	• Mandate I/M test procedures • Authorize local government to issue and manage I/M inspection stations • Set I/M enforcement and inspection pass rate target • Establish remote sensing test procedure • Require on-site inspection and spotter programs at local level	• Establish inspection station operation and management requirements • Establish and implement I/M compliance and enforcement program • Set stricter test requirements for specific vehicle fleets • Plan and implement remote sensing, on-site inspection and spot-checking programs
Cleaner fuel	• Set national fuel standard • Grant province authority for early adoption	• Early adoption of stricter fuel standards (for PRD and other cities) • Encourage development of alternative fuel vehicles programs; • Set fleet target for alternative fuel vehicles (percent of public fleet) for some cities (Guangdong and Shenzhen)	• Establish inspection mechanism of fuel quality compliance • Deploy cleaner fuel related infrastructure development and fleet arrangement
Eliminating high emitters and older vehicles	• Set scrappage age • Set provincial vehicle scrappage target • Establish scrappage procedure	• Set scrappage target for cities • Authorize local government to set scrappage age for special vehicle fleet	• Set stricter scrappage target and timeline • Set stricter scrappage age for certain fleets • Set subsidy measures for early scrappage
Low emission zone	• Encourage LEZ • Mandate vehicle environmental labeling • Set environmental labeling noncompliance penalty	Set minimum LEZ area requirements	Establish LEZ development and implementation work plan
Vapor recovery	Establish gas station emission standards	Set target and timeline for vapor recovery control	• Develop work plan and technical guidance for vapor recovery control • Set subsidy measure for device retrofit

EVALUATION OF IN-USE VEHICLE EMISSION COMPLIANCE PROGRAMS

IN-USE COMPLIANCE

Inspection and maintenance program

Guangdong has been making efforts to improve I/M management, including revising test procedures, improving the inspection rate and pass rate, and improving I/M enforcement. Table 3 summarizes the status quo and targets of I/M programs in the cities, followed by an evaluation of ongoing local exercises based on the best practices listed above.

Table 3. I/M program requirements and targets in Guangzhou, Shenzhen, Foshan, and Dongguan[3]

	Guangzhou	Shenzhen	Foshan	Dongguan
Test cycle	VMAS (gasoline) Lugdown (diesel)	ASM (gasoline) Lugdown (diesel)	ASM (gasoline) Lugdown (diesel)	ASM (gasoline) Lugdown (diesel)
First time pass rate (2013)	82.6% all 75% (diesel)	77% all 50%-60% (diesel)	74% all 39% (diesel)	84% (2012 gasoline) N/A (diesel)
Inspection rate target	80%	80%	80%	80%
Pass rate target	90%	90%	90%	90%
Enforcement measures (for vehicles failing to pass I/M test)	• Forbid on road • Mandatory scrappage after three failed inspection cycles	• Forbid on road • Mandatory scrappage after three failed inspection cycles • Disqualified for early scrappage subsidy after three failed inspection cycles	• Forbid on road • Mandatory scrappage after three failed inspection cycles • Disqualified for early scrappage subsidy after two failed inspection cycles	• Forbid on road • Mandatory scrappage after three failed inspection cycles • Disqualified for early scrappage subsidy after three failed inspection cycles

1. Design a comprehensive institutional structure for I/M management.

The deployment of the vehicle emission I/M management structure was made very clear from the national to the local level in China. In 2005, China's Ministry of Environmental Protection (MEP) released *Notice on In-use Emissions Inspection Station Technical Manual*, standardizing the management and monitoring of in-use vehicle emission inspection stations. All I/M inspection stations are test-only facilities that are not allowed to conduct any vehicle adjustment or repair. However in 2013 Guangdong began authorizing inspection stations to conduct vehicle emission tests in addition to safety tests for I/M in 2006. Beginning May 7, 2013, Guangdong decentralized the power of authorizing inspection stations to local environmental protection agencies. With that regulatory power, city agencies are responsible for both the assessment and the approval of new inspection stations, and management of existing authorized inspection stations. Currently, all four cities have issued regulations with detailed implementation measures for I/M inspection stations to carry out their work, including the inspection data reporting and violation penalties.

2. Base I/M program technical design on local impact assessment studies and make it subject to improvement over time.

The emission standards are the same across all cities in Guangdong. Guangdong requires all cities to adopt I/M test procedures to best reflect real-world emission levels.

In 2009, Guangdong mandated that PRD cities use a simple transient chassis dynamometer for I/M testing of both LDVs and HDVs by July 1, 2010[4]. The simple transient

3 Information from closed-door workshop with Guangdong EPB in November 2013 and local regulations listed in Appendix I.

4 Guangzhou and Shenzhen had adopted simple transient chassis dynamometer testing by that date.

test, which replaced the unloaded two-speed idle test, better represents in-use vehicle emissions in the real world. As for the detailed measurement method, Guangdong released three local standards in 2009 for gasoline and diesel vehicle testing, including two simple transient test procedures for gasoline vehicles—Acceleration Simulation (ASM) and Vehicle Mass Analysis System (VMAS)—and the Lugdown test procedure for diesel vehicles. Cities have some flexibility with regard to adopting test cycles following the provincial guidance based on their capacity to invest in testing facilities. Larger investments are required for VMAS than for ASM, so only Guangzhou has adopted VMAS to test gasoline vehicles. The other three cities are using the ASM testing procedure.

The frequency of vehicle environmental inspections is generally identical to vehicle I/M requirements. However, beginning September 1, 2014, Yellow Label Vehicles (YLVs), which consist of China 0 gasoline vehicles and China 0, I, and II diesel vehicles, are required to pass quarterly inspections[5]. Table 4 shows national test frequency requirements based on vehicle type and age.

Besides the regular I/M standards, some cities have special requirements for certain vehicle fleets. For instance, Guangzhou shortened the useful life of taxis from eight years to six years while Shenzhen mandated that taxis change three-way catalysts annually to pass I/M testing.

Table 4. I/M inspection frequency of different vehicles types

	Vehicle age																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Light-duty passenger vehicle	Exempt						Every year									Twice a year				
Commercial passenger car	Every year						Twice a year													
Commercial truck	Every year											Twice a year								
Medium/heavy-duty passenger vehicle	Every year											Twice a year								
School bus	Twice a year																			
Yellow label vehicles	Four times a year																			
Others	Every year																			

Source: State Council, 2004 and DOS & AQSIQ, 2014

However, as cleaner vehicles with new technologies enter the market, the testing accuracy of existing methods is not accurate enough to detect high emitters (Posada, Yang, & Muncrief, 2015). Thus revision is needed to improve the testing accuracy of I/M programs in the long term.

3. Promote I/M program compliance and enforcement.

The general penalty for I/M noncompliance is set at the national level while its enforcement is in the hands of city agencies. The problem of low I/M testing pass rates varies across cities. In principle, vehicles that fail I/M testing must be grounded until they are able to meet the standards and pass I/M testing. Based on the *Vehicle Registration Rules*, vehicle owners who violate the regulations will be penalized for 200 renminbi (RMB), which is roughly $32 US, and get 3 points on their license. Passing the I/M test also renews the vehicle environmental label, which is affixed to the front windshield of the vehicle. Meanwhile, according to *Vehicle Mandatory Scrappage Standards*, "vehicles that fail to receive vehicle I/M qualified labels in three consistent vehicle inspection cycles after a valid inspection expire" will be scrapped mandatorily. If a vehicle qualified for scrappage is still being used, according to *On-road Transportation Safety Law*, local agencies will confiscate and scrap the vehicle and its driver will face punishments including revocation of his or her driver's license and a penalty up to 2000 RMB (around $324 US). Cities also combine the compliance of I/M test with the early scrappage subsidies. That is, vehicles that failed to pass two or three inspection cycles are disqualified from receiving early scrappage subsidies.

5 This regulation is conflict to existing regulation that: vehicle environmental inspection is carried out with safety inspection at the same time. Since there is no special requirement for YLV safety inspection frequency, the quarterly environmental inspection of YLVs is not implemented in Guangdong Province at present.

Guangdong highlighted the enforcement of its I/M program in the *Guangdong Air Pollutant Emission Prevention and Control Implementation Plan* issued in 2014. The test results were transmitted to the Guangdong EPB for verification. The provincial annual I/M statistics eventually will be submitted to the MEP. Nevertheless, the low first-time pass rate of I/M inspection is a general concern, especially for domestic diesel HDVs. Table 3 illustrates the difference in pass rates for each city. Guangzhou shows the highest pass rate for the first test in four cities. In Guangdong's 2014-2017 action plan, Guangdong requires every city to achieve a minimum of 80% I/M enforcement and a 90% inspection pass rate by the end of 2014. It is unclear whether these targets had been met at the time this report was written.

To ensure the effective implementation of its I/M program, Guangdong will conduct a thorough check of uninspected vehicles by the end of 2015 while increasing the quantity of spot checks. To reduce noncompliance rates, Guangdong maximized the fine amount within the national requirement range. Other cities also have taken their own actions, which will be discussed in the next two sections, remote sensing and spotter programs.

4. Obtain and manage resources.

The Bureau of Commodity Price of each city determines the inspection fee for I/M testing at all inspection stations. Thus all cities are able to set inspection fees at levels that will sustain their I/M programs.

5. Build up maintenance capacity in I/M programs.

To support the shift of test procedures, Guangdong provides specific guidance for inspection stations about conducting testing as well as having standards for verifying the qualification of vehicle repair stations. Nevertheless, there is a lack of attention at the city level with regard to improving the capacity of vehicle repair stations, especially the maintenance and repair of advanced aftertreatment devices, including onboard diagnosis. Because the repair stations are managed by traffic management agencies, environmental protection agencies can consider working with traffic management agencies to improve repair station qualification requirements or provide training to repair station personnel.

Table 5 summarizes the evaluation of the I/M programs in the four cities in the context of the identified best practices.

Table 5. Evaluation of I/M programs in Guangzhou, Shenzhen, Foshan, and Dongguan

Best practices of I/M program	GZ	SZ	FS	DG
1. Design a comprehensive institutional structure for the I/M management				
2. Base I/M program technical design on studies and make it subject to improvement over time				
3. Promote I/M program compliance and enforcement				
4. Obtain and manage resources				
5. Build up maintenance capacity in I/M programs				

Meets Partially meets Does not meet

Remote sensing program

Guangdong established its provincial remote sensing test procedures and corresponding emission limits for in-use vehicles in 2009. Additionally, it encouraged local environmental protection agencies to carry out on-road vehicle spot checks to correlate the accuracy of its I/M program. Table 6 summarizes the status quo of remote sensing program in four cities. The summary includes only the quantity of remote sensing equipment without its daily working hours, thus making it difficult to evaluate the equipment's effective testing capacities. According to the equipment numbers, Guangzhou invested heavily in remote sensing devices, mainly in the time preceding the Asian Games in 2010. It is likely that the remote sensing program has been less active since 2010.

Table 6. Remote sensing status quo in Guangzhou, Shenzhen, Foshan, and Dongguan[6]

	Guangzhou	Shenzhen	Foshan	Dongguan
Quantity of equipment	14 remote sensing vehicles, 52 remote sensing locations (in 2010)	5 remote sensing vehicles, 4 remote sensing stations	At least one remote sensing spot	At least one remote sensing spot
Location	Roadside of main street, entrance of city	Roadside of main street	Roadside of main street, or fixed spot for bus testing	Exit of low emission zone
Penalty to high-emitting vehicles	Require inspection and repair; temporarily retain vehicle registration certificate; reject nonlocal vehicles access to the city	Notify vehicle owner to do maintenance	Require inspection and repair	Educate vehicle owner about LEZ regulations, require environmental labeling, or charge fine for breaking LEZ regulations

1. Choose good locations to collect useful data.

Each city chooses its remote sensing locations to accomplish specific program goals. Most cities conduct roadside testing along busy streets to receive most data from on-road vehicles. Guangzhou sets remote sensing stations at the entrance of the city to keep high-emitting vehicles out of the city. Foshan establishes weekly remote sensing testing for buses. Dongguan sets the system at the exit of LEZ to detect restricted vehicles that "break into" the LEZ. However, the locations of remote sensing systems cannot prevent drivers from cheating on the testing, especially as the number of remote sensing locations in the city is limited. Vehicle drivers can purposely avoid accelerating the vehicle as they pass by the equipment. Therefore, the setting of remote sensing system locations should be more strategic to accurately detect the exhaust plume of the vehicles operating under load.

2. Establish enough remote sensing systems to prevent cheating.

The cities in Guangdong are still developing their remote sensing programs and do not have sufficient remote sensing systems in place. Guangzhou has the most remote sensing equipment among the four cities, but the number of remote sensing systems and spots is not enough, considering the vehicle population in the city[7]. For example, Beijing currently has 86 remote sensing test spots for emission testing. All four cities need more remote sensing systems to capture the larger fleet and to maximize program effectiveness. Given the high cost of capital investment of remote sensing systems, increasing coverage means proportionally increasing costs.

6 Information from closed-door workshop with Guangdong EPB in November 2013 and local regulations listed in Appendix I.

7 Beijing currently has 86 remote sensing test spots for emission testing. http://news.cnr.cn/native/city/201411/t20141109_516752426.shtml

3. Set the on-road emission standards (i.e., cutoff thresholds) properly and take corrective action once high emitters are detected.

This report does not find any document from Guangdong to guide cities in setting the emission threshold to identify high emitters. Only Guangzhou and Foshan require vehicle owners to take their vehicles for I/M testing once their vehicles are detected with emissions above the thresholds. Shenzhen and Dongguan do not require additional actions to confirm a vehicle's emission levels.

4. Use remote sensing results to effectively reduce emissions.

While the cities aim to use their remote sensing programs to detect gross emitters, the programs' effectiveness in doing so varies. Guangzhou had been tough on high-emitting vehicles in the course of the buildup to the Asian Games. Once a high-emitting vehicle was detected, the agency would temporarily detain the vehicle registration certificate. Vehicles registered outside the city were rejected from passing through the city. These methods served to immediately reduce emissions in the city. Nevertheless, it is unknown how the remote sensing initiative in Guangzhou proceeded after the Asian games.

Other cities have differing procedures when responding to noncompliant vehicles. Shenzhen notifies vehicle owners to perform maintenance without mandatory follow-up inspections. Foshan requires high-emitting vehicle owners to undergo follow-up inspections and make necessary repairs, but the limited number of remote sensing spots constrains its efforts to reduce emissions. Dongguan is targeting detection of YLVs that are driving in the LEZ, but needs more remote sensing spots to cover more LEZ exits. Furthermore, compared to other measures, such as using cameras to identify vehicle plate number, using remote sensing may not be the most cost-effective approach to detect vehicles "breaking into" the LEZ.

5. Ensure adequate enforcement for effective pollution control.

Guangzhou and Foshan require that vehicle owners repair their vehicles to meet emission standards before getting back on the road. Dongguan charges fines for vehicles detected breaking LEZ regulations. Shenzhen only notifies the vehicle owners after the detection without penalty or requiring repairing requirement.

Table 7 summarizes the evaluation of the remote sensing programs in the four cities in the context of the identified best practices.

Table 7. Evaluation of remote sensing programs in Guangzhou, Shenzhen, Foshan, and Dongguan

Best practices of remote sensing program	GZ	SZ	FS	DG
1. Choose good locations to collect useful data				
2. Establish enough remote sensing systems to prevent cheating				
3. Set on-road emission standards properly and take corrective action				
4. Use remote sensing results to effectively reduce emissions				
5. Ensure adequate enforcement for effective pollution control				

Meets | Partially meets | Does not meet

Spot-checking program

Guangdong Province requires local agencies to design spot-checking programs to selectively check potential high-emitting vehicles. The basic format of a spotter program includes roadside spot checks that focus on high-emitting vehicles and "black smoke" vehicles (i.e., vehicles emitting visible black smoke), and parking lot spot checks that focus on companies with more than 10 vehicles in operation. The owners of detected noncompliant vehicles must fix the vehicle by the given deadline and pay a fine for

the violation. The cities are following the provincial regulations with almost the same monitoring and enforcement measures (Table 8).

Table 8. Spotter programs in Guangzhou, Shenzhen, Foshan, and Dongguan[8]

	Guangzhou, Shenzhen, Foshan Dongguan
Monitoring measures	• Roadside spot-checking • Parking lot spot-checking • Bus station spot-checking
Penalty for unqualified vehicles	• Set deadline for repairing • Fine • Public announcement of unqualified vehicles

1. Choose good locations to target possible high-emitting vehicles.

The spotter programs in the four cities all aim to identify possible high-emitting vehicles and "black smoke" vehicles. The parking lot spot checks in particular can focus on specific vehicle fleets, such as bus, taxi, or other government/company-owned operations. Guangzhou set separate spot-checking schedules for buses at bus terminals. Other locations, such as roadside and parking lots, allow the inspectors to better identify possible high emitters. For roadside testing, Foshan prioritizes checking vehicles that are listed in the high-emitting model inventory as well as vehicles with visible black smoke.

2. Establish test procedures and train inspectors to conduct testing.

As a general practice, Guangdong Province requires all the cities to conduct spotter programs without causing congestion on the street or charging vehicle owners a fee for testing. Most cities in Guangdong established test procedures for spot-checking programs. In Guangzhou, the inspectors are well trained to perform the tests. It is unclear whether the other cities are doing the same.

3. Ensure adequate enforcement for effective pollution control.

All four cities in Guangdong penalize vehicles that fail the inspection, including setting a deadline for repair or imposing a fine. The individual or company name of the unqualified vehicle owners and the vehicle license number will be announced on a government website as well.

Table 9 summarizes the evaluation of spotter programs in the four cities in the context of the identified best practices.

Table 9. Evaluation of spot-checking programs in Guangzhou, Shenzhen, Foshan, and Dongguan

Best practices of spot-checking program	GZ	SZ	FS	DG
1. Choose good locations to target possible high-emitting vehicles				
2. Establish test procedures and train inspectors to conduct testing				
3. Ensure adequate enforcement for effective pollution control				

Meets | Partially meets | Does not meet

Public spotter program

All cities have a public reporting program for "black smoke" vehicles. Citizens are encouraged to report the license plate numbers of vehicles visibly emitting smoke from their tailpipes.

8 Information from local regulations listed in Annex I.

1. Promote the program to receive public support.

In terms of public participation, the cities' general populace is well aware of the reporting process. The city government even provides rewards to individuals if the vehicles they report are confirmed as gross emitters. Nevertheless, none of these cities have established programs that train citizen volunteer spotters in their recent practices, which is identified as a key element of Hong Kong's successful practice to effectively improve public participation. Only Guangdong trained some voluntary spotters, which goes back to 2008.

2. Provide the public easy reporting methods when they identify smoking vehicles.

The most common ways of reporting are through a government website, email, mail, or a special reporting phone number. Guangzhou also allows text message reports of "black smoke" vehicles.

3. Ensure follow-up with the vehicle owners who are reported.

As smoky vehicles are one of the most obvious indicators of the need for vehicle emission control, all cities treat reported smoky vehicles seriously. Once a vehicle is reported, the Department of Traffic Management is responsible for sending the reported vehicles for testing. Vehicles that failed the test must be repaired and pass the test to run on the road.

Table 10. Evaluation of public spotter programs in Guangzhou, Shenzhen, Foshan, and Dongguan

Best practices of public spotter program	GZ	SZ	FS	DG
1. Promote the program to receive public support				
2. Provide the public easy reporting methods for smoking vehicles				
3. Ensure to follow-up with the vehicle owners who are reported				

Meets | Partially meets | Does not meet

USE OF CLEANER FUELS

The deployment of clean fuel comes from the national level, where the effective implementation of clean fuel strategy requires coordination among multiple regulatory agencies at various levels. As the MEP sets a general implementation timeline for each phase of fuel standards, provinces or large cities are authorized to engage in the early adoption of stricter fuel quality standards with approval from China's National Development and Reform Commission (NDRC) of the fuel price changes.

Fuel quality impacts the effectiveness of emission control technologies, especially in terms of lead and sulfur content. Figure 3 below illustrates the timeline of fuel sulfur level standards at the national level as well as the Guangdong and PRD standards. The figure shows that the PRD has adopted fuel standards ahead of other regions in Guangdong. To develop the fuel quality standards in parallel with emission standards, Guangdong has taken the lead in implementing 10 ppm fuel 2 to 3 years ahead of the national schedule.

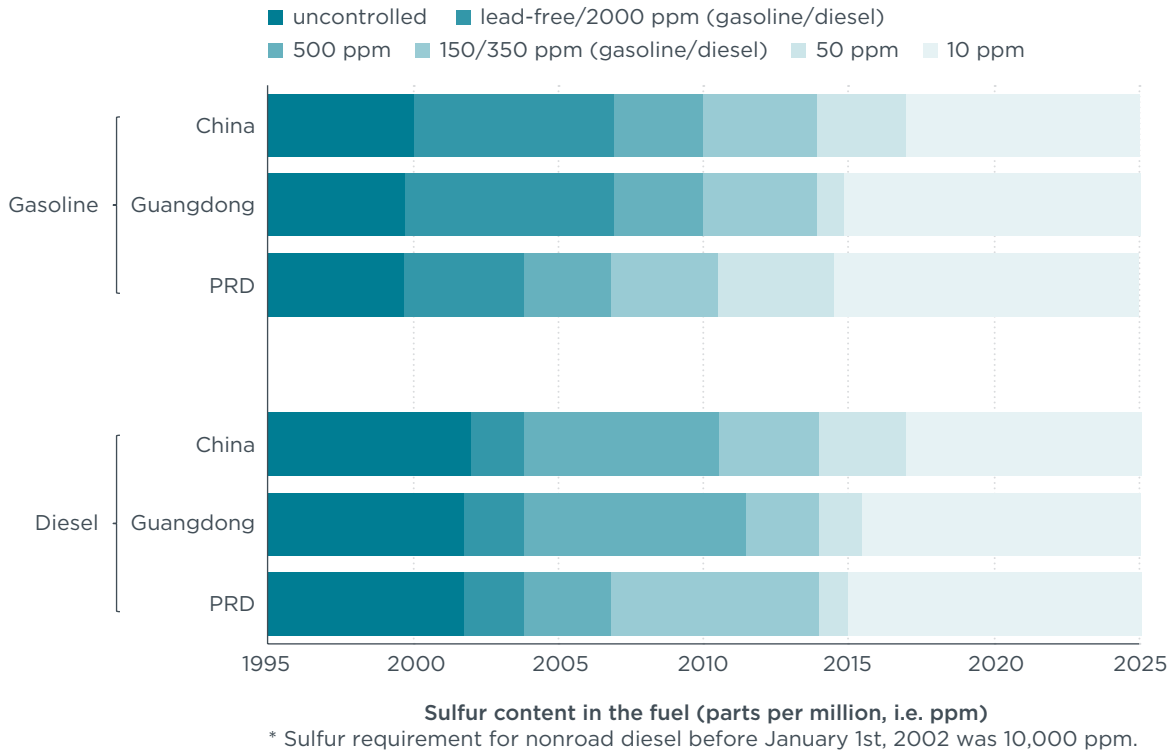

Figure 3. Fuel standard timeline for China, Guangdong, and Pear River Delta

Besides improving gasoline and diesel fuel quality, Guangdong encourages the promotion of alternative fuel vehicles in the public transportation fleet, including compressed natural gas (CNG), liquefied natural gas (LNG), and electric vehicles. Local governments are responsible for the installation of public refueling and charging stations to support the operation of alternative fuel vehicles fleet in the regions.

1. Adopt a systems approach.

Under the national and provincial fuel strategy framework, cities in the PRD area systematically adopt quality standards to match the same aggressive vehicle tailpipe emission standards. Supplying qualified fuel maximizes the function of advanced vehicle technologies to ensure vehicles meet their certified emission standards during operation.

2. Build a solid and flexible regulatory mechanism.

Though local agencies do not have the authority to set their own fuel standards, they have the flexibility to engage in early adoption of stricter national fuel quality standards. As shown in Figure 3, cities in the PRD area have a more aggressive timeline than other cities in Guangdong. Moreover, local governments have the autonomy to establish their own alternative fuel programs.

3. Adopt progressive pricing to encourage cleaner fuels.

The pricing of cleaner fuels in Guangdong is somewhat competitive with conventional fuels. The fuel price in China is regulated by NDRC. To incentivize the rollout of China IV and China V compliant fuels, NDRC announced a new pricing policy for higher quality fuels. The total price increases for upgrading from China III to V gasoline and diesel are 460 and 530 RMB per ton ($75 to $86 US per ton), respectively, equivalent to about 0.33 RMB per liter ($0.05 US per liter) for gasoline and 0.45 RMB per liter for diesel. This price increase exceeds the additional cost to produce China V (10ppm) fuels in China suggested by an ICCT study, which shows cost increases of 0.04 and 0.11 RMB per liter for gasoline and diesel, respectively. Therefore, the NDRC left ample room for big refineries to cover the required refinery upgrades and increased production costs (ICCT, 2012).

The most common alternative fuels promoted at the city level are CNG, LNG, and electricity. At present, there is no subsidy for CNG or LNG in Guangdong cities. Nevertheless, the price of natural gas is cheaper than gasoline and diesel in China. Because the cost of burning natural gas per kilometer of travel is much lower, this encourages the use of CNG and LNG, especially for fleets that are heavily utilized, such as taxis and busses. For electric vehicles, the NDRC issued a notice to provide reduced electricity price at public chargers to accelerate the uptake of electric vehicles. Additionally, city governments can reduce the installment fees and electricity prices for private charging. Because the capital cost of these alternative fuel vehicles is typically higher than conventional vehicles, adopting low pricing for alternative fuel to lower the cost of operation is critical to encourage consumers to switch fuels.

4. Implement an effective compliance program.

The Guangdong EPB requires local agencies to enhance the inspection of fuel quality at service stations. Generally, the local department of industry and commerce is responsible for the market fuel quality testing. Independent fuel testing entities are authorized to test selected samples of fuel. It is unclear in this study how local agencies monitor fuel quality in different cities, what the sample coverage is, what the pass rate of inspection is, and what penalties will be imposed for noncompliant service stations. Thus we will not evaluate the cities' performance under this practice. As this report is being written, there is an ongoing project investigating and evaluating the effectiveness of the fuel quality compliance program in Guangdong, which will be published separately (Fung, 2015).

5. Use captive fleets to create demand for cleaner fuels.

All cities are using large public fleets to create a market for alternative fuels. Guangzhou, Dongguan, and Foshan are strongly promoting the use of CNG and LNG to their bus and taxi fleets while Shenzhen is promoting LNG heavy-duty trucks. There are some private cars in each city that use public refuel/charge infrastructure as well. Most cities are also heavily developing an electric bus fleet.

Meanwhile, it is also important to improve regional cooperation in providing alternative fuels. For vehicles that travel between cities, such as taxis, long hauls, and some private vehicles, ensuring the accessibility of alternative fuel in the surrounding regions will improve the compatibility of alternative fuel vehicles, therefore contributing to further reduction of emissions in the region.

Table 11 summarizes the evaluation of the cleaner fuel programs in the four cities in the context of the identified best practices.

Table 11. Evaluation of cleaner fuel program in Guangzhou, Shenzhen, Foshan, and Dongguan

Best practices of cleaner fuel program	GZ	SZ	FS	DG
1. Adopt a systems approach				
2. Build a solid and flexible regulatory mechanism				
3. Adopt progressive pricing to encourage cleaner fuels				
4. Implement an effective compliance program	N/A	N/A	N/A	N/A
5. Use captive fleets to create demand for cleaner fuels				

Meets Partially meets Does not meet

ELIMINATING HIGH-EMITTING VEHICLES FROM THE ROAD

Scrappage and replacement

Guangdong Province scrapped an accumulated 270,000 YLVs[9] by the end of 2013. There were 1.29 million on-road YLVs at the beginning of 2014. In the *2014-2015 Energy Saving and Emission Reduction Low Carbon Development Action Plan*, the NDRC established three concrete goals: (1) scrap all pre-2005 operational YLVs 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; and (3) scrap all YLVs nationwide by 2017. The plan set a target for Guangdong to scrap 493,000 YLVs and aged vehicles[10] in 2014. Based on the national and provincial target, each city established or updated its YLV scrappage plan, which included scrappage targets, incentives, and other complementary measures (Table 12). The emission reduction targets for each city reinforce the promotion of cleaner vehicles because local officials will receive "credit" toward their emission reduction goals for each vehicle scrapped. By the end of 2014, Guangdong achieved its 2014 target by scrapping more than 500,000 YLVs.

Table 12. Yellow label vehicle (YLVs) scrappage target, progress, and measurements in four cities

	Guangdong Province	Guangzhou	Shenzhen	Foshan	Dongguan
YLV population (at the end of 2013)	1,290,000	111,000	258,000	137,753	111,586
Scrappage target	• All YLV from before 2005 by 2015 • Almost all[12] YLV in PRD by 2015 • Almost all YLV by 2017	• Almost all YLV by 2015	• All government /commercial YLV by 2014 • Almost all YLV by 2015	• All government YLV by 2013 • All public YLV by 2014 • All commercial YLV before 2005 • Almost all YLV by 2015	• All YLV before 2003 by 2014 • Almost all YLV by 2015
Subsidies start date	N/A	June 1, 2009	July 1, 2011	July 1, 2012	June 1, 2009
Accumulative scrappage	N/A	140,000 (2007-2013)	100,000 (before 2013)	68,000 (2011-2013)	N/A

To achieve 2017 YLV scrappage targets, local governments made or updated fiscal policies to encourage early scrappage. The subsidies for YLV scrappage are as high as 32,000 RMB ($5,161 US). There are also small amounts of subsidy for YLVs that transfer outside the city. The subsidies come mainly from the local budgets with some supplementary support from the provincial government. The Guangdong Department of Finance provides financial support for PRD scrappage, which is 20% of the per-vehicle 6,000-30,000 RMB ($968-$4839 US) baseline. City governments design their own financial policy and share the financial liability with their jurisdictions.[11]

Guangzhou started to subsidize YLV scrappage in June 2009 and updated its subsidy policy in December 2014 in order to meet the scrappage targets. Shenzhen started to subsidize in 2011. The first wave of Shenzhen's subsidies, from July 1, 2011, to June 30, 2012, did not significantly affect early scrappage. Shenzhen then extended the subsidy policy to June 30, 2015, and provided differential incentives for early scrappage and transfer-out to encourage first actors. Dongguan's first YLV scrappage subsidies ran

9 Yellow label vehicles are China 0 gasoline vehicles and China 0, I, and II diesel vehicles.
10 Aged vehicles are vehicles not achieving (and include) China 2/II emission standards.
11 Information from closed-door workshop with Guangdong EPB in November 2013 and local regulations
12 The province regulatory document doesn't clarify the definition of "scrap almost all YLVs."

from June 1, 2009, to May 31, 2010. In 2014, Dongguan updated its subsidy policy and provided two-phase subsidies from August 2014 to the end of 2015. Foshan provided subsidies in 2009 to encourage scrappage of buses aged 6-8 years. In 2012, Foshan issued an implementation suggestion, setting scrappage targets and subsidy standards that will be effective until 2015. Table 13 summarizes scrappage and transfer subsidies in the four cities.

Table 13. Summary of YLV subsidies in Guangzhou, Shenzhen, Dongguan, and Foshan (RMB)

Vehicle Type	Vehicle Type		Guangzhou[13]	Shenzhen[14]			Dongguan[15]		Foshan[16]
Start date			Dec. 15, 2014	June 1, 2013	July 2, 2014	Jan. 1, 2015	Aug. 22, 2014	June 30, 2015	July 1, 2012
End date			Dec. 31, 2015	June 30, 2014	Dec. 31, 2014	June 30, 2015	June 30, 2015	Dec. 31, 2015	Oct. 31, 2015
Passenger	Light passenger	>1.35l	20,000	18,000	12,600	7,200	9,000	7,200	18,000
		1-1.25l	12,000	10,000	7,000	4,000	6,000	4,800	10,000
		<1	8,000	6,000	4,200	2,400	5,000	4,000	6,000
	Micro bus		7,000	5,000	3,500	2,000	5,000	4,000	5,000
	Small bus		12,000	11,000	7,700	4,400	9,000	7,200	7,000
	Medium passenger		18,000	15,000	10,500	6,000	13,000	10,400	11,000
	Large passenger		30,000	32,000	22,400	12,800	28,000	22,400	18,000
Freight	Micro truck		8,000	6,000	4,200	2,400	5,000	4,000	6,000
	Light truck		15,000	12,000	8,400	4,800	10,000	8,000	9,000
	Medium truck		22,000	18,000	12,600	7,200	16,000	12,800	13,000
	Heavy truck		30,000	36,000	25,200	14,400	30,000	24,000	18,000
Specialty vehicle			30,000	10,000	7,000	4,000	8,500	6,800	6,000
Transfer out			—	7,000	5,000	3,000	—	—	2,000

1. Replace scrapped vehicles with vehicles that are as clean as possible.
Almost all vehicles used to replace scrapped YLVs meet more stringent emission standards in the four cities. New vehicles sold in the market must meet the latest emission standards (i.e., China 4/IV). Although there is no regulation forbidding YLVs to be sold in the used car market, due to the expanding travel restriction of YLVs in the city area (see low emission zone section for more details), people are less likely to buy vehicles without a green label. Nevertheless, to maximize program benefits, cities should consider requiring replacement vehicles to meet the most stringent emission standards. Shenzhen, for example, requires public service YLVs to be replaced by vehicles meeting China IV or above emission standards or clean energy vehicles since 2014. As another example, Guangdong decided to adopt China 5/V emission standards early. Therefore the overall benefit is even larger because replacement vehicles meet China 5/V standards.

13 Guangzhou provides different subsidies to vehicles registered before 2000, from 2001 to 2004, and 2005 and after. The subsidies in the table are for vehicles registered in or after 2005 (highest subsidies). See details at http://news.ycwb.com/2014-11/10/content_8065871.htm (Chinese)

14 Shenzhen YLV Early Scrappage Subsidy Rules. (2013). http://www.sztb.gov.cn/jtzx/tzgg/201308/P020130819547321351176.doc.

15 Dongguan YLV Early Scrappage Subsidy Implementation Plan (2014-2015). http://www.dg.gov.cn/business/htmlfiles/cndg/s1272/201408/789792.htm

16 Suggestions on Accelerating YLVs Scrappage Implementation. (2012) http://hbj.ss.gov.cn/zwgkhb/flfghb/201410/W020141031650213500643.doc.

2. Ensure expected benefits are actually achieved.

As scrapping vehicles contributes to achieving emission reduction goals, local program managers have incentives and are under pressure to successfully run the program and accomplish the replacement goals. As shown in Table 12, all cities have successfully removed a significant quantity of YLVs in recent years.

In terms of scrapped vehicle recycling, Guangdong Province in 2005 issued *Notice on Enhancing Management of Scrapped Vehicle Recycling*. The notice clarified responsibilities of the local departments of commerce and public security and emphasized scrappage procedures and requirements of issuing Scrappage Vehicle Recycling Certifications. Guangdong also enhanced the monitoring and management of vehicle recycling entities to ensure the legal disassembly of scrapped vehicles to prevent illegal trading.

However, the programs in Shenzhen and Foshan encourage YLVs to be transferred to regions outside the city. This allows these high-emitting vehicles to continue polluting other areas.

3. Maximize both environmental benefits and cost-effectiveness.

In general, China's scrappage programs do not yet employ cost-effectiveness as a parameter for prioritizing grants. In terms of fiscal incentive design, all four cities are offering a variety of different subsidies for different types of vehicles. Shenzhen, Dongguan, and Guangzhou have had success at offering fiscal subsidies that decrease over time or differentiate vehicle age. This encourages owners of high-emitting vehicles to replace their vehicles as early as possible, therefore resulting in the largest environmental benefit.

Although the cities provide generous subsidies for early scrappage, the fiscal incentives are not currently high enough to incentivize owners to scrap their vehicles instead of selling them to others in the used vehicle market.

4. Balance national and local-level roles.

China has a strict top-down structure for scrappage and replacement deployment. The MEP, along with other agencies, required Guangdong Province to scrap 493,000 YLVs and aged vehicles in 2014 and has a long-term target of scrapping all YLVs by 2017. Guangdong Province established an implementation framework and provided financial support to achieve these targets. City-level agencies planned their own programs according to the provincial guidelines or set even stricter targets. For example, Shenzhen and Foshan set an early deadline for the scrappage of government and public service vehicles.

5. Employ complementary policies

Resulting from the top-down approach, all cities have done a good job of employing complementary policies. The national regulation sets age and activity limits (i.e., maximum vehicle kilometers traveled, or VKT) for nearly all categories of vehicles. As a vehicle can no longer be legally registered or operated once it reaches the maximum age or activity limit, owners are incentivized to take advantage of the fiscal incentives prior to mandatory scrappage, at which point no financial subsidy would be given.

The national government also has taken actions to increase the operating cost of YLVs. This is critical to discouraging the use of high-emitting vehicles as China removed mandatory scrappage requirements for private passenger cars. Recently, the *2014 YLV and Aged Vehicles Scrappage Implementation Plan* increased I/M test frequency for YLVs from twice a year to four times a year, which further increased the testing burden for YLV owners.

At the local level, the cities created low emission zones to restrict YLVs' travel area, which further bolsters the scrappage and replacement programs. With national and provincial guidance, the low emission zone program is expanding in all areas. See the low emission zone section for more details.

Table 14 summarizes the evaluation of the scrappage and replacement programs in the four cities in the context of the identified best practices.

Table 14. Evaluation of scrappage and replacement programs in Guangzhou, Shenzhen, Foshan, and Dongguan

Best practices of scrappage and replacement program	GZ	SZ	FS	DG
1. Replace scrapped vehicles with vehicles that are as clean as possible	■	■	■	■
2. Ensure expected benefits are actually achieved	■	■	■	■
3. Maximize both environmental benefits and cost-effectiveness	■	■	■	■
4. Balance national and local-level roles	■	■	■	■
5. Employ complementary policies	■	■	■	■

■ Meets ■ Partially meets ■ Does not meet

Retrofit and repower

Retrofit and repower programs are heavily technology based and require professional management and certification capacity. It is difficult to fully meet the emission reduction expectation without comprehensive program design, implementation, and monitoring. In recent years, there were limited retrofit and repower programs in Guangdong. For example, some taxi drivers in Shenzhen repowered their vehicles to burn CNG, but this activity was subsequently forbidden due to safety concerns. For this report, we didn't collect sufficient detailed information on the retrofit and repower programs in the four cities, and therefore will not evaluate these programs.

LOW EMISSION ZONE PROGRAM

Following the MEP's requirement for banning YLVs from operating in all prefecture-level and above cities by July 2015, Guangdong Province aggressively promoted YLV travel restrictions to support YLV scrappage in 2014. By the end of 2015, Guangdong requires all PRD cities to have at least 40% of their constructed jurisdiction area[17] be LEZs and sets the level at 30% for other (non-PRD) cities. Cities are encouraged to ban YLVs from operating within their jurisdictions. Guangdong required all cities to make a YLV operation restriction plan by 2013. Table 15 illustrates the plan in four cities and their current implementation progress.

17 Constructed jurisdiction area means areas in the city that have been developed with basic public service and facilities.

Table 15. YLV road restriction plan in Guangzhou, Shenzhen, Dongguan, and Foshan[18]

	Guangzhou	Shenzhen	Foshan	Dongguan
Starting date	January 1, 2014	January 1, 2015	January 1, 2015	November 1, 2014
End date	Dec. 31, 2018	N/A	N/A	Dec. 1, 2015
Restriction Area in 2014 (km²)	528	841	101	N/A
Jurisdiction constructed area (km²)	990	841	101	153
% Area	53%	100%	100%	N/A
Restriction time	All day	All day	All day	Daily 9:00-18:00
Supervision	Surveillance cameras, police	Surveillance cameras, police	Surveillance cameras, police	Surveillance cameras, police
Penalty	200 RMB and 3 points on license	300 RMB and 3 points on license	200 RMB and 3 points on license	200 RMB and 3 points on license
Exception	Emergency vehicles*, municipal vehicles, and road maintenance vehicles are not restricted	Emergency vehicles, city buses, passenger vehicles with more than 20 seats, China II diesels with Transportation Permit	Emergency vehicles	Emergency vehicles, China II buses

* Emergency vehicles usually include: Army, police, fire, ambulance, project emergency.

1. Receive political support.

The LEZ programs at the city level receive tremendous political support from national and provincial environmental protection agencies. This enables city agencies to carry out aggressive LEZ plans and gives them strong enforcement power.

Moreover, the environmental labeling program provides significant support to the implementation of LEZ. In July 2009, the MEP issued *Regulations on Vehicle Environmental Inspection Label Management*, which implemented vehicle environmental label management nationwide. Since then, Guangdong adopted national management standards and expanded the yellow label vehicle fleet definition to include gasoline vehicles unqualified for China 1 standards and diesel vehicles unqualified for China III standards. Guangzhou, Dongguan, and Foshan successively established local vehicle environmental label management measures from 2011-2012. By following the rules of I/M testing frequency, vehicle owners get environmental labels once their vehicles pass the safety and emission inspection. Unqualified vehicles or vehicles that do not go for inspection on time will not receive environmental labels. Environmental labeling creates an important foundation for identifying high-emitting vehicles and keeping them from traveling in restricted areas.

2. Reduce emissions from gross-emitting vehicles effectively in the city.

All LEZ in the cities started from the most polluted areas and expanded from there as the programs were phased in. The restriction times of YLV admittance into LEZs vary by city. At the time this report was written, Shenzhen and Foshan had fully restricted YLVs from traveling in the city in 2015. Guangzhou completely blocks the YLVs from restricted areas (53% of jurisdiction construction area) 24 hours a day, while Dongguan forbids YLVs from traveling in the LEZ during the busiest hours of the day. All cities keep tightening both their LEZ area and restriction time in their phase-in plan. Dongguan

18 Information from closed-door workshop with Guangdong EPB in November 2013, 2013 China City Yearbook and local regulations.

plans to fully forbid YLVs in jurisdiction area by the end of 2015. All cities have penalties for unauthorized entry to the restricted zones.

3. Educate operators affected by the scheme changes.

Local public security agencies, working with local environmental protection agencies, are responsible for training personnel to monitor the implementation of the LEZ program either through surveillance cameras or on-site supervision. All cities carry out their LEZ programs in several phases. The phase-in period leaves enough time to inform vehicle owners of the implementation of the program. In most cities, violating vehicles are notified without penalty during the "education phase" at the beginning of the program.

4. Establish cost-effective enforcement mechanism

All cities provide a strong enforcement network to ensure high-emitting vehicles stay out of the LEZ. To monitor the program, the public security agencies install surveillance cameras in the LEZ area. The cameras recognize the plate numbers of on-road vehicles and search for their label status in the database. Once YLVs are identified to be driving in the LEZ during restricted times, the public security agency will bill the vehicle owners to collect a fine and record 3 points on their licenses. Moreover, the nine cities in the PRD area have connected their management system and YLV database, so they can work together to manage and penalize YLVs that break into the LEZ in any city in the network. Other programs, such as remote sensing and spot-checking, also work well to support the enforcement of LEZ.

Table 16 summarizes the evaluation of the LEZ programs in the four cities in the context of the identified best practices.

Table 16. Evaluation of low emission zones in Guangzhou, Shenzhen, Foshan, and Dongguan

Best practices of low emission zone	GZ	SZ	FS	DG
1. Receive political support	■	■	■	■
2. Reduce emissions from gross-emitting vehicles effectively in the city	■	■	■	■
3. Educate operators affected by the scheme changes	■	■	■	■
4. Establish cost-effective enforcement mechanism	■	■	■	■

■ Meets ■ Partially meets ■ Does not meet

Stage II vapor recovery

Guangdong required all cities in the PRD area to install and retrofit Stage II vapor recovery systems by the end of 2009[19]. To achieve this goal, all cities in this study made detailed plans and timelines to retrofit refueling systems at service stations and establish subsidy standards to encourage retrofitting. Table 17 lists the specific subsidy amount in each city. All cities provide 6,000 RMB (around $983 US) for every nozzle retrofitted while Dongguan and Foshan provide a 40,000-60,000 RMB subsidy ($6,557-$9,836 US) toward the installation of gas station aftertreatment devices if all required retrofitting is accomplished on time and a station inspection is passed. The PRD area accomplished Stage II vapor recovery installation and retrofitting by the end of 2010 (Chinanews, 2015).

19 The install and retrofit timeline for other cities in Guangdong was by the end of 2011.

Table 17. Vapor recovery retrofit subsidy in Guangzhou, Shenzhen, Dongguang, and Foshan[20]

	Guangzhou	Shenzhen	Dongguan	Foshan
Subsidy to on time Stage II (RMB)	6000/nozzle	6000/nozzle	6000/nozzle 60,000/ gas station aftertreatment	6000/nozzle 40,000/ gas station aftertreatment

1. Maximize program coverage to improve control efficiency.

All cities require Stage II control for all sizes of service stations. The inclusion of all sizes of service stations regardless of throughput can effectively improve area-wide evaporative emission control efficiency.

2. Ensure strong local oversight of system installations.

All cities require service stations to apply for retrofit inspection and gas station environmental evaluation. There are clear national standards for air pollutant emissions at service stations and technical standards for inspection of air pollution control systems for oil storage facilities and refuel stations. Guangdong EPB also provides guidance and training for installation inspection. Only service stations that finished retrofitting and passed the inspection on time would receive subsidies.

3. Monitor and maintain the Stage II vapor recovery system consistently to remain high vapor recovery efficiency.

Guangdong Province authorizes local agencies to monitor the operation of vapor recovery devices at gas stations. For operation monitoring, the installation of an online monitoring system is mandatory for gas stations with throughput above 5,000 tons in Guangzhou and Shenzhen, and above 8,000 tons in other cities. However, for this report, we don't have sufficient information on the results of how well these systems are monitoring the operation and maintenance of vapor recovery devices and the pass rates for annual inspection.

4. Evaluate the cost-effectiveness of the program.

Due to the lack of a robust VOC testing system, it is difficult for the cities to evaluate the efficiency of their stage II program. Though we are not able to evaluate the cost-effectiveness of the program, in general, Stage II vapor control starts with a high capital cost investment followed by continued maintenance costs from refueling stations. Local agencies provide large subsidies to support retrofitting and invest additional resources for inspection and monitoring. Therefore the high effectiveness of Stage II control usually comes with substantial cost.

Table 18 summarizes the evaluation of the Stage II vapor recovery programs in the four cities in the context of the identified best practices.

Table 18. Evaluation of Stage II vapor recovery in Guangzhou, Shenzhen, Foshan, and Dongguan

Best practices of Stage II vapor recovery	GZ	SZ	FS	DG
1. Maximize program coverage to improve control efficiency				
2. Ensure strong local oversight of system installations				
3. Monitor and maintain the Stage II vapor recovery system consistently	N/A	N/A	N/A	N/A
3. Evaluate the cost-effectiveness of the program	N/A	N/A	N/A	N/A

Meets **Partially meets** **Does not meet**

20 Information came from local gasoline recovery retrofit plans.

CONCLUSIONS AND SUGGESTIONS

This report introduces the best practices to reduce in-use vehicle emissions and actions local policymakers can take to maximize the environmental benefits. The report discusses a number of major in-use vehicle emission control programs in four cities in Guangdong Province and assesses the effectiveness of each program. Table 19 evaluates the quality of these programs.

Table 19. Evaluation of in-use vehicle emission control programs in Guangzhou (GZ), Shenzhen (SZ), Foshan (FS), and Dongguan (DG)

In-use compliance	GZ	SZ	FS	DG
Inspection and Maintenance (I/M) program				
1. Design a comprehensive institutional structure for I/M management				
2. Base I/M program technical design on studies and make it subject to improvement over time				
3. Promote I/M program compliance and enforcement				
4. Obtain and manage resources				
5. Build up maintenance capacity in I/M programs				
Remote sensing program				
1. Choose good locations to collect useful data				
2. Establish enough remote sensing systems to prevent cheating				
3. Set on-road emission standards properly and take corrective action				
4. Use remote sensing results to effectively reduce emissions				
5. Ensure adequate enforcement for effective pollution control				
Spot-checking program				
1. Choose good locations to target possible high-emitting vehicles				
2. Establish test procedures and train inspectors to conduct testing				
3. Ensure adequate enforcement for effective pollution control				
Public spotter program				
1. Promote the program to encourage public support				
2. Provide the public easy reporting methods when identifying smoking vehicles				
3. Ensure follow-up with vehicle owners who are reported				
Cleaner fuel program	**GZ**	**SZ**	**FS**	**DG**
1. Adopt a systematic approach				
2. Build a solid and flexible regulatory mechanism				
3. Adopt progressive pricing to encourage cleaner fuels				
4. Implement an effective compliance program	N/A	N/A	N/A	N/A
5. Use captive fleets to create demand for cleaner fuels				
Eliminating high emitters and older vehicles from the road	**GZ**	**SZ**	**FS**	**DG**
Scrappage and replacement program				
1. Replace scrapped vehicles with vehicles that are as clean as possible				
2. Ensure expected benefits are actually achieved				
3. Maximize both environmental benefits and cost-effectiveness				
4. Balance national and local-level roles				
5. Employ complementary policies				
Low emission zone	**GZ**	**SZ**	**FS**	**DG**
1. Receive political support				
2. Reduce emissions from gross-emitting vehicles effectively in the city				
3. Educate operators affected by the scheme changes				
4. Establish cost-effective enforcement mechanism				
Stage II vapor recovery	**GZ**	**SZ**	**FS**	**DG**
1. Maximize program coverage to improve control efficiency				
2. Ensure strong local oversight of system installations				
3. Monitor and maintain the Stage II vapor recovery system consistently	N/A	N/A	N/A	N/A
4. Evaluate the cost-effectiveness of the program	N/A	N/A	N/A	N/A

Meets Partially meets Does not meet

Effective in-use vehicle emission control programs rely heavily on implementation and enforcement at the city level. Local governments face significant pressure to control in-use vehicle emissions, however having limited resources means that cities also need to strategically deploy their in-use control strategies to achieve the highest emission reductions. Based on our assessment, the following suggestions can improve in-use vehicle emission control in Guangdong:

» I/M program
  - Improve the compliance and pass rate of I/M testing, especially for diesel vehicles. Cities can perform extensive studies, make use of data from remote sensing devices (RSD), and investigate and estimate the characteristics and distribution of noncompliant fleets. Combined with other measures, such as remote sensing and spotter programs, cities can concentrate resources to monitor and improve the vehicle fleet with the highest noncompliance ratios and therefore increase the compliance and pass rate of I/M testing. Updating the I/M pass thresholds is important as the fleet changes in composition and age.
  - For China 4/IV and China 5/V vehicles consider incorporating On-Board Diagnostics (OBD) into I/M testing procedures to improve accuracy (see details in Posada, Yang, & Muncrief, 2015).
  - Increase attention to improving maintenance and repair station capacity to deal with advanced aftertreatment devices, such as providing technical guidance or training.

» Remote sensing program
  - Clarify the purpose of the program, such as the detection of I/M noncompliant or high-emitting vehicles, to maximize the impact of the remote sensing program. For instance, Dongguan should think about using remote sensing to detect I/M noncompliant vehicles rather than detecting YLVs in the low emission zone, if there are surveillance cameras that can serve the same purpose more cost-effectively.
  - Be more strategic in choosing locations to make the best use of remote sensing facilities.

» Spot-checking program
  - Make spot-checking programs consistent and frequent to be powerful and improve long-term effectiveness.
  - Consider increasing inspection spots or set checking stations for certain vehicle fleets to expand inspection coverage.

» Public spotter program
  - Educate the public, such as teaching them the high-emitting model inventory, to increase public awareness and maximize public participation in reporting smoking vehicles.

» Cleaner fuel
  - Ensure the supply of qualified low sulfur fuels through rigorous fuel quality inspection and a penalty system (see details in Fung, 2015).
  - Provide strong cleaner fuel supply to accelerate the uptake of the alternative fuel vehicle fleet. Cities can consider reducing the price of alternative fuels, such as CNG and LNG. For electric vehicles, city governments can subsidize the cost of electricity for private charging, or differentiate peak-hour and overnight charging prices. Subsidizing the building of refueling or charging facilities will also increase the availability of cleaner fuel.
  - Build up regional cooperation to balance alternative fuel supply capacity to support inter-city long distance travel.

» Scrappage and replacement

- Require replacement vehicles to be much cleaner than the scrapped vehicles. Particularly, as scrapped commercial HDV usually are replaced immediately to maintain transportation capacity, it is optimal to require replacement vehicles to meet the most stringent new vehicle emission standards.
- Set differential subsidies and backstop scrappage deadlines to encourage early scrappage.
- Stop providing subsidies to YLVs transferring out of the cities. Make sure the scrapped vehicles are destroyed to prevent further pollution in other cities, which will reduce regional pollutant emissions.
- Enhance complementary programs, such as LEZs and remote sensing programs, to increase the operating cost of high-emitting vehicles and make scrappage a better choice than selling them to someone else.

» Low emission zones

- Keep expanding LEZ restricted areas and effective hours. The earlier the LEZ can cover the entire city area, the more effective it will be in discouraging high-emitting vehicles and reducing local emissions.
- Expand the restricted vehicle fleet. While the current focus is on YLVs, in the future the LEZ can also cover aging vehicles with China 3/III or lower.
- Increase cooperation among cities to make sure all cities in the area have the same approach. Setting LEZ in only one city would just force high-emitting vehicles into polluting other cities. Thus, implementing LEZ is a regional effort.

» Vapor recovery

- Enhance monitoring of the operation and maintenance of Stage II vapor recovery facilities.
- Investigate and evaluate the efficiency of Stage II vapor recovery to assess the cost-effectiveness of the program.
- Consider requiring ORVR on new vehicles to improve vapor recovery efficiency.

In many regions, resources are constrained so it will not be possible to invest in all the programs discussed in this paper. In that case, regional authorities should analyze the comparative costs and benefits of each program to aid in determining where to focus their efforts. Table 20 gives an example of the potential level of resource investment compared to emission benefit for each program type and suggests which program types should receive priority. The cost and benefit analysis in the table is not conclusive, but based on our best judgment. Further research would be required to do a truly region-specific cost-benefit analysis comparison for a set of programs.

Table 20. Resource investment, efficient, priority of in-use vehicle emissions control programs

	Resource investment	Emission benefit	Program priority
I/M	Medium	High	High
Remote sensing	Medium	Medium	Medium
Spot-checking	Medium	Medium	Medium
Public spotter	Low	Medium	Medium
LEZ	Low	Medium	High
Scrappage	Medium	High	High
Retrofit	High	Medium	Low
Stage II vapor recovery	High	High	Medium

APPENDIX I

Table 21. Summary of environment/air and automobile emission control regulations.

	Document	Implementation date	Highest approval agency
National			
	Environmental Protection Law	Dec. 26, 1989	NPC
	Air Pollution Prevention and Control Law	Sept. 1, 2000	NPC
	Road Traffic Safety Law	May 1, 2004	NPC
	Air Pollution Prevention and Control Action Plan	Sept. 10, 2013	State Council
Guangdong Province			
	Environmental Protection Statute of Guangdong Province	Jan. 1, 2005	GDPC Standing Committee
	Automotive Emission Prevention and Control Statute of Guangdong	Sept. 1, 2000	GDPC Standing Committee
	Measures of Air Pollution Prevention and Control of Guangdong Province Pearl River Delta Region	May 1, 2009	GD Government
	Guangdong Air Pollution Prevention and Control Action Plan (2014-2016)	Feb. 7, 2014	GD Government
	Guangdong Automotive Emission Prevention and Control Implementation Plan	March 11, 2008	GD Government
Guangzhou			
	Environmental Protection Statute of Guangzhou	Sept. 1, 1997	GDPC Standing Committee
	Regulation of Automotive Emission Prevention and Control of Guangdong (Amended)	July 1, 2007	GDPC Standing Committee
	Guangzhou Air Pollution Prevention and Control Implementation Plan (2014-2016)	May 6, 2014	GZ Government
Shenzhen			
	Shenzhen Special Economic Zone Environmental Protection Statute	Dec. 31, 1994	SZPC Standing Committee
	Shenzhen Special Economic Zone Automotive Emission Prevention and Control Statute	June 1, 2004	SZPC Standing Committee
	Shenzhen Air Quality Improvement Plan	Sept. 20, 2013	SZ Government
Foshan			
	Management Measure of Automotive Emission Prevention and Control Foshan (Pilot)	Aug. 8, 2011	FS Government
	Foshan Air Pollution Prevention and Control Implementation Plan (2014-2017)	TBD	FS Government
	Foshan Automotive Emission Prevention and Control Implementation Plan	Sept. 26, 2009	FS Government
Dongguan			
	Dongguan Air Pollution Prevention and Control Implementation Plan (2014-2017)	June 30, 2014	DG Government
	Dongguan Automotive Emission Prevention and Control Implementation Plan	Sept. 8, 2008	DG Government

Law	Local statute	Local regulation	Plan	Environment/air quality	Transportation

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