Guangzhou Green Trucks Pilot Project:

Technology Pilot Report for the World Bank "Truck GHG Emission Reduction Pilot Project"

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About CAI-Asia

The Clean Air Initiative for Asian Cities (CAI-Asia) promotes better air quality and livable cities by translating knowledge to policies and actions that reduce air pollution and greenhouse gas emissions from transport, energy and other sectors. CAI-Asia was established in 2001 by the Asian Development Bank, the World Bank and USAID, and is part of a global initiative that includes CAI-LAC (Latin American Cities) and CAI-SSA (Sub-Saharan Africa).

Since 2007, this multi-stakeholder initiative is a registered UN Type II Partnership with over 170 organizational members, eight Country Networks (China, India, Indonesia, Nepal, Pakistan, Philippines, Sri Lanka, and Vietnam) and the CAI-Asia Center as its secretariat. Individuals can join CAI-Asia by registering at the Clean Air Portal: www.cleanairinitiative.org. Its flagship event, the Better Air Quality conference, brings together over 700 air quality stakeholders.

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1. Introduction

The World Bank (WB) initiated a pilot project – dubbed "Guangzhou Green Trucks Pilot Project" in support of Guangzhou's efforts to improve air quality in preparation for the 2010 Asian Games. The goal of this project was to develop a "proof of concept" for a truck program in Guangdong Province and China that aims to:

- Enhance the fuel economy of the truck fleet
- Reduce black carbon and other air pollutants from trucks
- Consequently obtain GHG emission savings.

The project was implemented by the Clean Air Initiative for Asian Cities Center (CAI-Asia Center), in cooperation with Cascade Sierra Solutions, US EPA and World Bank, and with support from Guangzhou Environmental Protection Bureau (GEPB), Guangzhou Transport Committee (GTC), and Guangzhou Project Management Office (PMO) for the World Bank.

The pilot project aims to contribute to addressing three problems related to trucks in Guangzhou and the wider Guangdong province simultaneously: (a) fuel costs and security; (b) air pollution and associated health impacts, and (c) greenhouse gas emissions and climate change.

The **scope** of the pilot was limited to Guangdong Province, focusing on diesel trucks accessing or passing through the city of Guangzhou and surrounding cities, like Shenzhen. Aside from GHG emissions, the scope includes black carbon and other air pollutants from trucks because of their potential interacting effects and contribution to climate change, and because air pollution is an important local concern.

The pilot project consisted of the following components, each with its own output:

1. Background analysis
2. Survey of Guangzhou truck sector
3. Driver training course for fuel efficiency of trucks
4. Technology pilot

This document is the Technology Pilot Report. It is important to note that as the objective of the Guangzhou pilot was to develop a "proof of concept" for a broader program, the technology pilot in the first place aimed to

- Demonstrate that technologies applied in the US and other Western countries to improve fuel economy and reduce emissions can also work in China
- Identify factors of influence in China on the successful application of technologies and recommendations for a larger pilot in Guangdong Province or elsewhere
- Determine the potential for fuel savings and emissions reductions for Guangdong Province if technology packages were to applied to Guangdong registered trucks

Therefore, the results from the technology pilot should be considered as indicative only and must be verified under a larger pilot.

2. Technologies tested

This chapter presents the technologies tested on trucks as part of the pilot. The Analysis Report describes in more detail the strategies and technologies that can be used to improve fuel efficiency and reduce emissions as follows:

1 Vehicle activity and driving pattern improvement
2 Enhanced Maintenance
3 Vehicle body improvement
- Truck weight reduction: aluminum wheels
- Reducing tire rolling resistance: dual low rolling resistance tires & tire pressure monitoring system
- Improved aerodynamics to reduce drag above 75 km/hr: nosecone, cab fairing, skirts

4 Reduced idling
5 Fuel, oil and lubricant improvement
6 Oil by-pass filtration system
7 Emission retrofit systems
8 Fleet and Engine Modernization

As part of the Technology Pilot for Guangzhou, the vehicle body improvement technologies were tested.

2.1 Truck Weight Reduction

Every 10 percent drop in truck weight reduces fuel use between 5 and 10 percent. Generally, an empty truck makes up about one-third of the total weight of the truck. Using aluminum, metal alloys, metal matrix composites, and other lightweight components where appropriate can reduce empty truck weight (known as “tare weight”), improve fuel efficiency, and reduce greenhouse gas emissions. Aluminum wheels reduce the weight of the wheel and thus the weight of the truck. Aluminum wheels tested were of the Alcoa brand (model 886523) on the cabins of HDTs included in the pilot.

Figure 1: Aluminum wheels

2.2 Reducing tire rolling resistance

As the name suggests, low rolling resistance tires reduce the rolling resistance of tires on the road and thus reduce fuel use. Due to legislation in China that does not allow making changes to the truck structure, it was not possible to trial single-wide rolling resistance tires. Dual low rolling resistance tires of the brand Michelin XZA2 Energy LRR Tires were tested on garbage trucks, short-haul and HDTs during the pilot.

Since the bulk of the load is carried in the trailer, a 10-psi under inflation in a trailer tire may have nearly twice the impact on truck fuel economy as the same amount of under inflation in a drive tire. A tire pressure monitoring system consists of chips on each of the trucks' tires and a display panel in the truck cabin. The moment a tire is below a set pressure, a red light will turn on indicating which tire is underinflated. This allows the driver to immediately increase the tire pressure rather than finding out about under-inflation at regular inspections. Aside from reducing fuel use and emissions, it also helps reduce tire wear and maintenance. A tire pressure monitoring system of the brand Doran was tested on garbage trucks, short-haul and HDTs during the pilot. A waterproof external signal booster (to improve transmission of signals from the sensor to the display panels) was also installed (Doran, model 3625). It is noted that also a different technology exists that automatically inflates the tire when the pressure drops below a set value, but this was not tested because it is much more costly.

Figure 2: Tire pressure monitoring system

2.3 Improved aerodynamics to reduce drag

Aerodynamic drag (wind resistance) accounts for most truck energy losses at highway speeds. Reducing drag can improves fuel efficiency. The longer the drive and the higher the speed, the greater are the potential efficiency benefits. For example, cutting drag by 25 percent could raise fuel economy up to 15 percent at highway speed. It is important to note that a minimum speed of 75 km/hour is needed for aerodynamics equipment to deliver fuel savings. At lower speeds the aerodynamics of the trucks are also slightly improved but the increased fuel use due to the weight of the equipment offsets fuel savings.

The following strategies were applied during the technology pilot on HDTs:

- Cab roof fairing, which is an integrated air deflector mounted on the top of the cab and reduces the gap between the tractor and the trailer. Fairings of the brand DongGuan CAIJI were used in the pilot.
- Nose cone, which is installed on the front of the trailer and reduces air turbulence. Nose cones were purchased from a Guangdong-based supplier, DongGuan CAIJI.
- Skirts, which are panels that hang down from the bottom of a trailer to enclose the open space between the rear wheels o the tractor and the rear wheels of the trailer. Skirts reduce the amount of wind underneath the trailer and, according to the manufacturers, can improve fuel economy by up to 5 percent. Skirts were made to size in the US by FreightWing Inc, and shipped to China.

Figure 3: Cabin fairings of the brand DongGuan CAIJI installed on HDTs similar to the photo

东莞市蔡记玻璃钢有限公司

Figure 4: Nose cones of the brand DongGuan CAIJI installed on HDTs

FREIGHT WING INC.™
Driving Fuel Efficiency Into Tomorrow

Figure 4: Trailer skirts of the brand Freight Wing Inc installed on HDTs

3. Technology Pilot Results

This chapter presents the results of the technology pilot for the three participating companies in Guangzhou. As mentioned in chapter 1, the quantitative results from the technology pilot should be considered as indicative only and must be verified under a larger pilot. A key output is the identification of factors of influence on the successful application of technologies (explained in this chapter) and of lessons learned for consideration in a larger pilot in the future (described in chapter 4).

3.1 HDTs: Star of the City Logistics (SOCL)

3.1.1 Company description

Star of the City Logistics (SOCL, http://www.socl.net) is a private road logistics company based in the Pearl River Delta with subsidiary companies registered in Shanghai and Shenzhen. SOCL has more than 120 branches around China. SOCL has more than 300 trucks and 2,600 employees. The main business area of SOCL is the PRD as well as long-haul transport service to East and North China.

3.1.2 Details of technologies tested

The table below presents the details of the technologies tested on two HDTs. It is noted that as only a low number of technologies were purchased costs were higher than if technologies would be purchased in larger numbers.

Table 1. Details of technologies tested on SOCL's HDTs (Costs in US$)

Technology	Brand	Unit costs	No per truck	Costs per truck	Costs 2 trucks
Aluminum wheels	Alcoa Alcoa Part Number- 886523 Wheel Size- 8.25x22.5 Stud Pattern- 10 stud 335mm PCD Hub Bore- 281mm Bolt Hole Size- 26mm Wheel offset- 167mm Wheel Weight- 22.7 Kilograms We'll Finish- Mirror Polished	194	10 (only on tractor)	1,940	3,880
Low rolling resistance tires	Michelin XZA2 Energy 285/80R22.5 LLR Tires	456.1	22 (10 tractor, 12 trailer)	10,034	20,068
Tire pressure monitoring system	Doran 360HD18 (sensor 0 to 188 PSI ±2 PSI)	1,199	1	1,199	2398
External signal booster	Doran #3625	125	1	125	250
Cabin fairing	DongGuan CAIJI *[provided in kind but assumed in cost calculations]*	835	1	835	1,670

Technology	Brand	Unit costs	No per truck	Costs per truck	Costs 2 trucks
Nose cone	DongGuan CAIJI	700	1	700	1,400
Trailer skirts	Freight Wing Inc., Aeorflex trailer skirts	1,500	1	1,500	3,000
TOTAL				16,333	32,666

3.1.3 Details of the pilot and control trucks

The table below presents details of the trucks and of factors of influence on the pilot results.

Table 2. Details of SOCL's HDTs (Costs in US$)

Details	Pilot truck 1	Pilot truck 2	Control truck
Truck details	Scania Tractor (3 axle) and Zhongi Trailers (17 meters) combination, total length 19.5 meters		
Truck number plate	A73230	A73355	A75053
Duration of pilot	16 August 2009 thru 30 October 2009 (77 Days)		
Drivers for pilot duration (drivers alternating every 5 hours)	Zhou / Deng	Huang / Li	Yang / Fang
Same truck-trailer combination for entire duration of pilot	Yes	Yes	Yes
Route driven	2422.66 km round trip surfaced highway Guangzhou, Shanghai, Guangzhou		
Total trip time	48 hours (Guangzhou Shanghai return trip)		
Total km driven during pilot	29196 km	22929 km	26936 km
Average weight per load	53.8 Ton (heaviest 66.29 ton)	52.4 Ton (heaviest 61.4 ton)	52 Ton (heaviest 61 ton)
Average speed	55 - 60 km/hr. Weight, weather conditions, highway construction, and traffic congestions were major contributing factors in highway speeds obtained		
Fuel use during pilot	10,557 liters	8,926 liters	10,432 liters
Fuel economy (liters per 100 km)	• 36.16 • Aug: 37 • Sep: 36 • Oct: 35.5	• 38.93 • Aug: 39 • Sep: 39 • Oct: 38.6	• 38.73 • Aug: 38 • Sep: 39 • Oct: 39.2
Maintenance and other irregularities during pilot in relation to truck itself	No maintenance information	No maintenance information	No maintenance information
Irregularities in relation to equipment	Drivers mistakenly took pressure monitoring sensors off equipment for two trips – these were replaced		
Other factors of influence on pilot results	• SOCL does not invoice by weight, they invoice by items in trailer. There is no check on weight • The timing of the pilot project for SOCL was bad. The months of		

	August and September are the most demanding for the company. The emphasis for SOCL management is to move freight, take care of customers. • The weight of trucks in August and September can be as high as 66 metric ton+. The remaining of the year the weight will average 50 metric ton or below • The average speed on the pilot vehicles was 55 - 60 km/hr. The heavier the truck the slower the speed. Aerodynamics equipment is more effective at speeds of 75 km/hr and higher.

3.1.4 Results

The table below presents the calculations of fuel, cost savings and emissions. Interpretation of the results must take into consideration the factors explained in Table 2. SOCL determined at an early stage of the pilot that the technologies were working, and committed to purchase the technologies for the other trucks in their fleet. Their commitment to these technologies was based on the numbers, and the trust of the Green Truck Pilot team.

Based on the results for pilot truck 1, if the equipment package were to be installed for the entire long-haul fleet of SOCL, consisting of 30 HDTs to which the package can be applied, then this would require US$ 489,996, resulting in 106,704 liters of fuel savings, which is equivalent to US$ 96,033. The payback period would be 5 years. Emissions reductions would be 276 tons CO_2, 996 kg NOx and 42 kg PM10 per year.

It is noted that a more favorable payback period would be achieved if:

- Equipment would be factory-installed on trucks
- Equipment would be purchased in bulk (current costs are based on low number purchased as part of the Guangzhou pilot project)
- The longer life time of LRR tires compared to existing tires would be considered as this would lower the LRR tire investment costs over a certain time period

Table 3. Calculations of the technology pilot at SOCL

	Pilot truck 1	Pilot truck 2	Remarks
Investment costs	$ 16,333	$ 16,333	
Fuel economy compared to control truck	6.64% (36.16 liters per 100 km compared to 38.73 for control truck)	-0.1% (38.93 liters per 100 km compared to 38.73 for control truck)	
Fuel savings per day	750.3 liters = 10,557 liters / (1 – 6.64) * 6.64	-	
Fuel savings per year	3,557 liters = 9.186 liters * 365 days	-	
Fuel cost savings	$ 3,201 per year = 3,557 liters * 0.9	-	
Payback period	5.1 years		Based on results from pilot

	Pilot truck 1	Pilot truck 2	Remarks
	= $16,333 / $3,201		truck 1 only
Payback period adjusted for LRR tire life	Not available	-	LRR tires last longer than normal tires
CO2 reductions (kg per year)	9.18 tons = 3,557 liters * 2.582 kg CO2 per liter / 1000 kg per ton	-	2.582 kg CO2/liter IEA SMP Model http://www.wbcsd.org/web/publications/mobility/smp-model-document.pdf) The (Euro III) European Transient Cycle (ETC) Loaded European Load Response (ELR) uses 2.62 kg/l
NOx reductions (kg per year)	33.21 kg = 3,557 liters * 9.34 g NOx per liter / 1000 g per kg	-	China National emission factors (provided by Tsinghua University), compared to 28.052 g/l Euro emissions factor
PM10 reductions (kg per year)	1.41 kg = 3,557 liters * 0.40 g PM10 per liter / 1000 g per kg	-	China National emission factors (provided by Tsinghua University) compared to 0.0209 g/l Euro emissions factor

3.2 Short-haul trucks: Xinbang Logistics (XBWL)

3.2.1 Company description

Xinbang Logistics (XBWL, www.xbwl.cn) is a private road logistics company based in the Pearl River Delta with 230 branches around China. XBWL has more than 5,000 employees and 600 trucks. The company runs inter-city short-haul business within the Pearl River Delta (PRD) and Yangtze River Delta (YRD). It also has long-haul service connecting PRD, YRD and east China. XBWL also provides transfer services for aviation freight transport.

3.2.2 Details of technologies tested

The table below presents the details of the technologies tested on three short-haul trucks.

Table 4. Details of technologies tested on XBWL short-haul trucks (Costs in US$)

Technology	Brand	Unit costs	No per truck	Costs per truck	Costs 3 trucks
Low rolling resistance tires	Michelin XZA2 Energy 285/80R22.5 LLR Tires	456.1	8	3,648	10,946

Steel rims	To fit with XZA2+Energy LRR tires	74	8	592	1,776
Tire pressure monitoring system	Doran 360HD12 (sensor 0 to 188 PSI ±2 PSI)	899	1	899	2,697
External signal booster	Doran #3625	125	1	125	375
TOTAL				5,264	15,792

3.2.3 Details of the pilot and control trucks

The table below presents details of the pilot and control trucks and of factors of influence on the pilot results.

Table 5. Details of XBWL's short-haul trucks (Costs in US$)

Details	Pilot truck 1	Pilot truck 2	Pilot truck 3	Control truck 1	Control truck 2	Control truck 3
Truck details	DongFeng 8 Ton 3/Axle [2 steer axle](8 Wheels) 300 Hp Domestic Engine [Euro IV]					
Truck number plate	S49593	S49625	S49598	S45722	S49822	S49833
Duration of pilot, 14 or 17 Aug until 30 Sep 2009	62 days, 35 load dispatch	65 days, 39 load dispatch	62 days, 44 load dispatch	71 days, 35 load dispatch	69 days, 41 load dispatch	71 days, 39 load dispatch
Same drivers for entire pilot duration	Replaced in Sep	Replaced in Sep	Yes	Yes	Yes	Yes
Route driven	Guangdong Province Local Pickup / Delivery (routes varied between trucks and days)					
Average km per day	418 km	453 km	436 km	434 km	436 km	491 km
Total km driven during pilot	16329 km	17678 km	19162 km	15183 km	17883 km	19169 km
Weight per load	40 to 11,098 kg	5 to 11,703 kg	18 to 10250 kg	1 to 10617 kg	18 to 13350 kg	86 to 12548 kg
Average load weight	4279 kg (4.3 tons)	5235 kg (5.2 tons)	4049 kg (4.0 tons)	3575 kg (3.6 tons)	4013 kg (4.0 tons)	5695 kg (5.7 tons)
Fuel use during pilot (liters)	4,488	4,300	3796	4903	4249	4772
Fuel economy (liters per 100 km)	27.48	24.32	25.00	25.59	23.76	24.89
Maintenance and other irregularities during pilot in relation to truck itself	None					
Irregularities in relation to equipment	None					
Factors of influence on pilot results	• No mechanical history was obtained and evaluated on the 6 trucks in the pilot • The data supplied by XB was not collected from the 6 pilot trucks following the protocol set forth by the pilot team. Fueling records were from the actual fueling, the kilometer readings were not from the odometer. The kilometer readings were from office tracking records 'map' kilometers, delivery point to delivery point. Issues with this data: o Map calculations do not take into effect detours, out of route distance,					

	and other variations from map o Data is usually recorded for maintenance records, and other regulatory requirements. The drivers are not accountable for miles on the trucks. • The loads and routes were not matched up to be close to same for all 6 trucks. (See weight differences) • According to Mr. Cheng, XB team leader, the standard tires on all XB trucks are better quality Chinese tires, (factory equipped). • In September the drivers that were assigned to the pilot trucks in August were replaced by drivers that had not had Doran training, or the CAI-Asia driver training. The original pilot drivers were put on new trucks purchased by XB. The new drivers did have issues with the Doran system because nobody explained how to use the monitor.

3.2.4 Results

Based on table 5, the fuel consumption in pilot trucks was 1.8% lower than in control trucks (fuel economy of pilot trucks was average 25.62 liters per 100 km compared to average 24.76 for control trucks). However, due to the many variables, and in particular the data collection methods applied, these results are not considered reliable, and therefore no further calculations were done.

XBWL indicated that it is certain that actual fuel savings were much higher. If XBWL were to install the equipment package for its fleet then this would be applicable to 50 long-haul and 550 short-haul trucks. XBWL would not consider using LLR tires in their operation, because the tires that come from the factory generally last until the trucks are traded in (every 3 years) and the cost is a third more for Michelin LLR tires.

3.3 Garbage trucks: Baiyun District - Guangzhou

3.3.1 Company description

The garbage fleet of Baiyun District is part of the public garbage fleet of Guangzhou, which is owned by the Bureau of City Appearance, Environment and Sanitation of Guangzhou Municipality. Now there are more than twenty thousand employees and eleven hundred trucks for sanitation service in Guangzhou. The garbage fleet is responsible of collecting urban garbage and transferring them to waste disposal plants or landfill sites.

3.3.2 Details of technologies tested

The table below presents the details of the technologies tested on two garbage trucks.

Table 6. Details of technologies tested on Baiyun District garbage trucks (Costs in US$)

Technology	Brand	Unit costs	No per truck	Costs per truck	Costs 2 trucks
Low rolling resistance tires	Michelin XZA2 Energy 285/80R22.5 LLR Tires	456.1	10	4,561	9,122
Steel rims	To fit with XZA2+Energy LRR tires	74	10	740	1,480
Tire pressure monitoring system	Doran 360HD12 (sensor 0 to 188 PSI ±2 PSI)	899	1	899	1,798
External signal booster	Doran #3625	125	1	125	250
TOTAL				6,325	12,650
Adjusted LRR tires costs	*Based on 5 years life of LRR tire compared to 8 months life of normal tire*	*50*	*10*	*500*	*1000*
TOTAL adjusted for				*3,038*	*6,326*

3.3.3 Details of the pilot and control trucks

The table below presents details of the trucks and of factors of influence on the pilot results.

Table 7. Details of Baiyun District garbage trucks (Costs in US$)

Details	Pilot truck 1	Pilot truck 2	Control truck 1
Truck details	Hongyan 10 Ton 3/Axle (10 Wheels) 330 Hp Domestic Engine [Euro III]		
Truck number plate	A76415	A75705	A74540
Duration of pilot (17 Aug – 29 Sep 2009)	45 days	44 days	33 days
Same drivers for entire pilot duration	Huang / Zeng (drivers would alternate pilot trucks)		Ye / Li (drivers would alternate)
Route driven: Garbage Compacter Transfer Station to Land Fill	Yes	Yes	Yes
Average km per day	38 km per trip 2-4 times daily	38 km per trip 2-4 times daily	38 km per trip 3-4 times daily
Total km driven during pilot	4324 km	4263 km	4354 km
Average load weight	15.7 tons	15.9 tons	13.7 tons
Fuel use during pilot (liters)	1490	1280	1715
Fuel economy (liters per 100 km)	34.5	30	39.4
Maintenance and other irregularities during pilot in relation to truck itself	None		
Irregularities in relation to equipment	Pressure monitoring readout was not	None	None

	electrical connection correctly – was fixed		
Factors of influence on pilot results	• No mechanical history was obtained and evaluated on the 3 pilot trucks • The baseline pilot truck was not engine mechanical equal to trucks with technologies • Both drivers Huang / Zeng attended driver CAI-Asia training prior to pilot, whereas the driver of the control truck did not • The Doran system did not function properly, the Baiyun mechanic wired the system incorrectly • The tires used on baseline pilot truck are of poor quality with a life-cycle of 8 months (life-cycle on Michelin est. 5 years). The LRR tires provide a more stable and better ride than those used by fleet which contributes to fuel savings.		

3.3.4 Results

Interpretation of the results must take into consideration the factors explained in Table 8. The conclusion from the Baiyun District pilot is that especially the LRR tires contributed to the large fuel and emissions savings because they reduced rolling resistance and also stabilized the truck because the existing tires are of poor quality.

If the equipment package were to be installed for the entire Baiyun District garbage fleet, 1500 garbage trucks, then this would require US$ 9,487,500. This would result in 3,780,250 liters of fuel savings, which is equivalent to US$ 3,402,225 (at $0.9 per liter). The payback period would be 3.09 years.

If the costs for the LRR tires were to be adjusted based on a 5 year lifetime for LRR tires compared to 8 months for currently used tires, then the total investment costs for 1,500 garbage trucks would be US$ 4,557,000 and the payback period would be reduced to 1.49 years.

In both cases, annual emissions reductions would be

- 9,761 tons CO_2
- 35.3 tons NO_x
- 1,501 kg PM_{10} per year.

The company commented that as long as LRR tires last on average 3 years their use is beneficial. It is noted that a more favorable payback period would be achieved if:

- Equipment would be factory-installed on trucks
- Equipment would be purchased in bulk (current costs are based on low number purchased as part of the Guangzhou pilot project)

Table 8. Calculations of the technology pilot at Baiyun District garbage trucks

	Pilot truck 1	**Pilot truck 2**	**Average per truck**	**Remarks**
Investment costs US$	6,325	6,325	6,325	
Fuel economy compared to control truck	12.52% (34.46 liters per 100 km compared to 39.39 for control truck)	23.77% (30.03 liters per 100 km compared to 39.39 for control truck)	18.14%	
Fuel savings during the pilot period	213.2 liters = 1490 liters / (1 – 12.52) *12.52	399.2 liters = 1280 liters / (1 – 23.77) *23.77	306.2 liters	
Fuel savings per day	4.74 liters = 213.2 liters / 45 days	9.07 liters = 399.2 liters / 44 days	6.90 liters	
Fuel savings per year	1,729 liters = 4.74 * 365 days	3,311 liters = 9.07 * 365 days	2,520 liters	Even though actual driving days is less than 365, the pilot period calculations already accounts for down time
Fuel cost savings	$ 1,556 per year = 1,729 liters * 0.9	$ 2,980 per year = 3,311 liters * 0.9	$ 2,268 per year	US$ 0.90 per liter diesel
Payback period	4.06 years = $1,556 / $ 6,325	2.12 years = $2,980 / $ 6,325	3.09 years	
Payback period adjusted for LRR tire life compared to existing tire life	*1.95 years = $1,556 / $ 3,038*	*1.02 years = $2,980 / $ 3,038*	*1.49 years*	*See Table 6*
CO2 reductions (kg per year)	4.47 tons = 1,729 liters * 2.582 kg CO2 per liter / 1000 kg per ton	8.55 kg = 3,311 liters * 2.582 kg CO2 per liter / 1000 kg per ton	6.71 kg = 2,520 liters * 2.582 kg CO2 per liter / 1000 g per kg	2.582 kg CO2/liter IEA SMP Model http://www.wbcsd.org/web/publications/mobility/smp-model-document.pdf) The (Euro III) European Transient Cycle (ETC) Loaded European Load Response (ELR) uses 2.62 kg/l
NOx reductions (kg per year)	16.15 kg = 1,729 liters * 9.34 g NOx per liter / 1000 g per kg	30.92 kg = 3,311 liters * 9.34 g NOx per liter / 1000 g per kg	23.53 kg = 2,520 liters * 9.34 g NOx per liter / 1000 g per kg	China National emission factor (provided by Tsinghua University), compared to 28.052 g/l Euro emissions factor
PM10 reductions (kg per year)	0.69 kg = 1,729 liters * 0.40 g PM10 per liter / 1000 g per kg	1.31 kg = 3,311 liters * 0.40 g PM10 per liter / 1000 g per kg	1.00 kg = 2,520 liters * 0.40 g PM10 per liter / 1000 g per kg	China National emission factor (provided by Tsinghua University) compared to 0.0209 g/l Euro emissions factor

4. Discussion

The previous chapter showed that technologies applied in the US and other Western countries to improve fuel economy and reduce emissions can also work in China. It also identified the factors of influence on the results and reliability of the technology pilot and thus on future pilots also.

The chapter presents recommendations for future pilots. It also determines the potential for fuel savings and emissions reductions for Guangdong Province if technology packages were applied to HDTs registered in Guangdong Province.

4.1 Lessons for future pilots

4.1.1 Lessons about technologies tested

A general conclusion is that technologies applied in the US may thus not always be suitable for China. With regards to the individual technologies tested, the following lessons can be drawn for consideration in future pilots and a broader program:

- Tires form a key area for fuel efficiency gains and emissions reductions. Low rolling resistance (LRR) tires were tested to, as the name suggests, reduce the rolling resistance of tires on the road and thus reduce fuel use. Single-wide LRR tires would provide the largest savings but could not be tested due to legislation in China that does not allow making changes to the truck structure. Dual LRR tires appear to generate enough savings for them to be economically feasible, especially due to the longer life span compared to normal tires. An important observation was that the improved stability of tested garbage trucks with the LRR tires likely contributed to the large savings, because the former tires were of poor quality. This could mean that simply improving the quality of conventional tires used on trucks could already result in significant savings. Aluminum wheels could be considered as part of the tire package especially if factory installed instead of replacing existing steel wheels. The first verified SmartWay Chinese made tire, Double Coin Holding is a very important influence for developing SmartWay technology verification to technologies manufactured and distributed in China.[1]
- Tire pressure monitoring systems have a good potential to reduce fuel and emissions, but hinge on good installation of the system and instruction of the drivers on how to operate it.
- Nosecones and cabin fairings were considered successful technologies because of reasonable savings, even at lower speeds, and relatively low investment costs. For this reason SOCL indicated to install these equipments on the entire long-haul fleet.
- The trailer skirts, aimed to reduce drag, were less successful because the long-haul trucks did not reach average speeds of 75 km/hr above which fuel savings can be significant. At lower speeds the added weight of trailer skirts offsets the fuel savings from reduced drag. Reasons why high average speeds may be more difficult to achieve in China compared to the US are speed limits on roads, traffic congestion, weather conditions, quality of the road. The weight of truck loads also plays an important role, as overloading of trucks is common and renders driving at high speeds unsafe. The pilot found a wide range

[1] See: http://fleetowner.com/green/archive/china-made-first-smartway-0322/
http://www.tirereview.com/Article/72045/epa_smatway_adds_first_chinese_tire.aspx

of truck load, which is not always measured because customers often pay per freight volume or units transported.

A future pilot project should have a stronger focus on domestic trucks, such as DongFeng, HOWO, STEYR. These trucks manufacturers could be involved in a pilot by installing selected technologies at the time of assembly of trucks, providing financial support for the pilot project in return for the use of the pilot results to promote their trucks. Global engine manufactures that have agreements with Chinese engine manufacturers could also be asked to financially support pilot projects to test new technologies, such as JAC and Navistar.[2]

4.1.2 Lessons about process

The process is equally important to a successful application of technologies. The main lessons for consideration in future pilots and a broader program are:

- Training of drivers can greatly add to fuel and emissions savings, including training on eco-driving as well as on the equipment itself. For example, drivers mistakenly took pressure monitoring sensors off when increasing tire pressure because instructions on handling the equipment had not covered this. Technology training to the drivers of pilot trucks directly by the technology supplier or OEM supplier would be preferred.
- Clear and detailed pilot protocols for data collection are essential. Their implementation can be difficult, and if not implemented correctly, the margin of error may exceed the savings percentage, thus rendering unreliable results as was the case for XWBL. At SOCL the protocols were initially not correctly followed, and it was due to strong personal interest and commitment from top management that the right incentives were provided to pilot drivers during an expanded pilot to ensure the data collected was reliable. Ideally, data collected for equipment tests should be integrated into a company's overall monitoring system. Some of the questions to ask are:
  - What is the business model for each fleet?
  - Understand the routes traveled, kilometers daily, how are mileages accounted daily, are time requirements for drivers when dispatched, how are drivers paid (by kilometer, by day, by trip)?
  - How many days a month are the trucks utilized to move freight?
  - How are drivers trained by the company (by management, by other drivers)?
  - How often are trucks replaced in the fleet?
  - Does senior management empower middle management to make decisions about driver assignments, maintenance issues, and fuel efficiency improvements?
- Conditions for pilot and control trucks need to be kept as close as possible. Of particular importance are the load weight / daily load factor, same driver, with same training, same cab – trailer combination, and same routes.
- Participating companies were keen to be considered leaders in their sector. Identification of leading companies that would profile fleets that advance emission reduction and fuel savings in the transportation sector would benefit a future pilot or program.

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[2] http://fleetowner.com/trucking_around_world/archive/navistar-chinese-engine-maker-1030/

4.2 Potential for fuel and emissions reductions

In chapter 3 the potential for fuel and emissions reductions was calculated for SOCL and the garbage trucks based on the results for their trucks.

Step 1. Number of HDTs in Guangdong Province

To determine the fuel and emissions reduction potential for HDTs registered Guangdong Province, first the number of HDTs was derived as follows:

- 1.23 million trucks registered in Guangdong Province in 2007 (Source: Guangdong Statistics Yearbook 2001 – 2008)
- In absence of a breakdown by truck type, we used the results from the Trucks Survey conducted as part of the Guangzhou pilot, which found that 67.7% of surveyed trucks were HDTs
- This results in 826,520 HDTs. Our survey of 43 companies with trucks registered in Guangzhou found a split of HDT of 68% 20 T, 3% 30 T and 29% 40 T. However, based on interviews and meetings in Guangzhou as part of the pilot project, a split that better matches the reality is likely to be 40% 20 T, 40% 30 T and 20% 40 T. For this reason we took the latter breakdown.

Step 2. Km driven and fuel use per year

There is insufficient information on annual vehicle km traveled (VKT) by trucks in China. We considered the following:

- Several past international studies put the VKT of HDT in China at about 50,000 km, but it is not clear to what extent these were primary studies or were using same secondary data sources.[3]
- A National Census on Pollution Sources reported 106,500 annual VKT for HDT in 2007. [4]
- The survey of 1040 truck drivers conducted as part of this study found for the 698 drivers of HKTs an average 114,418 annual VKT.
- The survey of 43 Guangzhou based companies found 512 km per day[5], and with an assumed number of dispatch days of 250 this would lead to 128,000 VKT. It is noted that in the US the average days a year for HDTs is 245.

For the calculation we used 106,500 VKT.

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[3] Argon National Laboratory (2006). Projection of Chinese Vehicle Motor Growth, Oil Demand and CO2 emissions through 2050. http://www.transportation.anl.gov/pdfs/TA/398.pdf;
ADB (2009). Green Transport: Resource Optimization in the Road Sector in the People's Republic of China. www.adb.org/Documents/.../Green-Transport/Green-Transport.pdf
IFEU (2008). Transport in China - Energy Consumption and Emissions of Different Transport Modes. www.kfw-entwicklungsbank.de/.../Transport/KfW_Final_Draft_Report_China_20080508_rk_.pdf

[4] Ministry of Environmental Protection, State Statistics Bureau and Ministry of Agriculture (2010). First National Census on Pollution Sources. http://www.china.org.cn/china/2010-02/09/content_19394384.htm. The study with data for trucks that fed into this national census was: Vehicle Emission Control Center of China (2008). Research report on national vehicle emission rates development as part of the project of developing emission rates for urban area source for the first national census on pollution sources" (prepared in Chinese).

[5] 68% of trucks 20 T, 300 km/day; 3% of trucks 30 T, 600 km/day; 29% of trucks 40 T, 1000 km/day

The fuel use was calculated as follows:

- The Truck Survey found an average fuel efficiency of 39.3 liters per 100 km (this is in range of 38.3 for SOCL HDTs)
- Average fuel use per truck is then 41,855 liters per year
- Total fuel use for the entire fleet is then 34,595,355,520 liter per year (= 346 million hectoliters or 217 million barrels)

Step 3. Technology packages

Next, two technology packages were considered, and costs made during the pilot were used:

- Tires: LRR tires, aluminum rims (although not always possible we assumed this would be applied to all trucks for this calculation), tire pressure monitoring system and external booster.
- Aerodynamics: the full aerodynamics package (nosecone, cab fairing and skirts) was assumed only for 40 HDT while for 20 T and 30 T trucks only the nosecones, because skirts are most applicable to the largest trucks.

Table 9. Technology packages applied in Guangdong calculation

Equipment	Brand	Unit costs	Number per truck	Costs (US$)
Low resistance tires	Michelin	456.1	40T: 22 30T: 14 20T: 10	Per truck: 20T: 9,125 30T: 10,425 40T: 15,626
Aluminum wheels	Alcoa	194	22	
Tire pressure monitoring	Doran	1199	1	
External signal booster	Doran	125	1	
Total costs package 1 – TIRES for 826,560 trucks				9,047,095,949
Skirts (assumes 2 trailers	Freightwing	1500	1	Per truck: 20T: 700 30T: 700 40T: 3035
Nosecone	DongGuan CAIJI	700	1	
Cabin fairings	DongGuan CAIJI	835	1	
Total package 2 – AERODYNAMICS for 826,560 trucks				964,595,520
Total package 1 and 2				10,011,691,469

Step 4. Fuel savings and emissions reductions

Based on the above, the following fuel savings and emissions reductions were calculated. It is noted that larger fuel and emission reductions and more favorable payback periods would be achieved if:

- Equipment would be factory-installed on trucks
- Equipment would be purchased in bulk (current costs are based on low number purchased as part of the Guangzhou pilot project)
- The longer life time of LRR tires compared to existing tires would be considered as this would lower the LRR tire investment costs over a certain time period
- Less conservative figures would be used in particular for fuel % reductions, VKT and diesel price. For example, if the 128,000 VKT from the survey would have been used, fuel and emissions savings

would be 20% higher. It is also noted that savings from aerodynamics equipment, especially skirts, is highest when speeds of 75 km/hr are achieved.

Table 10. Potential fuel savings and emissions reductions for Guangdong HDTs

	Per HDT (avg for 20T, 30T and 40T)	**Guangdong HDTs (826,520)**	**Remarks**
Package 1 – Tires			
Costs US$	20T: 9,125 30T: 10,425 40T: 15,626	9,047,095,949 (= 9.05 billion)	
Percentage fuel savings	5%		US experience shows 6-8%
Fuel savings (liters per year)	2,093	1,729,762,776 (= 1.73 million hectoliter)	
Fuel cost savings ($ per year)	1,883	1,556,786,498 (= US$ 1.56 billion)	Diesel price $ 0.9 per liter
Payback period	4.8 years	4.8 years	
CO2 savings (tons per year)	5.4	4,466,247 (=4.47 million tons)	2.582 kg CO2/liter IEA SMP Model http://www.wbcsd.org/web/publications/mobility/smp-model-document.pdf)
NOx savings (kg per year)	19.5	16,155,984 (= 16,156 tons)	NOx = 9.34 g/liter China National emission factors (provided by Tsinghua University)
PM10 savings (kg per year)	0.8	691,905 (= 692 tons)	PM10 = 0.40 g/liter China National emission factors (provided by Tsinghua University)
Package 2 – Aerodynamics			
Costs US$	20T: 700 30T: 700 40T: 3035	964,595,520 (= US$ 0.96 billion)	
Percentage fuel savings	3.8 %		3% for 20T and 30T trucks 7% for 40T trucks compared to US experience of 10-13%
Fuel savings (liters per year)	1,590	1,314,619,710 (= 1.32 million hectoliter)	
Fuel cost savings ($ per year)	1,431	1,183,157,739 (= US$ 1.8 billion)	Diesel price $ 0.9 per liter
Payback period	0.5 year	0.5 year	= 6 months
CO2 savings (tons per year)	4.1	3,394,348 (= 3.4 million tons)	CO2 = 2.582 kg /liter
NOx savings (kg per year)	14.9	12,278,548 (= 12,279 tons)	NOx = 9.34 g/liter
PM10 savings (kg per year)	0.6	525,848 (= 525 tons)	PM10 = 0.40 g/liter
Package 1 & 2 – Tires & Aerodynamics			
Costs US$	20T: 9,825 30T:11,125	10,011,691,469 (= US$ 10.01 billion)	

	Per HDT (avg for 20T, 30T and 40T)	**Guangdong HDTs (826,520)**	**Remarks**
	40T: 18,661		
Percentage fuel savings	8.8%	8.8%	8% for 20T and 30T trucks (US experience shows 9-11%) 12% for 40T trucks (US experience shows 16-21%)
Fuel savings (liters per year)	3,683	3,044,382,486 (= 3.04 million hectoliter)	
Fuel cost savings ($ per year)	3,315	2,739,944,237 (= US$ 2.74 billion)	Diesel price $ 0.9 per liter
Payback period	5.3 years	5.3 years	
CO2 savings (tons per year)	9.5	7,860,596 (= 7.9 million tons)	CO2: 2.582 kg/liter
NOx savings (kg per year)	34.4	28,434,532 (= 28,435 tons)	NOx = 9.34 g/liter
PM10 savings (kg per year)	1.5	1,217,753 (= 1,218 tons)	PM10 = 0.40 g/liter

Similarly, the potential for reductions can be calculated for all trucks (HDT, MDT and LDT) registered in Guangdong Province. This assumes the application of the tire package for all trucks and the aerodynamics package for HDT only. Table 11 presents the results and it is noted that the investment costs applied are high because they do not consider bulk purchase, and the reduction percentages and emissions factors used are the same as for Table 10.

Table 11. Fuel and Emissions Reduction Potential for All Trucks Registered in Guangdong Province

Parameter	**Total**	**Remarks**
Total number of trucks registered in Guangdong Province	1,230,000	67.2% HDT (826,520); 19.8% MDT (243540); 13.0% LDV (159,900) based on the ratios found in the trucks survey
Total investment costs (tires and aerodynamics)	12,137,461,109	$12 billion dollars
Total fuel savings (liters per year)	3,962,456,995	4 billion liters
Total fuel cost savings ($ per year)	3,586,066,990	$3.6 billion
Total CO2 savings (tons per year)	10,233,591	10 million tons
Total NOx savings (kg per year)	37,009,348	37000 tons
Total PM savings (kg per year)	1,584,983	1584 tons
Payback period in years	3.38	