Slow diffusion of LPG vehicles in China—Lessons from Shanghai, Guangzhou and Hong Kong

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ABSTRACT

Compared with other alternative fuel vehicles (AFV), LPG vehicles (LPGV) have lower economic and technological barriers, leading to its faster growth in some developing countries in recent years. By means of regulation, Shanghai managed to have nearly all taxis converted to LPGV in the early 2000s, and all taxis and 80% of buses in Guangzhou are LPGV. Nevertheless, LPGV diffusion in China (excluding Hong Kong) has been slow and even showing signs of retreating. By 2008, less than 5% of taxis in Shanghai were LPGV. This paper looks into the problem by comparing the LPGV development of Shanghai, Guangzhou versus that of Hong Kong where the LPGV development seems to be running well. The obstacles of LPGV development in China include a lack of policy coherence between the central and local governments; insufficient price advantage of Autogas; not enough fueling stations; and high maintenance costs due to immature technology and poor quality control. Bi-fuel system has further magnified the problems in China. In order to facilitate the use of alternative fuel, efforts should be made to increase the number of AFVs as well as to ensure the availability and price-competitiveness of the alternative fuel concerned.

1. Introduction

Liquefied petroleum gases (LPG) are predominantly propane and butane, derived as a by-product from natural gas production (~60%) and to a lesser extent from crude oil production and refining. LPG are commonly used as a domestic fuel for cooking and heating. LPG can also be used as an automotive fuel, in which case it is often called “Autogas”. “Autogas” is LPG but it is better to use the term “Autogas” because it is not uncommon for a country to have different specifications, pricing policies and fuel duties for, domestic use LPG, petrochemical use LPG, and automotive use LPG.

WLPGA (2005) summarized the results of two studies on regulated emissions performance of a range of conventional and alternative fuels from Euro 2 standard light duty vehicles and a study carried out by the US Argonne National Laboratory (Argonne, 2000) into two tables which are reproduced below.

From Tables 1 and 2, it can be seen that for regulated emissions, Autogas are comparable to or even better than gasoline; and Autogas PM and NOx emissions are much lower than that of diesel. For non-regulated emissions, the environmental advantages of Autogas over gasoline and diesel are very obvious. On the other hand, LPGV also have certain disadvantages, e.g. (a) limited availability of refueling stations in some countries and regions; (b) a bigger fuel tank is required to achieve the same overall driving range due to LPG being lighter than conventional fuels; (c) loss of boot space; (d) a marginal loss in acceleration and speed due to the weight of the LPG fuel tank; (e) choices of OEM LPGV models are limited (WLPGA, 2005).

Autogas is a widely used alternative automotive fuel in the world today. As of 2008, there were over 14.6 million Autogas vehicles in use around the world, a 21% increase in global Autogas consumption over the past 5 years, with Korea, Turkey, Poland and Japan being the world’s top four in terms of Autogas consumption (WLPGA, 2010).

In 1999, China launched a “Clean Air—Clean Auto Act Program” by which 12 model cities (Beijing, Changchun, Chongqing, Guangzhou, Hainan, Harbin, Shanghai, Shenzhen, Sichuan mid area, Tianjin, Urumqi, Xian) were chosen to conduct pilot projects on clean automobiles. Programs to promote vehicles using LPG (LPGV) were launched in various cities. A number of factors at the time were in favor of the development of LPGV in China. First, while Euro 1 and 2 emission standards for passenger cars were adopted in Europe in as early as 1992 and 1996, respectively, the equivalent regulation (National I and National II emissions standards) only became effective in China in 2000 and 2004, respectively. As emission standards were only applicable to newly licensed vehicles, many vehicles running on the road by 2004 were of pre-Euro standards. Adopting more stringent emission standards not only required a higher level of automobile technology but also a higher level of refining technology and capacity to produce better quality fuels. It was not until 2010 that gasoline with max 150 ppm sulfur...
TABLE 1
Regulated emissions by fuel (g/km).

<table>
<thead>
<tr>
<th></th>
<th>THC</th>
<th>NMHC</th>
<th>CO</th>
<th>NOx</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>0.08</td>
<td>0.07</td>
<td>0.60</td>
<td>0.03–0.08</td>
<td>0.001</td>
</tr>
<tr>
<td>Diesel</td>
<td>0.06</td>
<td>0.06</td>
<td>0.50</td>
<td>0.30–0.50</td>
<td>0.040</td>
</tr>
<tr>
<td>Diesel with PM filter</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.30–0.50</td>
<td>0.002</td>
</tr>
<tr>
<td>CNG</td>
<td>0.15</td>
<td>0.30</td>
<td>0.30</td>
<td>0.03–0.06 &lt; 0.001</td>
<td></td>
</tr>
<tr>
<td>Autogas</td>
<td>0.05 n.a.</td>
<td>0.30</td>
<td>0.05–0.08 &lt; 0.001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

VOC—volatile organic compounds, including Total Hydrocarbons (THC), aldehydes, methane and ethane; NMHC—non-methane hydrocarbons; CURE is the Cancer Units Risk Estimate, relative to benzene (CABR method).

(meeting National III gasoline standards) became nationwide standards.1 Sulfur content of National II gasoline standards was as high as max. 500 ppm. On the other hand, LPG imported from gas fields are naturally low in sulfur. Secondly, compared with vehicles running on electricity or natural gas, the technologies related to LPGV and LPG storage were more mature at the time. Thirdly, LPGV could be kicked off by retrofitting a standardized conversion kit to an existing gasoline vehicle. The cost of the conversion was not prohibitively high (~USD360). The construction cost of Autogas fueling station is also lower, about one-tenth of that of CNG fueling station (WLPGA, 2009). Fourthly, gasoline vehicles retrofitted with LPG unit are capable of running on either gasoline or Autogas. This "bi-fuel" capability can alleviate part of the problem of not having enough Autogas fueling stations (especially during the initial phase) or no Autogas fueling stations outside the coverage area. Fifthly, LPG import supply network at the time was better developed than that of natural gas. China imported 5.5 million tons of LPG in 1999 but China's first LNG import terminal was not completed until 2006.

Interestingly, around the same period of time, LPG was legalized in Turkey as an automotive fuel, and Turkey is now the world's number two in terms of Autogas consumption. Judging from the favorable factors mentioned above and the facts that (a) both China and Turkey introduced LPGV around the same period of time; (b) the world's top Autogas users – Korea and Japan – are China's close neighbors; and (c) Hong Kong successfully switched all diesel taxis to LPG taxis during early 2000s; one would expect a comparable progress to be seen in China. The data, however, suggest otherwise. Table 3 summarizes the LPGV development in Korea, Turkey and China. It can be seen that not only was the number of LPGV low in China, instead of trending up like that of Korea and Turkey, it was heading downwards. This study is to find out why diffusion of LPGV was so slow in China from late 1990s up to 2008.

There are many barriers in developing alternative fuel vehicles (AFV) and it is not uncommon that the number of AFV and fueling stations failed to reach a critical mass. Some encouraging development, however, was found in some cities in China with strong policies towards Autogas. Through regulations mandating taxis to switch to LPGV, nearly all taxis in Shanghai were LPGV by early 2000s, and all taxis together with over 80% of public buses in Guangzhou are currently LPGV. The problem is, by 2008 less than 5% of taxis in Shanghai were LPGV, and Guangzhou failed to act as a role model to inspire other cities to engage in LPGV development.

This study therefore concentrated in examining the public policies and LPGV development of Shanghai and Guangzhou, and compared it with that of Hong Kong where the LPGV program is running well. While Hong Kong was returned to China in 1997, her administration and economic framework are still very different from that of China. As these elements are important in the analysis of this study, “China” in this paper excludes Hong Kong.

With respect to benefits of LPGV, it should be noted that in recent years, the environmental benefits of LPGV on regulated and non-regulated tailpipe emissions are becoming smaller in developed countries. This is due to (a) higher quality gasoline/diesel (ultra low sulfur diesel, with a max sulfur content of 10–15 ppm) being used in Europe and USA; (b) improvement in gasoline/diesel engine technology and more and more stringent emissions standard being adopted (Euro 5 emission standards became effective in Europe from 2009); and (c) improvement in after treatment technologies (by installing catalytic converters/diesel particulate filters). The focus for developed countries to promote the use of Autogas has been shifting to reduction of global green house gases (GHG) emission, and to a certain extent energy security (Johnson, 2002). According to the Well-to-Wheels analysis 2008 conducted by the European Commission Joint Research Centre (ECJRC, 2008), the well-to-tank GHG emissions for LPG is about 40% less than that of gasoline and diesel fuels; and the tank-to-wheel GHG emissions for LPG bi-fuel vehicle is about 10% less than that of gasoline but about 2.4% more than that of diesel vehicle fitted with particulate filter.2 While the figures for LPG might not be bad but just for the purpose of reducing GHG, natural gas has surpassed Autogas under certain conditions3; and in the long run Autogas is likely be over taken by energy from renewable sources.

Hence, it should be noted that the purpose of this paper is not to advocate the use of Autogas. Depending on the local/national conditions, Autogas may continue to have an appeal to some places but not necessarily the other. The objective of this paper is to learn from the lesson and to avoid making similar mistakes when launching programs for alternative automotive fuels in general.

The rest of the paper proceeds as follows. Section 2 describes the details of the LPGV development in Hong Kong, Shanghai and Guangzhou. Section 3 discusses the problems of LPGV development in China. Section 4 goes over some historical factors affecting the policies taken by Hong Kong and cities in China. Section 5 gives the conclusion.

2. LPGV development in Hong Kong, Shanghai and Guangzhou

Among the three cities, Shanghai was the first to launch a large-scale LPGV development program (in 1998) with a view to convert all Shanghai taxis to LPGV. Although nearly 100% of the 2008 taxi fleet in Shanghai was retrofitted with Autogas, the development was not as successful as expected. A large number of Shanghai taxis failed to switch to LPGV due to the cost of conversion and the availability of LPG supply.

Table 2
Non-regulated tailpipe emissions—Argonne results (% of conventional gasoline).

<table>
<thead>
<tr>
<th></th>
<th>Formaldehyde</th>
<th>Acetaldehyde</th>
<th>1,3-butadiene</th>
<th>Benzene</th>
<th>CURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>125 103</td>
<td>108</td>
<td>110</td>
<td>68</td>
<td>98</td>
</tr>
<tr>
<td>CNG</td>
<td>40 200</td>
<td>37</td>
<td>2</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Autogas</td>
<td>80 76</td>
<td>58</td>
<td>10</td>
<td>4</td>
<td>13</td>
</tr>
</tbody>
</table>

VOC—volatile organic compounds, including Total Hydrocarbons (THC), aldehydes, methane and ethane; NMHC—non-methane hydrocarbons; CURE is the Cancer Units Risk Estimate, relative to benzene (CABR method).


2 According to ECJRC (2008), the well-to-tank GHG emissions for LPG (from remote gas fields)/gasoline and diesel are 8, 13 and 14 g CO2 eq/MJ final fuel, respectively. The tank-to-wheel GHG emissions for LPG bi-fuel, gasoline, diesel without particulate filter and diesel with particulate filter vehicles (all based on the projected 2010+ vehicle configurations), are 125.7, 140.3, 119.7, and 123.1 g CO2 eq/km, respectively.

3 The well-to-tank GHG emissions for natural gas vary widely depending on distance from supply source. According to ECJRC (2008), the GHG emissions (g CO2 eq/MJ) are 8 for LPG from remote gas filed (3500 nautical miles), 9 for EU-mix natural gas but as high as 22 for natural gas transported via a 7000 km pipeline. The tank-to-wheel GHG emissions for LPG bi-fuel and CNG bi-fuel vehicles are 125.7 and 108.2 g CO2 eq/km, respectively.
taxis were converted to LPGV in early 2000s, less than 5% of taxis in Shanghai were LGPV by 2008.

Independent of the development in China, Hong Kong banned the import of diesel taxi in 2001. By 2003, all taxis in Hong Kong were LPGV. By 2008, over 60% of the public light buses had also been converted to LPGV on a voluntary basis. The LPGV program in Hong Kong seems to be running well.

Guangzhou had two LPGV development programs. The first one was in 1999 which failed to make much advancement and died quickly. The second one started in 2003 and by 2006, all taxis and over 80% of the public buses in Guangzhou are LPGV. Despite such progress, Guangzhou failed to act as a role model to inspire other cities to engage in LPGV development.

Details of the LPGV development of each city are described below.

2.1. Shanghai

It was reported in CAIY (China Automotive Industry Yearbook) (2001) that it was Shanghai’s plan to have all of the 40,000 existing taxis converted to LPGV by 2001–2002 and to be served by about 135 Autogas stations. Autogas consumption was expected to reach 260,000 tons per year after completion of the conversion program.

Effective from 1 January 1998, all new taxis in Shanghai were required to be fitted with either a dedicated LPG or a gasoline–LPG bi-fuel system. During 1998–1999, existing taxi could receive a subsidy of CNY3000 for retrofitting with a LPG system (CNY3000 was sufficient to cover the cost of conversion at the time).

As shown in Fig. 1, over 30,000 units (75%) of the taxis had been converted to LPGV by end of 2001. The number of LPGV taxis continued to rise to close to 40,000 units then dropped sharply in 2006.

Fig. 2 shows the changes in number of LPG taxi versus Autogas consumption in Shanghai. It can be seen that while the number of LPG taxis was increasing and staying high until 2006, Autogas consumption started to drop after 2001. This implies many of the LPGV were actually not using Autogas but gasoline. In June 2005, out of 38,709 LPGV taxis in Shanghai, less than 10,000 taxis were actually running on Autogas; and out of 107 fueling stations, about 20% had been closed down. Due to objection from the taxis operators, the government removed the regulation for new taxis to be equipped with either dedicated or bi-fuel LPG system in early 2006. This explains why the number of LPGV dropped sharply from 2006. By 2008, less than 5% of the taxis were LPGV.

2.2. Hong Kong

Before 1997, taxis in Hong Kong were running on diesel. Due to the worsening air quality, the Hong Kong government carried out an one-year trial on LPG taxis in November 1997. The findings from the trial on exhaust emissions are reproduced in Table 4.

Table 3
LPGV development in Korea, Turkey and China.
Source: Data for Korea from E1 Corp. (2009), WLPGA; Data for Turkey from Karamangil (2006); WLPGA; Data for China from CAIY (2005, 2008). “Total number of vehicles” in China refers to “civil vehicles” only.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total no. of vehicles (million units)</td>
<td>14.9</td>
<td>17.3</td>
<td>10</td>
<td>14.3</td>
<td>27</td>
<td>44</td>
</tr>
<tr>
<td>No. of LPGV (million units)</td>
<td>1.8</td>
<td>2.4</td>
<td>1.2</td>
<td>2.4</td>
<td>0.114</td>
<td>Below 0.08</td>
</tr>
<tr>
<td>% of LPGV in vehicle fleet</td>
<td>12%</td>
<td>13.8%</td>
<td>12%</td>
<td>16.8%</td>
<td>0.4%</td>
<td>Below 0.2%</td>
</tr>
</tbody>
</table>

Fig. 1. Change in number of LPG taxis and LPG fueling stations in Shanghai, 1998–2009.

5 The trial was launched in November 1997 with 30 LPG taxis comprising 20 new ones and 10 used ones, divided into 5 fleets. Four temporary LPG fueling
Based on the finding of the trial concluded in late 1998, the government legalized taxis to operate on LPG with immediate effect. A law was subsequently passed banning import of diesel taxis effective from August 1, 2001. Under this ban, the import of gasoline taxis was allowed but due to the huge price advantage of Autogas over gasoline, this ban effectively drove all taxis to LPGV.

In order to facilitate the conversion of all the 18,000 taxis to LPGV, a subsidy incentive program was opened from August 2000 to December 2003 by which eligible diesel taxi owners who replaced their diesel taxis with LPG taxis could apply for an one-off grant of HKD40,000 (≈USD5130).

Subsequently, two subsidy incentive programs were launched and targeted at the diesel public light buses (PLB, 16-seater light-duty vehicles). The first one was opened from August 2002 to December 2005 by which eligible diesel taxi owners who replaced their diesel taxis with LPGV could apply for a one-off grant of HKD40,000 (≈USD5130).

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In the Environmental Report 2008 of the Transport Department of Hong Kong (HKG, 2008), one of the objectives and targets for 2009 raised was “to continue the incentive scheme and encourage more owners to have their diesel PLB converted to LPG or electric ones”.

With respect to development of Autogas infrastructure, the government earmarked and provided 12 sites at nil land premium for the setting up of large-scale, Dedicated Autogas Stations. These sites were tendered out under Design, Build and Operate (DBO) contract terms for a period of 21 years. The bidders competed primarily for the lowest operating price (sum of operating expenses and profits). Five of the 12 dedicated stations were completed in 2000, four in 2001 and three in 2002.

Furthermore, when new petrol fueling stations (PFS) sites are available for auction, it is a must for PFS operators to install Autogas facilities at the PFSs (Wong, 2009). In addition, before 2000, when leases of existing PFS expired, existing lessees might be granted new leases on payment of a premium. This practice was discontinued in 2000. All PFS sites under a 21-year PFS lease would be tendered out upon expiry of their lease term. However, in order to encourage more owners to have their diesel PLB converted to LPG or electric ones, the government introduced a new policy that was applied to certain existing PFSs. For sites that are suitable for retrofitting Autogas facilities, existing lessees were offered lease extension at a nominal premium if they agreed to retrofit Autogas facilities at the PFS. The new tendering policy was and would only be applied to such PFSs when their extended leases expired.6

It should be noted that the LPG taxis and LPG PLBs in Hong Kong are neither “bi-fueled” nor “retrofitted”. They are brand new Original-Equipment Manufacturer (OEM) dedicated LPGVs (mostly imported from Japan). This is mainly because technically it is more complicated and costly to convert diesel engine vehicles to LPGV. Fig. 3 summarizes the outcome of the LPGV development in Hong Kong. As of 2008, 100% of taxis and over 60% of the PLBs in Hong Kong are running on Autogas, and there are 58 Autogas stations including the 12 large-scale “Dedicated Autogas Stations”.

2.3. Guangzhou

In 1999, Guangzhou city government announced a plan to convert all taxis and public buses to LPGV plus constructing 50
LPG fueling stations by year 2001. The conversion program did not make much progress and died quickly. (During 1999 to early 2003, there were a total of 599 buses and 6249 taxis converted to bi-fuel LPGV but Autogas consumption in 2003 was only about 10 tons per day (Chen, 2006). Also, the number of Autogas stations reduced from six in 2000 to five in 2003.)

In June 2003, seeing the encouraging development in Hong Kong (nearly all taxis had been replaced by LPGV) on one hand and the deteriorating air quality in Guangzhou on the other hand, the Guangzhou government announced a new plan to have all public buses and taxis converted to LPGV in 3 years. The government also planned to have 5 new Autogas stations completed in 2003, 23 in 2004, and to have a total of 52 Autogas stations serving Guangzhou by end of 2005.7

Fig. 4 shows the changes in percentage of LPG taxis and number of LPG fueling stations in Guangzhou during 2003–2009. By the end of 2006, nearly 100% of the taxis (16,000) and 80% of the public buses (6400 out of 8000) had been switched to LPGV. While the rate of vehicle conversion was pretty much in line with the government’s original plan, progress for the establishment of fueling stations was not as satisfactory. By end of 2005, instead of having 52 stations as wished, there were only 23 (Chen, 2006). This was increased to 32 by June 2009 (Gong, 2009).

With respect to the effect of the LPGV program, on the positive side, according to Centre for Environmental Economics and Policy Research (CEEPR) (2009), compared with gasoline taxis of the same model, LPG taxis in Guangzhou emits 63.3% less CO, 30.5% less HC and 81.2% less NOx. As of November 2006, there were 6400 LPG buses and 16,000 LPG taxis in Guangzhou, which could serve to reduce 22,000 tons of CO, 2400 tons of hydrocarbons, 1700 tons of NOx, and to replace 400,000 tons of conventional fuels in 2007.8

Furthermore, although bi-fuel LPG taxis were still the norm, all buses were to adopt the dedicated LPG system. The older buses were required to be scrapped and replaced by new dedicated LPGV, and the newer buses were to have their diesel engines replaced by new dedicated LPG engines. Each bus would receive a government subsidy of CNY20,000 (~USD2415).

According to Guangzhou Public Transport Committee Vehicle Control Unit (Gong, 2009), as of 2004, there were an average of 10,000 complaints per month on black smoke from vehicles, of which about 50% of complaints were on public buses although the number of public bus vehicles was only 1.3% of all automobiles in Guangzhou. This black smoke problem from public buses was totally resolved by all taxis and most public buses switching to LPGV. On a separate development, in November 2006, Guangzhou passed the assessment and was honored the “National Model City for Environmental Protection” (only 63 cities and 5 townships passed the assessment and received the same honor among a total of 657 cities).


3. Problems of LPGV development in China

Various studies have stated that there are many barriers in developing alternative automotive fuel vehicles (AFV), for example: (a) high R&D costs in developing AFV technology; (b) high costs of AFVs; (c) requirement for a simultaneous development of fuel supply infrastructure; (d) insufficient codes and standards, and (e) low emission being a consumer externality, etc. (Boyle, 2005; Köhler et al., 2008; Lopez and Steenberghen, 2008). In the late 1990s/early 2000s, the technology and economic barriers of developing LPGV in China can be said to have been lower than other types of AFVs because LPGV was already a mature technology with much R&D on LPGV having been conducted in Japan/Korea and other developed countries; and the cost of LPG conversion kit was not prohibitively expensive. The “bi-fuel” capability of LPGV could also relieve some pressure on the requirement of simultaneous development of Autogas supply infrastructure.

According to Köhler et al. (2008), regulation is the most powerful option to increase the consumer demand for low-emission vehicles. Imposing regulation on taxis mandating their switch to LPGV was exactly the route taken by Hong Kong, Shanghai and Guangzhou (see Table 5). The regulations proved to be very effective because all three cities had nearly all of the taxis switched to LPGV within the time frame planned by the respective governments. However, this is about where the similarities of the three cities end.

Why then did the LPGV program seem to proceed well in Hong Kong but not quite in China? Problems with the LPGV development in China are discussed in detail below.

Table 5
Regulations adopted by Hong Kong, Shanghai and Guangzhou.

<table>
<thead>
<tr>
<th>City</th>
<th>Regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong Kong</td>
<td>Legalizing LPG taxis in late 1998 and banning import of diesel taxis effective from August 1, 2001.</td>
</tr>
<tr>
<td>Shanghai</td>
<td>All new taxis are to be fitted with either a dedicated LPG system or a gasoline-LPG bi-fuel system, effective from 1 January 1998.</td>
</tr>
<tr>
<td>Guangzhou</td>
<td>In 2003, the city government strongly requested transportation companies to convert all of their taxis/bus fleets to LPGV within 3 years. (Despite being a “strong request”, it was as powerful as official regulation.)</td>
</tr>
</tbody>
</table>

Table 6
Comparison of retailing price and fuel duties of Gasoline in Hong Kong and Beijing, effective October, 2008.

<table>
<thead>
<tr>
<th>City</th>
<th>Retailing price (per liter)</th>
<th>Fuel duties (per liter)</th>
<th>% of fuel duties in retailing price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong Kong</td>
<td>HK$ 15.2</td>
<td>HK$0.06</td>
<td>40</td>
</tr>
<tr>
<td>Beijing</td>
<td>CNY 6.37 (~HK$ 7.27)</td>
<td>CNY0.2 (~HK$ 0.22)</td>
<td>3.1</td>
</tr>
</tbody>
</table>

3.1. Price advantage for Autogas was too small

By applying a very low fuel duty on gasoline and diesel, the Government failed to internalize the benefits of Autogas. Imposing nil or lower fuel duties on Autogas is a very common policy instrument adopted by many governments to promote LPGV (WLPGA, 2005). The fuel duties in Hong Kong are as high as 40% of the final retailing price; but they were a mere 3% in China (see Table 6). Although both Hong Kong and China impose no fuel duties on Autogas, the price advantage for Autogas in China is thus much smaller. (Note: with effective from 1 January 2009, gasoline fuel duties in China have been increased from CNY0.2 per liter to CNY1.0 per liter.)

There were nil or insufficient subsidies to cover the increase in LPGV conversion costs. One may have expected the cost of LPG conversion kits would get cheaper as time passed. In reality, it went up due to more stringent emission standards being imposed on vehicles. LPG conversion technology has evolved through four generations, with newer and better technology continuing to come:

- First generation: Mechanically controlled, Open Loop LPG system, suitable for carburetor engine.
- Second generation: Electronically controlled, close loop, single point injection LPG system, suitable for early electronic fuel injection (EFI) gasoline engine.
- Third generation: Mulpitop injection LPG system.
- Fourth generation: Mulpitop sequential injection LPG system.

As conversion technology advances, the cost of conversion goes up from about CNY3000 to as much as CNY8000 for the latest generation. In 2001, when China banned carburetor engines and required all new gasoline vehicles to be equipped with electric fuel injection (EFI) engines and catalytic converters, first generation conversion kit became obsolete and second generation LPG conversion kit cost as much as CNY5000–6500. For environmental protection, it is an improvement to abolish carburetor engines and put the latest LPG conversion technology into use. The problem, however, is that the local governments in most cities had not responded to this increase in conversion costs. Take Suzhou11 (fifth

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Table 7
Table showing fuel savings and payback period, basis fuel efficiency and fuel cost effective in Guangzhou in 2001.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Gasoline</th>
<th>LPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cost</td>
<td>CNY/l</td>
<td>2.3</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>/100 km</td>
<td>10.00</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>CNY/km</td>
<td>0.23</td>
</tr>
<tr>
<td>Fuel saving per km</td>
<td>CNY/km</td>
<td>0.08</td>
</tr>
<tr>
<td>Cost in refitting an LPG kit</td>
<td>CNY</td>
<td>3500</td>
</tr>
<tr>
<td>Breakeven mileage</td>
<td>km</td>
<td>43,750</td>
</tr>
<tr>
<td>Payback period</td>
<td>Day</td>
<td>146</td>
</tr>
<tr>
<td>For taxis running at 300 km/day</td>
<td>Year</td>
<td>4.38</td>
</tr>
<tr>
<td>For private cars running at 10,000 km/year</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

biggest city in China by 2008 GDP) as an example, in the late 1990s, the carburetor engine conversion fees of CNY3500 were virtually all borne by the local government and Autogas fueling stations operators, but no subsidies were available by mid-2000s when conversion fees rose to CNY7–8000 level. The subsidy of CNY3000 per taxi in Shanghai also finished in 1999. In Shanghai and Guangzhou, higher LPG conversion costs were not an issue because it was compulsory for taxis there to switch to LPGV, but in other cities, when conversion costs were getting higher, taxi owners became less keen to switch to LPGV. CNY6500 was equivalent to about 7 months’ salary (average annual salary in 2001 was CNY10,870 as per China Statistical Yearbook).

Fuel savings were possible but easily eroded by higher than expected running and maintenance costs. It should be made clear that although the price advantage of Autogas in China was said to be small and cost of conversion was getting higher, there was still a potential benefit for high mileage vehicles to convert to Autogas. Table 7 shows the theoretical fuel savings and breakeven mileage basis parameters effective in Guangzhou in 2001. The breakeven mileage of 43,750 km is substantially higher than 28,000 km of Korea and 14,000 km of Turkey (WLPGA, 2005). Nevertheless, due to taxis’ high mileage characteristics, the payback period was less than half a year. This explains why the Chinese government had been supportive to the LPGV development. Not only could LPGV help to improve the worsening air quality, it was also potentially cost beneficial. The problem was that the calculation assumed no change in running and maintenance costs, but in reality, the narrow price advantage of Autogas was often eroded by the higher than expected running and maintenance costs.

3.2. Bi-fuel system magnified the problems of LPGV development in China

Having the flexibility to run on either gasoline or Autogas is supposed to be an advantage as it extends the range of LPGV beyond areas with no Autogas supply infrastructure. It can also alleviate the problem of having not enough Autogas fueling stations, especially during the initial phrase. The reason that the bi-fuel system became a problem in China was because the price advantage of Autogas was so small that many factors could tip the balance, favoring gasoline even within the Autogas coverage area. The two main factors that tip the balance were: (a) insufficient number of Autogas filling stations (see Section 3.3); and (b) immature technology and poor quality control leading to high maintenance costs (see Section 3.4).

Funnily enough, bi-fuel system is not unique to LPGV, and bi-fuel vehicles primarily running on conventional fuel is not a phenomenon restricted to China either. Many flex-fuel vehicles (FFV) were sold in the USA during 1998–2000 possibly due to an incentive to attain AFV credits as a way of meeting the corporate average fuel economy (CAFE) standards, but many of the FFVs were primary running on conventional fuels (Melaina and Zhao, 2006).

The reasons why bi-fuel system magnified the problems of LPGV development in China are explained below.

Bi-fuel system provided a loophole in the LPGV regulation of Shanghai and Guangzhou. Narrow price advantage of Autogas and high conversion cost did not affect the acquisition of LPGV in Shanghai and Guangzhou as it was compulsory for taxis there to switch to LPGV, no matter whether they liked it or not. The problem was that the regulation in Shanghai and Guangzhou were not mandating taxis to run on Autogas but the ability to run on Autogas (there were some dedicated LPG taxis but bi-fuel taxis were by far the norm). In the early/mid-2000s, many taxis in Shanghai (see Section 2.1) and Guangzhou12 were not using Autogas but gasoline.

Bi-fuel vehicles are less efficient, thus further reduce the price advantage of Autogas. First, although bi-fuel engines can run on gasoline or Autogas; the engines are not best tuned for burning Autogas thus leading to a slight loss in efficiency. Second, bi-fuel vehicles are running at a lower than optimal compression ratio. LPG has a higher octane rating, which prevents the occurrence of detonation at high engine compression ratio. Hence, engines operating on LPG can run safely at a higher compression ratio than the equivalent engine operating on gasoline. However, the compression ratio in a bi-fuel vehicle is usually fixed by design (Karamangil, 2006).

Number of LPGV provides an easy but incomplete reference on the success of LPGV development program when most LPGV are bi-fuel. As all vehicles have to be licensed, it is easy for the transport department to monitor the number of LPGV. On the other hand, the figures for Autogas consumption were not as easy. Since LPG can also be used as a cooking and heating fuel, it is not possible to figure out from the customs’ import figures how much LPG are consumed as Autogas. Autogas consumption can only be obtained by collecting sales data from all Autogas fueling stations. During late 1990s to early 2000s, news reports boasting the progress of LPGV development tended to refer to the increase in number of LPGV only.13

Bi-fuel system led to wide fluctuations in sales volume of Autogas, further increasing the difficulties in running Autogas stations. Due to the small price advantage of Autogas and gasoline, there were times that Autogas might suddenly become substantially more or substantially less advantageous than gasoline. During that time, there could be a rush to shift from gasoline to Autogas or vice versa. For example, it was reported that (1) in 2006, Autogas sales in Shanghai jumped by 15% after a price hike of gasoline on 24 June, the number of bi-fuel vehicles calling into one auto service center to revive their Autogas system jumped to 30 odd vehicles per day14; (2) in 2008, when price of gasoline was adjusted upward on 20 June, the number of LPG taxis getting Autogas refuel at LianXin (the biggest Autogas operator in Guangzhou) increased from 5000 to 6000 units per day to more

than 10,000 units per day\textsuperscript{15}; (3) in 2009, due to two price adjustments of gasoline on 1 June and 30 June, respectively, Autogas sales in Xiamen jumped by 4 times; this led to long queues before Autogas fueling stations and tightness of Autogas supply in Xiamen.\textsuperscript{16}

Bi-fuel system provided an easy way to evade the problems, instead of solving the problems. When many technical problems (see Section 3.4) were found with LPGV during the initial development phase, had the taxis not been able to fall back on gasoline that easily, all concerned parties would have to had found ways to solve the teething problems; which might have included using better quality conversion kit, compiling a compatibility list for the conversion kits and gasoline engines, providing better training for the car mechanics, appointing only reputable auto shops to carry out the installation jobs; and imposing a tighter control on quality of Autogas being supplied at fueling stations.

3.3. Insufficient number of Autogas fueling stations

Other than cost of fuel ($/l) and fuel efficiency (km/l), real fuel savings have to take into account the extra mileage and extra waiting time in getting refueled. Insufficient number of fueling stations will increase running costs of Autogas. Again taking Suzhou as an example, in 2002, Suzhou had 1276 LPG taxis and three Autogas fueling stations, and by 2007 all three Autogas fueling stations closed down.\textsuperscript{17} “Three” Autogas fueling stations were low compared with about 180 petrol fueling stations\textsuperscript{18} in Suzhou.

Melaina and Zhao (2006) pointed out the AVF program design in China tended to focus more on the acquisition of AFVs rather than the use of alternative fuels. Local governments paid more attention to the conversion of LPGV and little attention to the availability of high quality gas and the construction of gas stations.

By comparing Shanghai/Guangzhou and Hong Kong, it can be seen that while similar public policies were adopted in all three regarding how to increase the number of LPGV, more active policies were found in Hong Kong on Autogas infrastructure. For example, in Hong Kong, 12 sites have been earmarked and provided at nil land premium for the setting up of large, dedicated Autogas stations; and special rules were set up to induce/compel petrol fueling station operators to retrofit/install Autogas fueling facilities at existing/new petrol fueling stations (see Section 2.2). Not only were there less active policies in China on Autogas infrastructure development, the Autogas price control mechanisms in Shanghai and Guangzhou could put fueling station operators at risks (see Section 3.5).

3.4. Immature technology and poor quality control led to high maintenance costs

“Technology break-through producing a cost break-through” is one of the key factors that can help to break free of gasoline car technology (Cowan and Hulten, 1996). LPGV should receive a high


\textsuperscript{18} There are 187 petrol fueling station in Suzhou in 2009 according to a survey done by the Consumers’ Association on service of petrol fueling stations, available at http://www.cca.org.cn/web/gddt/newsShow.jsp?id=45054 (accessed March 13, 2011).

score on this regard, as LPGV is a proven technology. According to WLPGA (2005), maintenance costs of LPGV are lower because “Autogas has a higher octane rating than gasoline, so converted gasoline-powered spark-ignition engines tend to run more smoothly. This reduces engine wear and maintenance requirements, including less frequent spark plug and oil changes. Autogas exhibits less soot formation than both gasoline and diesel, reducing abrasion and chemical degradation of the engine oil. In addition, Autogas does not dilute the lubricating film on the cylinder wall, which is a particular problem with gasoline engines in cold starts.”

In China, however, maintenance costs of LPGV were found to be high. The high maintenance costs were due to LPGV still being a relatively new technology in China during late 1990s/early 2000s, and poor quality control.

Engine adaptability to Autogas composition was poor. LPG used in China is a mixture of propane and butane, the composition of which is not constant. A properly installed electronically controlled LPG conversion kit should have a self-learning property, capable of adjusting the control parameters to account for variations in propane/butane composition, thus supposedly not necessitating adjustment of the engine during its life time (Karamangil, 2006). Adaptability of LPGV in China, however, was low, necessitating frequent tuning of the engine (Jiang, 2009). According to Jiang (2009), adaptability is a function of (a) quality of the original gasoline engine; (b) quality of the LPG conversion kit; and (c) conversion skills of car mechanics; and all three areas needed improvement in China.

Compatibility between LPG conversion kit and gasoline engine was poor. When the taxi market was moving from a couple of car models dominating the whole taxi market to multiple models co-existing, models of LPG conversion kits also proliferated. Due to lack of regulations on standards, compatibility became an issue.\textsuperscript{19}

Sub-standard Autogas was being supplied at Autogas stations. LPG from most Chinese refineries cannot meet China’s standards of specifications for Autogas (Cao, 2009). Therefore, except for a small portion of refinery LPG which has gone through special treatment, Autogas requirement was basically met by imported LPG. However, due to loose control, sub-standard LPG was recurrently being supplied at Autogas stations, rendering LPGV prone to mechanical troubles\textsuperscript{20} (Jiang, 2009).

In Shanghai, the problem of high maintenance costs became apparent after July 2001, according to comments\textsuperscript{21} from Shanghai Jiuhuan Auto Energy Company (Shanghai’s biggest Autogas stations operator). With effective from July 2001, registration of new carburetor engine vehicles was banned and all new gasoline vehicles had to be equipped with electronic fuel injection (EFI) engines and catalytic converters. As second generation conversion kits were needed for EFI engines, LPG conversion costs jumped to about CNY6500 accordingly, the higher conversion costs compelled car users to use cheaper auto-repair shops, which often were not using the most appropriate equipment or having the proper skills in converting EFI engines; poor conversion quality and poor compatibility between conversion kits and engines necessitated repeated re-tuning of the engines, thus driving up


the maintenance costs. The frequency of troubles was so high that the original carmaker (Shanghai Volkswagen) refused to provide after-sale service and insurance companies refused to insure converted vehicles. It was also reported that some taxi companies prohibited their drivers to use Autogas because while fuel savings went to the driver, maintenance costs were borne by the company. 

In Guangzhou, technical problems became less an issue because when Guangzhou launched their second LPGV program (Gong, 2003), more attention has been paid to training, establishing after-sale service and insurance companies refused to insure converted vehicles. It was also reported that some taxi companies prohibited their drivers to use Autogas because while fuel savings went to the driver, maintenance costs were borne by the company. 

In Guangzhou, technical problems became less an issue because when Guangzhou launched their second LPGV program in 2003, more attention has been paid to training, establishing and ensuring quality standards of LPGV conversion/LPGV maintenance/and Autogas being supplied at Autogas stations (Gong, 2009). Furthermore, LPGV technology for taxis was getting more mature. However, the LPGV technology for heavy-duty bus engine was still very new and was plagued with the problem of low fuel efficiency. In 2003, the Autogas consumption of LPG buses had been as high as 95 l/100 km, which was improved to about 61 l/100 km after a few years later. 

3.5. Autogas price control mechanisms did not take into account LPG cost

Shanghai, Guangzhou and Hong Kong (for the 12 dedicated Autogas fueling stations only) all have price control on Autogas. Table 8 shows the detailed control mechanisms.

As shown in Table 8, the price formula in Hong Kong is composed of two elements, “A” and “B”. “A” reflects the import costs of LPG, and is adjusted on a monthly basis. “B” reflects the operating costs of the operator, and is adjusted on a yearly basis in line with inflation of Hong Kong. In other words, the price formula in Hong Kong avoids the dedicated LPG fueling stations, after being awarded the Design-Build-Operate contracts, charging excessive profits.

The Autogas price control mechanisms for Shanghai and Guangzhou, however, do not have any connection with the import costs of LPG or operating costs of the Autogas fueling stations. In China, prices of gasoline and diesel have always been under the control of the central government. There is, however, no nationwide price control for LPG due to LPG having been historically viewed as a refinery by-product. In order to provide a stable and profitable environment for LPGV owners, both Shanghai and Guangzhou city governments introduced a local price control mechanism for Autogas, which effectively guaranteed approx. 30% discount of Autogas over gasoline on a per liter basis. While such pricing mechanisms served to protect the LPGV users, they could put the Autogas stations operators at risks.

During the mid-2000s, the crude oil price was increasing when at the same time the pace of inflation in China was also picking up (see Fig. 5). In order to put inflation under control, the central government put extra pressure to suppress the price increases of gasoline and diesel. From Fig. 6, it can be seen that when the imported cost of LPG increased by more than 100% (price of January 2005 = 1), domestic gasoline price in China increased by only around 40–50%.

Consequently, for areas without local government price control on Autogas, LPGV owners were finding Autogas losing its competitiveness against gasoline. For Shanghai and Guangzhou, however, there was price control on Autogas, fueling station operators were forced to run at a loss. Many Autogas stations in Shanghai chose to close down or suspend operations to cut their losses. In June 2008 when the price of crude oil was close to its historical peak, out of about 110 fueling stations completed during the hay period, 69 were left, of which 26 suspended operations, leaving only 43 still in business.

In Guangzhou, large-scale suspension of operation by Autogas operators did not happen. It was because (a) Guangzhou government compensated 80% of the trading losses suffered by the

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Table 8

<table>
<thead>
<tr>
<th>Location</th>
<th>Autogas price control mechanism for Hong Kong, Shanghai and Guangzhou.</th>
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<tbody>
<tr>
<td><strong>Hong Kong</strong></td>
<td>Applicable to the 12 dedicated Autogas stations only for the full 21-year contract period. Autogas retailing price $P = A + B$ Where $A = $LPG international prices adjusted monthly $B = $operating prices adjusted yearly according to the year-on-year rate of change of the Composite Consumer Price Index for the previous year.</td>
</tr>
<tr>
<td><strong>Shanghai</strong></td>
<td>Autogas retailing price was put under Shanghai government’s control from November 2002. Autogas retailing price = Autogas mid-price $\times (1 \pm A%)$ Autogas mid-price = $G \times K$ where $G = $retailing price of 90# gasoline in Shanghai $K = $a discount factor between 0.66 and 0.70 to be determined and announced by the government $A = $adjustment allowance, to be determined and announced by the government (usually in the order of 5–8%) Government would announce Autogas mid-price and value of $A$ from time to time</td>
</tr>
<tr>
<td><strong>Guangzhou</strong></td>
<td>Autogas retailing price was put under Guangzhou government’s control from 2004 Autogas retailing price = Autogas mid-price $\times (1 \pm A%)$ Autogas mid-price = 0.7 $\times$ 90# gasoline retailing price in Guangzhou (as announced by Guangzhou Price Bureau)</td>
</tr>
</tbody>
</table>

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fueling stations; and (b) over 80% of the fueling stations in Guangzhou were controlled by two big companies who had strong relationships with the local government. The necessity for contingent government subsidies, and losses made by the Autogas operators, however, cast a shadow on the acceptance of LPGV by other cities.

The interesting thing is by reviewing Fig. 6 again, it can be seen that during this period, price increase of crude was much higher than that of LPG. This means the total expenses on automotive fuel could have been reduced if China had imported more LPG, which was cheaper; and less crude oil, which was more expensive.

3.6. LPG buses are intrinsically less efficient than diesel buses, thus difficult to promote when the price advantage of Autogas is small (Guangzhou)

As opposed to taxis, heavy-duty diesel vehicles are in general not good targets to run on Autogas. First, the conversion costs/OEM premium are high. According to an article reporting an interview with the public bus companies, it is understood that the cost of a new diesel engine is CNY60,000 vs. CNY95,000–11,000 for a new LPG engine, less CNY20,000 subsidy from the government, the net extra cost to the bus company was CNY15,000–30,000 per LPG bus. The actual outlay by the public bus companies was more because some of the buses were requested to take early retirement. A new LPG bus costs about CNY500,000. Second, the comparative fuel efficiency of Autogas is lower (63% against diesel bus as opposed to 91% against gasoline taxi) (see Table 9 for details). In other words, not only were LPG buses more expensive than diesel buses, Autogas fuel costs were higher too. Accordingly in early 2008, when it was reported that the bus companies accumulated CNY2 billion extra expenses in relation to the LPGV program and were showing discontent to continue with the LPGV program, it should not have been a surprise.

Nevertheless, back in the 2000s, it might not have been wrong for Guangzhou government to convert diesel buses to LPGV. Guangzhou was plagued with the problem of black smoke emissions from diesel buses (about 5000 complaints per month in 2004, Gong (2009)). Strengthening spot checks on bus emissions would not clear the problem as the root of the problem were poor diesel engine technologies and poor quality of diesels being used, both needed time to improve. CNG buses were not an option at the time due to the non-availability of natural gas supply (although the first LNG terminal was completed in 2006, the imported gas had been allocated for domestic and power generation use). Technology for electric vehicles was still immature. Having diesel buses switched to a cleaner fuel like LPG could be the only feasible option at the time. It should however, have been noted that due to the lower efficiency of LPG buses, either more public subsidies or more fare increases would have been needed.

Starting from 1 January 2009, fuel duties of diesel have been increased from CNY0.1 to 0.8 per liter. This may help with the economics of LPG buses. Nevertheless, LPG buses are facing increasing competition from other AFVs and diesel hybrids. By end 2008, Guangzhou No. 1 Bus Company was reported to be

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Table 9

<table>
<thead>
<tr>
<th>Type of vehicle</th>
<th>Type of fuel used</th>
<th>Fuel consumption (l/100 km)</th>
<th>Comparative LPG efficiency (by vol) (%)</th>
<th>Conversion/OEM extra costs (CNY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxi</td>
<td>Gasoline</td>
<td>13.6</td>
<td>91</td>
<td>8000–11,000</td>
</tr>
<tr>
<td>Bus</td>
<td>Diesel</td>
<td>40</td>
<td>63</td>
<td>35,000–50,000+</td>
</tr>
<tr>
<td></td>
<td>LPG</td>
<td>15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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taking delivery of 207 units of diesel-hybrid buses, which would meet Euro IV emissions standards and have a much better fuel efficiency than LPG buses.\textsuperscript{27} LPG buses would be fighting an uphill battle to maintain their dominance in Guangzhou.

4. Comparison of historic factors between Hong Kong and China

Although the LPGV program ran smoothly in Hong Kong but not quite in China, it is not fair to give all the praises or put all the blame to the respective governments. History does matter. Other than the difference in fuel duties and pricing mechanism of gasoline/diesel, there are a number of historic factors contributing to the different approaches taken by the governments in Hong Kong and China.

4.1. An “isolated” vs. “connected” city

Hong Kong is small (total area 1095 sq. km) and isolated. There is no worry of LPGV running out of the Autogas coverage area and it is therefore easier for Hong Kong to go for dedicated LPG vehicles. And because the LPG vehicles in Hong Kong can only run on Autogas, it is necessary for the government to adopt more active policies to support the establishment of Autogas infrastructure. The situation is quite different in China. Although taxis are mostly running within the cities, long trips to the suburbs or to other cities are not uncommon. Until a regional Autogas supply network is established, bi-fuel system will continue to have an appeal to taxis in China.

4.2. “Import” vs. “domestic” technology

Car-manufacturing industry is non-existent in Hong Kong, all of the LPG taxis have to be imported. On the other hand, not only were imported products too expensive for China, building up the domestic car-manufacturing industry was also one of the important goals of the Chinese government.

4.3. “Diesel” vs. “gasoline” taxis

Historically, taxis in Hong Kong were running on diesel. Due to technical reasons, conversion for diesel engine is more costly. As a result, Hong Kong did not take the conversion route, but phased out all diesel taxis and replaced them with brand new OEM LPG taxis. The problems related to quality of retrofitting and compatibility of original engine and conversion kit are therefore not applicable to taxis in Hong Kong.

5. Conclusion

One of the biggest problems in the LPGV development of China during 1997–2008 was a lack of policy coherence between central and local governments.

First, despite the central government being keen to promote LPGV and assigning 12 model cities to develop clean automobiles, the ultra low fuel duties applied on gasoline/diesel was detrimental to the LPGV development in provincial cities.

Second, the two-tier price control mechanism on Autogas – (1) Autogas retailing price pegged with retailing prices of gasoline by local governments, and (2) retailing price of gasoline set separately by the central government – led to undesirable outcomes at times. During 2005–2008, the central government’s policy to suppress price increase of gasoline not only delivered a serious blow to the LPGV development in provincial cities, but also increased China’s total energy expenses. Should there be better policy coherence, even if it were necessary to suppress price increase of gasoline to put inflation under control, the central government could have offered incentives to provincial cities to encourage them to step up the use of Autogas. This would have achieved two goals simultaneously (1) reduced national energy expenses by replacing part of the import of the more expensive crude with the cheaper LPG; and (2) provided a super opportunity for the LPGV development in China.

The LPGV development in Shanghai, Guangzhou and Hong Kong reaffirms regulation is a very effective tool in increasing number of AFVs. The LPGV program in Shanghai might have run a different course if there had not been a loophole in the regulation—bi-fuel system letting LPGV run on gasoline. The way to plug the loophole, however, was not to ban bi-fuel system, as the real culprit was the price advantage of Autogas being too small to cover the unexpectedly high running and maintenance costs of LPGV in China.

Consequently, the price advantage of Autogas should be widened, preferably by raising the fuel duties of gasoline and diesel. Running costs could be reduced by encouraging the establishment of more fueling stations. Providing training, setting up codes and standards, and tightening up quality control would have helped to put maintenance costs under control.

Regardless of which type of AFVs, efforts should be made to increase the number of AFVs as well as the availability and price-competitiveness of the alternative fuel. In the event that the AFV in question has a bi-fuel nature, even more efforts are needed to ensure availability and price competitiveness of the targeted fuel. Imagine if due to a lack of charging stations or whatever reasons, subsidized plug-in electric hybrids are mainly running on gasoline instead of electricity, it would be a waste of resources. Hence, not only the change in absolute number of AFVs but also the actual consumption of the respective fuels should be monitored.

Financial incentives for the promotion of AFVs are often worked out based on (a) upfront sales price and (b) subsequent fuel savings of AFVs vs. conventional vehicles. Unfortunately, during the initial deployment stage of AFVs, running costs and maintenance costs can be unexpectedly high due to all sorts of reasons—insufficient number of fueling stations, delays in construction of fueling stations, immature technology, unfamiliar technology, lack of qualified mechanics, lack of spare parts supply network, etc. As a result, during the initial deployment stage, it would be advisable to have incentives set larger than optimal. The incentives can be adjusted later when the running and maintenance costs stabilize or become better understood.

References


