APPENDIX 1: SUMMARY OF TECHNOLOGIES

A. CLEANER DIESEL & RETROFIT TECHNOLOGIES

Vehicle emissions – cleaner diesel fuels

- **Ultra Low Sulphur Diesel (ULSD)** reduces emissions of black smoke, particulates, hydrocarbons, carbon monoxide and carbon dioxide compared to standard diesel. In trials on a Euro I bus in Hong Kong, ULSD alone reduced particulate emissions by 8-9%.\(^1\) In conjunction with an oxidation catalyst, particulate and smoke emissions were reduced by 15-18%, though this is likely to be underestimated.
- **Fischer-Tropsch (F-T) diesel** has been found to reduce NOx by 12% and particulates by 24% in heavy duty trucks compared to standard diesel.\(^2\)
- Using 10% **water-diesel blend** in a Euro II bus in London reduced emissions of NOx by 9% and particulates by 20% compared to ULSD.\(^3\) However, it lowers exhaust temperature therefore may not be compatible with after-treatment devices. The California Air Resources Board (CARB) has found PuriNOx (a proprietary water diesel blend) achieves a 14% reduction in NOx and 63% reduction in particulates.\(^4\)

Vehicle emissions – retrofit technologies

- **Particulate traps** (locally developed) retrofitted to light duty vehicles reduced smoke by 30% for taxis, 35% for light goods vehicles and 21% for public light buses.\(^5\) However, if not cleaned daily, soot can build up and spontaneous combustion of the cartridge can occur.
- Tests done on higher sulphur diesel (0.2%) found DOCs reduced smoke by up to 65% although clogging occurred on some bus models.\(^6\) The DOC remained effective even after 2 years service, reducing particulates by 37%.
- **CRTs** require the use of ULSD and Euro 1 or 2 engines to function properly but can reduce particulate emissions by up to 80%. In Japan, trials of CRTs on heavy duty vehicles and ULSD reduced particulates by 84-95% on some routes but failed on others. Particulate emissions increased when higher sulphur fuel was used thereby reducing the regenerative effect causing plugging of the filter is a problem, particularly for urban driving conditions.\(^7\)

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Energy efficiency and Greenhouse Gas emissions

- Diesel engines are highly energy efficient and have lower life cycle greenhouse gas emissions (GHG) compared to petrol engines. However, both for light and heavy-duty vehicles diesel has higher life cycle emissions of GHG compared to other alternative fuels and vehicles.
- Reducing fuel sulphur consumes more energy in the refining process. Nonetheless, lifecycle GHG emissions for ULSD are only 1.6% higher than regular diesel.\(^8\)
- F-T diesel increases life cycle greenhouse gas emissions by an estimated 15%.\(^9\)
- After treatment devices, such as Exhaust Gas Recirculation (EGR), reduce engine efficiency and increase emissions of GHG. No significant changes in lifecycle emissions are predicted for heavy duty vehicles using ULSD with a CRT.\(^10\)

Impacts on vehicle performance

- ULSD reduces sulphur-induced corrosion and slows acidification of engine oil leading to lower maintenance costs. ULSD has lower lubricity, which can be enhanced by additives or oxygenate blends.
- F-T diesel can be used unmodified in diesel engines and has a very high cetane number.
- Water-diesel blends reduce power (by equivalent water content). Reduced lubrication compared to diesel. Possible problems with water-diesel separation.

Costs

- ULSD has a higher import price due to the extra refining required. However a tax concession for ULSD makes it competitive with regular diesel\(^11\) (which is no longer available at filling stations).
- F-T diesel may also be economically competitive if produced in large volumes.\(^12\)
  Advances in processing technologies, together with economic penalties for flared natural gas in some countries, will bring costs down.
- Water-blend diesel is estimated by the suppliers to cost a few percent more per litre than standard diesel. In France and Italy tax rates for water-blend diesel are 32% and 36% lower than the rates for on-road diesel respectively.\(^13\)

Table A1 Costs (HK$) of ULSD compared to standard diesel

<table>
<thead>
<tr>
<th>Diesel standard</th>
<th>Import price ($/L)</th>
<th>Duty ($)</th>
<th>Retail price ($/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular diesel (350ppm sulphur)</td>
<td>1.81</td>
<td>2.00</td>
<td>5.99</td>
</tr>
<tr>
<td>ULSD (50ppm sulphur)</td>
<td>2.27</td>
<td>1.11</td>
<td>5.94</td>
</tr>
</tbody>
</table>

\(^9\) ibid
\(^11\) Current diesel standard in Hong Kong is Euro 3 with sulphur content of 350 ppm (0.035%).
\(^12\) Already claimed to be competitive commercially with crude oil at $20/bbl or higher. There are a few large investments worldwide in Africa, Malaysia and under development in the US. Unlikely to become widespread within 10 years although smaller quantities will be available for blending. Histon P D (2001) Analysis and prediction of clean fuels in Asia. 2\(^{nd}\) China/Asia Clean Fuels Conference, Sinopec, Beijing, 1-2 March 2001.
\(^13\) M Attfield, Lubrizol, Pers. Comm.
Particulate traps for light duty diesel vehicles cost $1300 (fully subsidised by Government) but need daily washing which is time-consuming for operators. Moreover, operators lack convenient locations for filter washing and for disposal of particulate-laden waste water.

Diesel oxidation catalysts for light duty vehicles cost $4000 (Government provides $1300 subsidy).

CRTs for heavy duty vehicles cost HK$25,000-40,000

Infrastructure costs and requirement

- The existing infrastructure can be used. No modifications to diesel engines are required to use cleaner diesel fuels.

Safety

- ULSD poses no additional safety risks compared to conventional diesel, although diesel in general is carcinogenic.

Availability

- Euro 2 & light duty Euro 3 vehicles widely available. Euro 3 buses to be introduced 1/10/01.
- ULSD (50ppm) is now available from refineries in Singapore. There is no source of 10ppm sulphur diesel in Asia.
- Water blend diesel could be imported from the UK.
- Particulate traps for small vehicles are produced locally.
- CRTs produced by Johnson Matthey. For buses, a similar trap, DPX, is produced by Engelhard.
- Five manufacturers have oxidation catalysts certified by the US EPA to reduce urban bus particulate emissions by over 25%.

Status worldwide and Hong Kong

- Diesel engines most commonly used engine worldwide for heavy trucks and buses. In Hong Kong over 150,000 diesel vehicles registered. Many of these vehicles are pre-Euro standard.
- First Bus is currently testing a water blend diesel emulsion on 2 buses and may expand if the trial works well.
- F-T diesel produced from coal is used as a neat transportation fuel in South Africa and as a blend with petroleum diesel to achieve low sulphur specifications. Shell has a commercial plant in Malaysia and other oil companies are developing pilot or commercial plants.
- Over 13,000 CRT particulate filters in service in Europe, the United States and the Far East.
- The 3 main franchised bus operators have, or plan to, fitted DOCs to their pre-Euro or Euro 1 bus fleet. They are also testing CRTs for operability and effectiveness. If successful they will retrofit CRTs to the bulk of their Euro 1 & 2 fleets.
- Government is testing 5 CRTs on Euro 1 & 2 vehicles and may fit more if tests are positive.

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15 See footnote 3.
• A study on DOCs for larger vehicles by the Hong Kong Polytechnic University is due to be completed this summer and published in due course.

Applicability to Hong Kong
• Cleaner diesel fuels and technologies easily implemented since can be used immediately, with no infrastructure changes. Can be used by existing diesel vehicles.
• For the franchised bus operators who have many pre-Euro and Euro 1 buses, and for medium and heavy good truck operators, the use of cleaner diesel fuels with retrofit technologies offer a good short term solution.
• For cross-border vehicles, high sulphur mainland diesel would poison or clog many retrofit technologies such as DOCs and CRTs.

B. CLEANER PETROL

Vehicle emissions
• Cleaner petrol formulations tend to have lower amounts of aromatics, olefins and benzene, all of which contribute to ozone and airborne toxins.
• However, some ethanol blends can be detrimental in terms of ozone formation (see section on ethanol).
• Emission tests conducted in the UK on light duty vehicle emissions using cleaner petrol show only marginal improvement in NOx and hydrocarbons and no change for carbon monoxide.\(^{16}\)

Energy efficiency and Greenhouse Gas (GHG) Emissions
• Reducing sulphur in petrol to 50ppm reduces N\textsubscript{2}O (a potent GHG) by 60%).\(^{17}\)
• However, sulphur reduction requires additional energy and increases fuel consumption during vehicle use. Lifecycle GHG emissions during refining and vehicle use are 2-3% more than those of conventional petrol.\(^{18}\)
• Cleaner grades of petrol will indirectly encourage new fuel economy measures such as Gasoline Direct Injection (GDI), which is predicted to reduce CO\textsubscript{2} emissions by up to 15%.\(^{19}\)

Performance
• Performance would be slightly impacted due to generally lower energy density of oxygenates.
• Petrol oxygenated with ethanol can separate into phases if contaminated with water.
• Some cleaner petrol formulations can degrade natural rubber engine components.

Costs
• Vehicles do not require adjustments to use. Extends life of catalytic convertor.
• Cleaner petrol formulations tend to be more expensive due to additional processing. US EPA estimates that low sulphur petrol costs 0.75 US cents (HK$6) more per

\(^{16}\) See footnote 10.
\(^{17}\) See footnote 8.
\(^{18}\) Ibid
\(^{19}\) See footnote 10.
In UK, a duty differential of 3p/L (30 HKcents/L) has been provided as an incentive for low sulphur petrol (50ppm S).

Infrastructure Requirements and Costs
- Cleaner petrol formulations can be distributed and stored in the same manner as conventional petroleum. Euro 4, once introduced, will replace conventional petrol at the filling stations.
- For additional blends with ethanol or other oxygenates, new tanks and dispensers would be required.

Status of worldwide and in Hong Kong
- Petrol with added oxygenates (known as Reformulated Gasoline (RFG) in the US) accounts for 25 percent of all petrol sold in the United States due to federal mandates to reduce air pollution. Petrol with added oxygenates is, or will be, available in Italy, Germany, Sweden, Denmark and France to meet EU petrol standards. Hong Kong adopts EU specifications.
- Ultra low sulphur petrol (50ppm S) is widely available in the UK.

Availability and Applicability to Hong Kong
- Hong Kong currently has no available source of cleaner petrol (ie low sulphur or oxygenated) formulations.
- The 355,000 licensed petrol vehicles and motorcycles in Hong Kong contributed over 57% of VOCs emitted by vehicles in 1997—creating a big market for cleaner petrol formulations.

C. LIQUEFIED PETROLEUM GAS (LPG)

Vehicle emissions
- All emissions reduced compared to conventional diesel or petrol. Particulate emissions are virtually eliminated, and for heavy duty vehicles using high propane LPG, NOx is reduced by about 60%, and total hydrocarbons (THCs) by over 80% compared to diesel.\(^{21}\)
- Compared to diesel taxis, LPG taxis emit negligible particulates and smoke, 20-50% less hydrocarbons and NOx under idle test conditions.\(^{22}\)

Energy efficiency and Greenhouse Gas emissions
- LPG is about 30% less energy efficient than diesel. Lower energy density means fewer km per litre of fuel are obtained compared to petrol/diesel. The heavier tanks also add to fuel consumption. This is balanced by LPG’s low carbon content which produce less CO\(_2\).
- Life cycle emissions of greenhouse gases slightly better for diesel light duty vehicles and comparable or slightly better for diesel heavy trucks.\(^{23}\)\(^{24}\)

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\(^{20}\) See footnote 8.
\(^{21}\) See footnote 10.
\(^{23}\) See footnote 10.
\(^{24}\) See footnote 8.
Costs
- Capital costs of new LPG vehicles are higher than diesel counterparts in the Hong Kong market.
- Government is offering a $40,000 grant to replace diesel taxis by an LPG one before or during 2001. Same grant offered during 2002/2003 for diesel taxis newer than six years old.
- Operational costs of LPG taxis are lower than diesel. Government has capped the LPG cost at dedicated filling stations by a pricing formula.\(^{25}\) However, operators are concerned these subsidies are temporary.
- LPG taxis have lower or comparable maintenance requirements and costs to diesel taxis.

Infrastructure costs and requirements
- Hong Kong is developing an LPG filling station infrastructure but stringent safety requirements limit the possible sites available, especially on Hong Kong Island. At the end of 2000, there were 5 dedicated LPG filling stations, 4 temporary filling stations, and 3 petrol cum LPG filling stations, which can support about 8000 taxis.
- 40 stations (300 LPG nozzles) planned by end of 2001 to provide for entire taxi fleet. By end 2002, capacity could support 24,000 LPG vehicles including the light bus fleet of some 6000 vehicles.\(^{26}\)
- If LPG vehicle fleet expanded further (e.g. light goods vehicles), more (new) LPG filling stations and bulk storage capacity would be needed.

Safety
- More volatile, readily ignited and burns more intensely than diesel. In the event of spillage, tends to sink to the ground with danger of gas build up, leading to explosions.
- A major fuel leak from an LPG vehicle is much less likely than from a diesel vehicle, due to the greater structural integrity of the LPG tank and safety equipment.\(^{27}\)
- The very few accidents involving the fuel systems of gas vehicles which have occurred elsewhere in the world in the last 10 years, all involved converted LPG vehicles which are not allowed in Hong Kong.
- Accidents involving LPG taxis in Hong Kong have not caused damage to the fuel system.
- Vehicles with LPG tanks of over 65kg are currently not allowed to be driven through tunnels. In theory a detonation of a flammable vapour cloud, released from an LPG container in a tunnel is possible. Interim results of a consultancy study indicates it would be acceptable for vehicles with LPG tanks of 100kg (such as light buses) to be safely driven in tunnels.\(^{28}\)

\(^{25}\) The land premium on dedicated LPG filling stations has also been waived to keep LPG prices artificially low. Until 31/1/02 the price at dedicated stations ranges from $2.01-2.04/L compared to $3.88/L at converted LPG stations.
\(^{28}\) EMSD, Pers Comm
Performance
• Low propane content (and hence octane number) means less power, particularly for larger vehicles such as public light buses or trucks.
• With a premium grade of LPG (95% propane) even big buses can run on LPG.
• Performance of LPG taxis found to be comparable to diesel taxis.\textsuperscript{29}

Status worldwide and in Hong Kong
• Over 4 million LPG vehicles currently operate in over 30 countries, including Italy, Mexico, the Netherlands, USA, Japan, Australia and South Korea.\textsuperscript{30, 31} LPG with high propane content is also used for coaches, buses, garbage trucks and tow-trucks.
• Guangzhou retrofitted over 3,000 buses and taxis to use both petrol and LPG. Shanghai has also converted 25,000 of its 42,000 taxis to LPG.
• From 2001 onwards all new taxis in Hong Kong are required to use LPG. All Hong Kong taxis (about 18,000) will run on LPG by 2006. As of February 2001, 6,000 taxis were using LPG.
• Hong Kong has completed a trial of 11 LPG and 4 electric buses public light buses. The technical results are expected to be released by EPD this summer, however no policy decision on the way forward has yet been taken.
• Government will study whether LPG supply can service some 70,000 light goods vehicles.\textsuperscript{32}

Availability in Hong Kong
• Dedicated LPG taxis are currently available from Toyota, Nissan and Ford.\textsuperscript{33}
• LPG is currently imported from the Middle East or Singapore. Five LPG terminals at Tsing Yi, with a combined storage capacity of 15,000 tonnes (a 20-30 day supply but reduced to 10 days if all taxis and PLBs eventually are LPG which is insufficient on security grounds).\textsuperscript{34} The new LPG filling station operators propose to import LPG directly from China.
• Expanding supply further would require increased storage and barge landing capacity, and the necessary planning, environmental and risk studies.

Applicability to HK
• Hong Kong’s extensive investment in LPG infrastructure for taxis argues for extending the use to PLBs and, perhaps light goods vehicles, depending on the adequacy of LPG supply.
• Passenger vehicles also suitable, but loss in fuel duty revenue, and lack of LPG capacity may also limit this application. Since LPG offers few emission benefits over petrol vehicles, more sense to convert diesel vehicles.

D. ETHANOL

\textsuperscript{29} See footnote 22.
\textsuperscript{30} In 1997 2 million were in Europe, .7 million in Asia, .5 million in Australasia, .4 million in north america and .3 million elsewhere. \url{www.worldlpg.com/auto/index.htm}
\textsuperscript{31} See footnote 27.
\textsuperscript{32} EMSD, Pers. Comm.
\textsuperscript{33} Ford’s 6-cylinder dedicated LPG Falcon Wagon taxi received type approval in Hong Kong. Ford has been producing dual fuel LPG Falcons in Australia for many years.
\textsuperscript{34} EMSD, Pers Comm.
Vehicle Emissions

- Compared to conventional petroleum, ethanol generally reduces toxic vehicular emissions associated with hydrocarbon emissions. However, use of ethanol blends can be detrimental in terms of ozone formation, due to the increase in total reactivity of VOC emissions.\(^{35}\)
- Compared to petrol, pure ethanol reduces CO by 30%, VOCs by 12%, and aromatics like benzene and toluene by 30%. Studies on NOx show either small (about 3%) increase or decrease. The amount of the reduction falls if less ethanol is used in the fuel.\(^{36}\)
- Ethanol-diesel blends lower CO by 15%, particulates by 13 % and smoke by 22% compared to diesel (0.05% sulphur). NOx emissions increase slightly by 0.75 %.\(^{37}\)

Energy efficiency and Greenhouse Gas emissions

- Compared to petrol vehicles, pure ethanol-powered vehicles emit about 30 to 50 % less GHGs. Compared to passenger petrol vehicle, 85% ethanol blends can reduce lifecycle GHG emissions by 22% for ethanol from corn or 54% for ethanol from cellulose.\(^{38}\)
- Alcohol fuels can achieve a high thermal efficiency when used in engines optimised to take account of higher octane number.

Performance

- Loss of power and fuel economy compared to diesel due to lower energy content.
- Pure ethanol vehicles compare well to petrol vehicles in terms of acceleration, payload, idling and cruise speed. Can be used directly in petrol cars with minor changes to carburetor. Lubricates better than petrol and raises cetane level.
- More difficult to start and stalls more—especially in colder climates
- Requires more frequent refuelling since one-fifth less energy than same volume of petrol.
- Can corrode some metals, gaskets and seals, requiring special (more costly) components.
- Water-soluble: susceptible to phase separation if water intrudes.

Costs

- Ethanol blends of 10-15% can be used directly in petrol engine—at nominal cost.
- Ethanol blends of 85 % or more require special engines, tanks and components at extra cost.
- Ethanol costs in US$1.65/gallon (HK$3.4/L). Additional costs of 10-15% diesel-ethanol blends estimated to be HK$0.07-0.1/L.
- Ethanol is typically shipped by rail or truck rather than common carrier pipelines which although cheaper, typically contain moisture. Ethanol degrades in the presence of water. Shipping by road or rail is also more difficult logistically.


\(^{37}\) Kenreck C, BetzDearbon. Presentation to EPD 17/10/00.

\(^{38}\) See footnote 8.
Safety
• Safer than petroleum. Biodegradable (water soluble) if leaks from storage tanks.

Status worldwide and in Hong Kong
• Brazil is largest producer and user: about 200,000 barrels per day for 5 million vehicles. The government guarantees producers’ minimum prices. 25,000 ethanol refueling stations.
• Sweden has 400 operating Scania ethanol buses. Mexico City will replace its 12,000 buses with Scania’s ethanol ones.
• Ethanol blends comprise 12% of fuel used in United States (about 125 billion gallons/year). Ethanol demand will increase by 2.3 billion gallons with phasing out of MTBE due to concern about its contamination of aquifers.

Infrastructure Requirements
• Adaptation of existing refueling and distribution systems required for blends with high percentage of ethanol.

Availability in and Applicability to Hong Kong
• No ethanol fuel producers or importers currently in Hong Kong. 40% of fuel consumed in Hong Kong (excluding buses) is petrol—good market for ethanol blends.
• China recently announced plans to increase ethanol production dramatically (estimates are as high as 50 million tons/year if excess vegetable matter used) to decrease pollution, satisfy demand for petroleum and increase energy security.\(^{39}\)
• Several companies interested in producing ethanol in China and/or distributing ethanol and ethanol blends in Hong Kong: BioEnergy Technologies and Gaia Fuel. Estimated capital investment for a plant in China: US$100 million.
• Fully appropriate for petrol vehicles—especially private cars. Trials on diesel/ethanol blends needed to assess performance and emission reduction.

E. BIODIESEL

Vehicle emissions
• Contains approximately 11% oxygen by mass so produces less carbon monoxide and unburned hydrocarbons. Pure biodiesel most effective, but even biodiesel blends reduce most tailpipe emissions and proportionately to the amount of biodiesel used.

<table>
<thead>
<tr>
<th>Emission type</th>
<th>20% Biodiesel</th>
<th>100% Biodiesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulate matter</td>
<td>Less 5 to less 15%</td>
<td>Plus 27 to less 68%</td>
</tr>
<tr>
<td>Total Hydrocarbons</td>
<td>Less 15% to less 20%</td>
<td>Less 37 to less 63%</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>Plus 1% to plus 5%</td>
<td>Less 8 to plus 8%</td>
</tr>
</tbody>
</table>

\(^{39}\) 6/3/01 at National People’s Congress
\(^{40}\) Compilation of different studies. See footnote 8. See also US Department of Energy, Alternative Fuels Data Center website (afdc3.nrel.gov/afv/biodiesel).
• Considerable divergence in literature as to amount of increase of nitrogen oxide emissions; appears to depend upon the testing methods. Adding a fuel additive or changing engine timing can curtail the NOx.

• The University of Hong Kong, on behalf of the Government, is currently running emission trials on 10 different vehicle types using varying proportions of biodiesel (20% and 100%), and ULSD as a baseline. Results should be available in mid 2001.

Energy efficiency and Greenhouse Gas emissions
• Producing biodiesel from vegetable crops reduces upstream greenhouse gases (GHGs) since CO2 is consumed in plant production. Overall lifecycle emissions of GHGs with biodiesel are lower than petroleum-diesel. Producing biodiesel from animal wastes or recycled vegetable oil also consumes CO2 indirectly.
• Pure biodiesel and 20% biodiesel blends are estimated reduce lifecycle GHG emissions by 78% and 16% respectively compared to diesel (0.05%) sulphur.47

Costs
• Hong Kong promoters estimate the pump price for biodiesel will be about $5-6/L (without duty) compared to $5.94/L (pump price with duty) for ULSD.
• If duty was imposed on biodiesel the price would be higher and uncompetitive with USLD.
• Can be used directly in standard diesel engines without any retrofitting.

Infrastructure Costs and Requirements:
• Could be stored and distributed through the existing diesel system if the oil companies agreed.
• If existing system cannot be used, new refueling stations required adding to overall costs.
• If biodiesel’s classification as a flammable good could be changed (if deemed sufficiently safe) then garages could sell biodiesel like a fuel additive, such as motor oil.

Vehicle performance
• Better engine lubricant than petroleum diesel. Can be used directly in most conventional modern diesel engines.
• Slightly lower power, though depends on source of biodiesel.
• Can corrode natural rubber parts in older vehicles.

Safety
• Flash point of about 110 degrees C; about twice that of diesel so safer to handle and store.
• Classified as flammable good under the Dangerous Goods Ordinance.
• Contains no aromatics so less toxic than petroleum diesel. Completely biodegradable.

Status Worldwide and in Hong Kong
• Used in Brazil, Germany, Austria, the United States and France, and its production and use are increasing. The American Biofuels Association estimates that if

41 US Department of Energy, Alternative Fuels Data website NREL/TP-580-24772
biodiesel received subsidies comparable to the ones for ethanol, biodiesel would account for 8% of the United States diesel market.

- The University of Hong Kong is conducting a trial on 12 different vehicle types using biodiesel (20% and 100%) and ULSD as a baseline. Pending on the trial result EPD may consider adopting an international specification for biodiesel, which would most likely be based on the EU standard.

**Availability in Hong Kong**
- Several companies in Hong Kong are poised to market biodiesel here, if and when, the Government sets standards. Sunland Company imports rapeseed-based biodiesel from a German company, Oberland Mangold. Three others, Hednesford, Bioclear International and Dunwell International plan to use waste vegetable oil as their feedstock. Hong Kong restaurant owners currently spend $220 million to legally dispose waste oil at landfill. In 1998, registered dealers legally disposed of approximately 40,000 tonnes of waste oil to the WENT landfill.

**Applicability**
- As a blend with ULSD, biodiesel could help to improve emissions from in-use diesel vehicles further, especially pre-Euro vehicles. Also suitable for cross-border vehicles.

**F. BATTERY ELECTRIC VEHICLES**

**Vehicle emissions**
- Emit no tail-pipe pollution but life-cycle emissions depend on method of power generation at the power station.
- Compared with a Euro II diesel single decker bus, life cycle emissions of CO₂, CO, NOx and THCs are significantly reduced for a 12m electric bus in the UK.⁴²

**Energy efficiency and Greenhouse Gas emissions**
- Considering only the vehicle itself BEVs are far more energy efficient than internal combustion engines (ICE). A BEV operates at roughly 46% efficiency, whereas an ICE achieve only 18% efficiency.⁴³
- Electric drive can recover up to 15% of potential and kinetic energy via regenerative electrical braking and in addition, BEVs use almost no energy when stationary.
- Overall, BEVs have a lower global warming potential than conventional diesel and petrol vehicles.
- One Canadian study showed lifecycle GHG emissions of EV passenger cars to be significantly better than diesel⁴⁴ although in Hong Kong emissions are likely to be higher due to the higher proportion of fossil-fuelled power generation.

**Performance**
- Higher initial torque and acceleration than internal combustion engines.

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⁴² See footnote 10.
⁴⁴ See footnote 8.
• Most modern EVs can have top speed of 90-120 kph and range of 90-150 km per complete charge. EVS produced for urban use have a lower specification and performance.
• Drivers need to adjust driving style for maximum efficiency (i.e. use brakes rather than gears for slowing down to capture regenerative braking energy).

Costs
• Capital costs of BEVs are approximately 50-100% more than their conventional counterparts.\(^{45}\)
• In Hong Kong BEVs are already exempted from First Registration Tax and enjoy nominal annual vehicle licence renewal fees.
• However, operating costs are estimated to be half the costs of diesel due to lower price of electricity and high efficiency of the vehicles. When lower operating costs are taken into account, BEVS can achieve comparable or lower lifetime (5-7 years) costs compared to diesel.

Infrastructure costs and requirements
• Electricity from any source can be used to recharge a BEV. For slow charging, grid electricity is used which is supplied at 220V a.c. For faster charging rates a higher voltage (11 kV or a 3-phase 380V standard industrial supply) is required.
• Recharging stations are required for BEVs but relatively easy to install recharge points which can run off standard 220-volt wall sockets. The average battery pack can be recharged in 5-8 hours on 220 volts when fully empty.
• Fast charging only cost effective when multiple points are being considered for a site, eg at a fleet depot. These are able to recharge batteries to 80% in about 15 minutes. Need for thermal management critical.
• Alternatively, batteries can be recharged off the vehicle, and the whole battery pack swapped when flat.

Safety
• No flammable fuels therefore safer than conventional petrol and diesel vehicles.
• Utilise high voltages – wires and charging stations must be properly insulated.
• Safety of handling cadmium and lead would need to be addressed.

Status worldwide and in Hong Kong
• Currently more than 28,000 BEVs in Europe, which includes around 16,000 milk delivery vehicles in the UK, passenger cars, micro cars and other commercial vehicles.\(^{46}\) US Postal Office has the world’s largest fleet of 6000 BEVs.
• Most of the major motor manufacturers have developed BEVs, the more active include PSA Peugeot-Citroen, Toyota, Nissan, Ford and General Motors.
• Trials were held in Hong Kong in late 2000/early 2001 of electric minbuses on 4 routes. The technical results of the trial will be released by EPD this summer. However the Government has yet to make any policy decision on the way forward.
• Companies supplying electric vehicles in Hong Kong include Vicmax and AEL.
• The Vicmax buses uses recyclable Ni-Cd batteries which are recycled in France. Batteries are recharged to 80% of capacity in less than 15 minutes or full capacity in 3 hours.

\(^{45}\) See footnote 10.
\(^{46}\) See footnote 10.
• AEL’s electric bus is used as Cathay staff shuttle at airport. This also uses a Ni-Cd battery and can travel 190km with 1 full charge plus 2 shorter charges.
• Hong Kong Electric has 6 BEV sedans and one 16 seater minibus. The latter is supplied by US firm Solectria with a Goldpeak NiMH battery. Sedans recharge overnight from standard voltage. The minibus requires 10 hours recharging at a higher voltage.

Applicability to HK
• Best suited to predictable, regular routes of less than 160km per day, where significant stop-start driving in highly polluted areas. This would include: hotel and residential shuttles, school minibuses, corporate and government fleet vans, blood donation vans, mobile libraries, postal vehicles, and green minibuses.

G. TROLLEY BUSES

Vehicle emissions
• As for Battery Electric Vehicles, pollution-free at street level (and quieter than diesel buses).
• Pollution generated at the power plant, but due to the greater efficiency of electric traction, emissions per passenger mile will be lower than a conventional diesel bus.

Energy efficiency and Greenhouse Gas emissions
• Highly energy efficient with 90% of energy utilised compared with 35% for a diesel engine.

Performance
• Good hill-climbing abilities due to better torque than diesel buses.
• With careful design the wiring system can allow for overtaking and bus-stop ‘leapfrogging’.
• Lack of route flexibility

Costs
• Capital costs of a trolleybus vehicle ($3.7 million) are 150% that of a diesel bus ($2.3 million) but are offset by the longer lifetime of a trolley bus (25-30 years compared to 15 years for a diesel bus).\(^{47}\)
• Recurrent maintenance costs of vehicle low but overall maintenance costs would be higher.\(^{48}\)
• Operational costs slightly higher than diesel buses assuming current oil prices don’t rise and government doesn’t continue to rebate diesel duty to franchised bus companies.

Infrastructure costs and requirements
• Requires significant investment in overhead wires held up by metal poles or attached directly to building facades. The high current requires a relatively large cross

\(^{48}\) ibid
sectional area of wiring.\textsuperscript{49} Total capital costs of a trolleybus system has been estimated to be some 80\%-210\% higher than that of a comparable diesel bus.\textsuperscript{50}

- Substations required to stepdown voltage. Can be compact (2m high, 2.5m wide and 4.6m long) and situated in car parks, under flyovers and on roof tops. Subстанtion transforms 11kV ac supply to 600V direct current (dc).\textsuperscript{51}

Safety
- Overhead wires may impede fire fighting in narrow streets.
- Auxiliary traction batteries, or small internal combustion engine and generator could allow bus to go “offline” in emergency situations.

Availability
- Single-decker, 2 or 3 axle rigid chassis or 3-axle articulated versions available.\textsuperscript{52}
- No double deck trolleybuses are produced worldwide at present but it is possible to produce using an existing bus chassis. Hong Kong would need a 3-axle double decker trolleybus, with air conditioning and low floor.\textsuperscript{53}

Status worldwide and Hong Kong
- In operation in over 340 cities in Asia, America and Europe, including 26 cities in China
- In June 2001, Citybus launched a 6 month trial at Wong Chuk Hang on a converted short double-deck Dennis Dragon bus to check reliability, durability, performance and costs.
- The Transport Department study on trolley buses was published in June 2001.\textsuperscript{54} The Government intends to explore the merits of introducing a pilot scheme in a new development area, such as South East Kowloon Development.

Applicability to HK
- Relatively short and busy routes most promising. Good for hilly routes and polluted urban areas in both Hong Kong Island and Kowloon.
- Urban route 98 (Lei Tung Estate to Aberdeen) has been suggested as an ideal trial route, which would require 6 short double deck trolley-buses.\textsuperscript{55}

H. HYBRID VEHICLES

Vehicle Emissions
- Series design hybrids have potentially lower overall emissions than parallel hybrid systems. The latter have improved fuel economy which also reduces toxic and ozone forming pollutants.\textsuperscript{56}

\textsuperscript{49} Transport Department (1999).  A Case Study – Trolley Buses in Hong Kong.  Unpublished internal study.
\textsuperscript{50} Transport Bureau (2001).  Feasibility Study on Introducing Trolleybus System in Hong Kong.  Paper to Legislative Council Panel on Transport. 22 June 2001.  CB(1) 1575/00-01(03)
\textsuperscript{51} ibid
\textsuperscript{52} ibid
\textsuperscript{53} J Blay, Citybus, Pers. Comm.
\textsuperscript{54} See footnote 50.
\textsuperscript{55} See footnote 49.
\textsuperscript{56} See footnote 10.
- Honda’s Insight is an ultra low emission vehicle while the Toyota Prius is a Super Ultra Low one under California’s air quality rules.

**Table A3: Emission reductions for hybrid passenger vehicles compared to petrol (US RFG) (% of change)(all sampling locations)**

<table>
<thead>
<tr>
<th>VOCs</th>
<th>CO</th>
<th>NOx</th>
<th>Particulates(PM10)</th>
<th>SOx</th>
<th>CO₂</th>
<th>GHGs</th>
</tr>
</thead>
<tbody>
<tr>
<td>41%</td>
<td>59%</td>
<td>7%</td>
<td>4%</td>
<td>78%</td>
<td>27%</td>
<td>25%</td>
</tr>
</tbody>
</table>

- Emission reductions for hybrid buses compared to diesel are even more dramatic. Hino Motors’ hybrid HIMR bus reduces NOx by 34%, particulates by 55%, black smoke by 56%. In tests, the Orion diesel hybrid reduces particulates by 50% and NOx by 33%.

- In Japan, hybrid bus for 56 passengers, reduced fuel use by 10-15%, particulates and black smoke by 55% and NOx by 34%.

**Energy efficiency and Greenhouse Gas (GHG) Emissions**

- Hybrid vehicles are highly fuel efficient. Passenger vehicles can achieve 60 miles/gallon.

- Compared to conventional petrol vehicles, a petrol HEV can reduce GHG emissions by 35%. Compared to ULSD, a diesel hybrid passenger vehicle can reduce GHGs by 28%.

- A single decker bus diesel hybrid emits 40% less GHGs on a life cycle basis compared to a conventional ULSD bus. Diesel fuel hybrid most cost effective option for reducing GHGs.

**Vehicle Performance**

- Acceleration power: zero to 60 miles per hour in 11 seconds
- Quieter. More efficient power steering and air conditioning.

**Cost**

- More expensive than equivalent ICE. The Toyota Prius costs as much as US$41,000 initially to produce but is being sold for US$19995 in the US.

- Estimated increase in lifetime costs (without subsidies) of 22-37% for passenger car. Once HEV production is widespread, economies of scale could reduce costs.

- Cheaper operating costs due to about 30% better fuel economy. Over 10 years driving 15,000 miles year and paying US$1.20/gallon for petrol: net savings US$2500. Hong Kong’s higher fuel prices would increase net savings.

- Redbus’s diesel HEVs in Christchurch New Zealand will cost half that of ICE diesel buses after amortizing 14 years of running costs.

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60 See footnote 8.
61 See footnote 8.
Infrastructure Requirements and Costs

- No new fueling infrastructure required.

Status worldwide and in Hong Kong

- HEV cars, trucks and buses available with various fuels and fuel cells. Gasoline and diesel hybrids first to reach market.
- Toyota Prius has been sold in Japan since 1997, and now is sold in Europe and US. Honda's Insight has same market. Other manufacturers, including Ford, GM, Renault, Audi, Daimler Chrysler, all introducing HEVs in near future.
- FirstBus, UK, converted a 20 seat diesel Mercedes-Benz bus into an HEV capable of operating as an electric bus 25% of the time.
- Orion Bus and Novabus Inc. are testing HEV diesel buses. Hino Motors is using diesel HEV bus in Japan for mountain roads. Hybrid buses also being used in Aalborg, Denmark and Genoa, Italy in urban centers.
- 50 HEV diesel buses are operating in Tennessee and Arizona by Advanced Vehicle Systems. Also 26 HEV buses operating in Denver, Colorado. New York Transit Authority has just ordered 250 HEV buses.
- ISE Research Corporation will offer HEV heavy-duty vehicles, such as delivery and refuse trucks, which reduce fuel use by 25-50% and all emissions by 50-95%.
- A single Toyota Prius (1496 cc petrol hybrid) was registered in Hong Kong by an individual in late 1999.

Safety

- HEVs pose the same safety risks as the equivalent fuel ICEs.

Availability and Applicability to Hong Kong

- No double-decker hybrid bus models available.
- Parallel hybrids better suited to urban/suburban routes where can switch to cleaner electric mode in city. Series hybrid better suited to urban driving conditions typical of Hong Kong.
- Best suited for passenger vehicles, light buses and light goods vehicles.

I. NATURAL GAS (NG)

Vehicle emissions

- Clean-burning fuel being the simplest hydrocarbon. The high octane number (130) allows a higher compression ratio which improves thermal efficiency.
- Requires no vaporisation, hence has lower idling speeds, better performance and a more complete combustion, which all help to reduce emissions.
- Some NG vehicles sold by Original Equipment Manufacturers (OEMs) already classed as Ultra Low Emission or Super Low Emission.

Energy efficiency and Greenhouse gas emissions

- Less fuel efficient in converted engines due to less efficient engines and additional weight of the CNG fuel tank. Should be no loss in fuel efficiency in engines designed for NG.
- Methane itself is a potent greenhouse gas (GHG). Studies show mixed results for NGVs contribution to GHGs compared to petrol. One UK study found reduced
lifecycle GHG emissions compared to petrol in passenger vehicles, but comparable or slightly higher GHGs compared to diesel light and heavy duty vehicles.\textsuperscript{63}

- A Canadian study found lifecycle GHG emissions slightly better than ULSD counterparts for CNG passenger vehicles, LNG heavy duty trucks and CNG buses.\textsuperscript{64}

**Costs**

- Capital costs of NGV typically 15-20% more than conventional diesel counterpart.
- No retail market for NG in Hong Kong. Fuel costs without duty estimated to be significantly lower than diesel, making operation of NGVs cost effective in many applications.
- Maintenance costs vary. Increased fuel system inspection, tune up costs and more expensive parts can increase costs. Since NG a cleaner fuel, engine wear is less than diesel.

**Infrastructure costs and requirements**

- Currently no infrastructure for storage and distribution of NG in Hong Kong.
- NG compressors are large and need to be noise insulated.
- Depot refuelling is best for large fleets. China Light & Power (CLP) may develop a small LNG facility to convert some of their piped NG to LNG and transport it to electric sub-stations or fleet depots to supply CNG or LNG vehicles.\textsuperscript{65}
- Once a piped NG distribution system is in place, NGV refuelling could take place from converted petrol stations without underground tanks as is required for LPG, petrol and diesel. Additional costs involved to compress the NG and maintain compressor stations.
- Gas storage facilities would be required for fast-fill refuelling stations, which allow approximately 4 minutes for a 30kg fill.

**Safety**

- NG is non-toxic and lighter than air which means, if spilled, it will disperse quickly if adequate ventilation.
- Narrow flammability limits compared with conventional fuels, which reduces the risk of a flammable mixture occurring.\textsuperscript{66}
- Air tight, very strong containers reduce risk of rupture.

**Performance**

- Converted engines less efficient than diesel counterparts, particularly at part load due to reduction in compression ratio and throttling losses.\textsuperscript{67} For purpose-built engines minimal loss of efficiency and in some cases equivalent torque of diesel engine.
- In some cases, CNG bus engines and fuel systems found to be less reliable than components in diesel buses, though these tend to be converted engines.\textsuperscript{68}

\textsuperscript{63} See footnote 10.
\textsuperscript{64} See footnote 8.
\textsuperscript{65} For CNG vehicles, the LNG is vaporised into NG before being admitted into the engine.
\textsuperscript{66} See footnote 8.
\textsuperscript{67} National Renewable Energy Laboratory Report. NREL/DR-540-27503 [www.nrel.org](http://www.nrel.org)
Status worldwide and in Hong Kong

- Over 1.2 million NG vehicles (NGVs) in use worldwide in over 40 countries including Argentina, Russia, Italy, Canada and the US. In the region Malaysia, Australia and parts of China have active NGV programmes. The majority are conversions.
- All major car, truck and bus manufacturers have built dedicated prototype NGVs and many NGVs are directly available from the OEMs, though still in small numbers.
- In Hong Kong CLP Power are looking into the use of NGVs.
- Towngas now running a one year trial of a CNG light goods van (currently using bottled methane gas). Slow filling (8 hours) used.

Availability

- Globally distributed and substantially higher known reserves than petroleum fuels.
- NG in Hong Kong currently piped from Hainan and used at CLP’s Black Point gas-fired power station. CLP propose to use some of this gas for a small number of their fleet vehicles. Under the Scheme of Control Agreement with the Government the use of the gas is currently restricted to power generation.
- Hong Kong also produces significant quantities of landfill gas (a mixture of methane and carbon dioxide) from its 3 strategic landfills WENT, SENT and NENT (530,000 m$^3$ per day currently, 1.5 million m$^3$ per day at peak in years 2011-2019)$^{70}$ and 13 old landfill sites. Only some of the gas being used for on-site energy needs, nearly half is flared. The gas will need processing and cleaning before use in vehicles. Landfill gas utilisation schemes must obtain permission from EPD. Landfill gas is also a source of synthetic diesel (see Diesel section).
- A liquified natural gas (LNG) plant in Shenzhen, China, planned for 2005 will supply Hong Kong Electric (HKE) new gas-fired power plant on Lamma Island. Towngas will likely be another user for this gas.
- The extensive distribution network for Towngas$^{71}$ could be used for NG in a common carrier system in future.$^{72}$

Applicability to HK

- Most appropriate for heavy-duty vehicles including fleet operators, non franchised buses and delivery vehicles with own depot for overnight fuelling. Also suitable for franchised buses if filling speeds sufficiently fast.
- If landfill gas is utilised, refuse transfer/collection vehicles could be converted to CNG or LNG. If a filling station near the border is established, LNG vehicles could be used for cross-border traffic, depending on range.$^{73}$ It is estimated 95% of cross border traffic operates within range of CNG/LNG fuelled vehicles.

$^{69}$ Sam Shum, Towngas, Pers. Comm.  
$^{70}$ Lawrence Lau, EPD, Pers Comm.  
$^{71}$ 49% hydrogen, 28.5% methane, 19.5% carbon dioxide and 3% carbon monoxide. www.hkgc.com  
$^{73}$ Charles Wong, CLP, Pers. Comm.
J. FUEL CELL VEHICLES

Vehicle Emissions

- A hydrogen-powered FCV emits zero tailpipe emissions. Methanol or petrol FCVs emit traces of emissions from the reformer but far less than a similar petrol-fuelled ICE.
- Greater efficiency of FCV’s drive train and engine partly accounts for improved emissions.

Energy efficiency and Greenhouse Gas emissions

- No GHGs from hydrogen FCV during operation. Lifecycle emissions depend on method of hydrogen generation.
- Methanol from biomass consumes and produces GHGs. Natural gas (NG) produced methanol produces more GHGs than biomass-produced methanol.
- Petrol FCV GHG tailpipe emissions are half of ICE vehicles but higher than other FCVs.
- Compared to a conventional petrol passenger vehicle, fuel cell vehicles can reduce lifecycle GHG emissions by 39% (methanol), 53% (hydrogen from NG) or 85% (hydrogen from renewable power sources). However this is considered by one study to be the least cost effective way to reduce GHGs from vehicles.\(^{74}\)
- Compared to a single decker bus running on ULSD, fuel cell buses can reduce lifecycle GHG emissions by 24% (methanol), 40% (hydrogen from electrolysis) or 44% (hydrogen from NG).\(^{75}\)

Costs

- Conventional petroleum engine now costs US$2,000-3,000 (HK$16,000-23,000), a comparable prototype fuel cell stack costs about US$35,000 (HK$273,000).\(^{76}\)
- Fuel cell and car manufacturers both expect 10 fold drop in fuel stack prices over next decade with economies of scale. Economies of scale will also lower operating and maintenance costs to levels comparable with CNG within 20 years. Once FCVs are available, maintenance costs should be low due to simpler engine design and fewer parts.
- Fuel economy will be higher, so operating costs will be lower, irrespective of the fuel.
- Methanol in US cheaper than petrol but 47% higher costs per unit of energy.

Infrastructure Requirements and Costs

*Hydrogen*

- Cost of producing and distributing hydrogen in United States by 2030: US$230-400 billion and US$175 billion respectively (if FCVs get 80 miles/ gallon of hydrogen) Per vehicle investment in hydrogen infrastructure: US$3500-5000, but higher if FCV fuel efficiency is lower.\(^{77}\) This assumes a hydrogen pumping network.
- Cheaper alternative: ship hydrogen-rich fuels (eg natural gas) in existing gas pipelines to end-users, with small-scale reformers to convert to hydrogen on-site.

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\(^{74}\) See footnote 8.

\(^{75}\) ibid


\(^{77}\) Stork K et al. Assessment of Capital Requirements for Alternative Fuels Infrastructures. Argonne National Laboratory Report No. ANL/ESD/TM-140. *Source for all infrastructure costs on this page*. 
• Stuart Energy Systems of Toronto, Ontario (partly owned by Cheung Kong Infrastructure) developing mini-hydrogen stations to deliver compressed, purified hydrogen from cheap hydropower into vehicles or for storage. Stuart’s estimated cost: about US$2.50-3.00/kg\(^{78}\)--similar to petrol.

• Interim solution before widespread conversion to hydrogen: Storage and distribution of compressed hydrogen in cylinders, like CNG is today.\(^{79}\) Directed Technologies estimates that compressed hydrogen, if untaxed, could meet price of taxed petrol (assuming vehicles operating with 24.5 miles/gallon) if the FCVs’ efficiency was 80 miles/gallon.

• Shell Hydrogen, Hydro-Quebec and GfE have established a joint venture for developing, manufacturing and marketing hydrogen storage projects such as metal hydrides. [www.shell.com](http://www.shell.com)

• A hydrogen refuelling station has been built in Palm Desert, California, to provide hydrogen to power advanced fuel cell buses and conventional buses powered by mixtures of natural gas and hydrogen. The system generates hydrogen on site from natural gas, with a hydrogen compression and dispensing system.

**Methanol**

• Methanol: worldwide production only about 26 million tons/year—less than 6% of petrol used in United States/year. Methanex, the largest world producer, plans to construct large plants, each sufficient to fuel 500,000 FCVs, for about US$700/vehicle.

• Petrol infrastructure could be retrofitted for methanol if oil companies willing. Cost for developing a delivery system in United States estimated US$350 million - 9 billion, or US$70-100/vehicle. Cost of full infrastructure in United States: about US$84 billion.

**Gasoline**

• Well-established world-wide infrastructure for distribution. Would need a separate pump for fuel cell grade petrol. Introduction of unleaded petrol serves as an example.

• Development of fuel-cell grade petrol involves additional cost and investment at refineries.

**Safety**

• FCV safety depends upon the fuel used and how it is distributed and stored.

• *Hydrogen* more flammable, burns hotter and faster than petrol but without toxic fumes. If released, disperses much faster, reducing risk of fire.\(^{80}\)

• *Methanol* is toxic and highly odorous. Spills into water supply render the water unpalatable. Biodegradable. Harder to ignite than petrol and burns slower and cooler. Not carcinogenic.

• *Natural gas and petrol* – see separate sections.

**Performance**

• FCVs are largely experimental—performance testing is generally premature except for the Ballard Systems trial bus run in Vancouver and Chicago. Three FCV buses

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80 During the 1937 Hindenberg explosion (caused by atmospheric electricity igniting flammable substances coating the airship’ s envelope), the hydrogen fuel ignited but did not explode. Hydrogen’ s unique burning properties meant that the fire remained in the fuel compartment, without spreading far, limiting injuries.
used in each city for 2 years, for 118,000 km, 10,599 hours on road and with 205,000 riders.

- FCV buses were quieter, weighed more and carried 3/7 fewer passengers. FCV buses accelerated equally to diesel buses from 0-20 mph, but slower from 30 and 40 mph.
- Due to system or coach break-downs, upgrade work and unexpected maintenance, in the shop almost half the trial period.

Status Worldwide and in Hong Kong

- FCVs are not commercially available anywhere. Major auto manufacturers are heavily investing in fuel cell vehicles (FCVs) development.
- 9 largest automobile manufacturers all have prototypes, usually with PEMFCs and methanol. Daimler Chrysler plans wide scale commercial sale of FCVs by 2004. GM hopes to have petrol FCV on sale by end of decade.
- Daimler Chrysler plans to begin a 2 year field demonstration of a medium duty fuel cell van in Germany, with a parcel delivery company.  
- 30 transit single-decker buses fuelled by compressed hydrogen will go on trial in 9 European cities in 2002 and 2003.
- In London in 2002, 35 traditional taxis converted to a fuel cell system will be operated as part of a pilot project to demonstrate viability, performance, safety and public reaction. 
- By 2020, FCVs will comprise between 7 to 20 percent of vehicles worldwide, or some 40 million FCVs.

Applicability

- Long term solution for entire fleet. Transit buses and passenger vehicles likely to be first commercially available vehicles.

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81 www.media.daimlerchrysler.com
82 www.its.ucdavis.edu
APPENDIX 2: SUMMARY OF POLLUTION REDUCTION PERFORMANCE

There are numerous studies documenting emissions performance for different technologies. However, these studies often record a wide variation in results even for the same technology. This variation may be due to an artefact of the testing procedure, such as the type of vehicle tested or the test cycle used.\(^1\)

To minimize such variations, studies have been chosen which have tested a range of technologies under approximately the same test conditions. While the absolute figures may be different from that likely to be experienced in Hong Kong, the relative performance of different technologies may be ascertained.

This report has focussed on 3 main pollutants: RSP, NOx and Volatile Organic Compounds (VOCs). RSP and NOx are health-threatening pollutants are regularly present at elevated levels in Hong Kong. VOCs can be toxic upon direct exposure and contribute heavily to ozone pollution, which is a growing problem in the region.

Figures 1-3 provide a comparison of lifetime emissions of RSP, NOx and total hydrocarbons (includes non volatile hydrocarbons such as methane) for some of the technologies for different vehicle types.\(^2\)

- All alternative technologies show significant improvements in RSP emissions, even compared to ULSD.
- For passenger and light goods vehicles, ULSD shows significantly higher emissions of NOx compared to other technologies.
- For single decker buses CNG and LPG show improvements in NOx emissions over ULSD.
- CNG vehicles show the largest emissions of total hydrocarbons, though much of this is likely to be methane, which does not contribute to ozone formation.
- For passenger vehicles petrol is also a large source of hydrocarbons.

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\(^1\) For example, using the same vehicle and same fuel, an urban, stop-start test cycle will often produce much higher emissions than a highway, steady-driving test cycle. Similarly, testing the same fuel on vehicles of different ages (and therefore emission standards) can also yield quite different results.

Figure 2.1: Comparison of pollutant emissions for passenger vehicles
(see footnote 2)

Figure 2.2: Comparison of pollutant emissions for light vans
(see footnote 2)

Figure 2.3: Comparison of pollutant emissions for single decker buses
(see footnote 2)
APPENDIX 3: SUMMARY OF LIFE-CYCLE GREENHOUSE GAS EMISSIONS

This report has tried to cite studies that compare different technologies using similar assumptions. This will hopefully reduce variations attributable to local conditions rather than the technologies themselves. Obviously, local circumstances greatly impact GHG emissions, but it is beyond the scope of this study to examine life cycle emissions for Hong Kong. Nonetheless, the studies provide a rough comparison of different technologies on a relative basis. The absolute figures are subject to many assumptions.

Figures 3.1-3.3 provide comparisons of lifecycle GHG emissions associated with different technologies.\(^1\),\(^2\) Figures 3.1 and 3.2 shows lifecycle GHG emissions for passenger vehicles, the latter based on technologies believed to be in commercial use by 2020. Figure 3.1 shows electric, hybrid and fuel cell vehicles reduce GHG emissions significantly due to the improved fuel economy of the vehicle. Figure 3.2 shows hybrid vehicles to be the most efficient. Considerable uncertainty exists on the estimates for fuel cell vehicles and depends on the source of fuel energy. For heavy duty buses, diesel hybrid buses and hydrogen fuel cell buses show the lowest emissions of GHGs.

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1 Transportation Table of the National Climate Change Process (1999). Alternative and Future Fuels and Energy Sources for Road Vehicles.

Figure 3.2: Lifecycle GHG emissions from passenger vehicles in 2020
(see footnote 2)

Figure 3.3: Lifecycle GHG emissions for heavy duty buses
(see footnote 1)
APPENDIX 4: COSTS OF DIFFERENT TECHNOLOGIES

Tables 4.1 and 4.2 summarise the relative costs of some of the technologies for passenger vehicles and large buses. For the technologies presently in use in Hong Kong the data is quantitative and more reliable. For technologies not yet introduced into Hong Kong, such as natural gas or hybrids, many of the costs are approximate or qualitative only (indicated by shading). The data for fuel cells is even more speculative since the technology is still under development and therefore has not been included.

The tables show that the high capital costs of some of the cleaner vehicle technologies may be offset to a certain extent by the lower operating costs (fuel efficiency and maintenance). Infrastructure costs may still be an issue that requires government assistance. The costs of alternative fuels is greatly influenced by government duties.

Table 4.1: Relative costs (HK$) for cleaner passenger vehicle technologies compared to petrol

<table>
<thead>
<tr>
<th>Technology</th>
<th>Infrastructure</th>
<th>Vehicle</th>
<th>Operating$</th>
<th>Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular petrol</td>
<td>Baseline</td>
<td>Baseline</td>
<td>$12/L @ 0.1L/km = $1.2/km</td>
<td>Baseline</td>
</tr>
<tr>
<td>ULSD</td>
<td>Same</td>
<td>Slightly more</td>
<td>$6/L @ 0.07L/km = $0.4/km</td>
<td>Lower</td>
</tr>
<tr>
<td>Cleaner petrol</td>
<td>Same</td>
<td>Same</td>
<td>Additional 20-30 cents/L (50ppm S)</td>
<td>Lower</td>
</tr>
<tr>
<td>LPG</td>
<td>Significant</td>
<td>Slightly more</td>
<td>$2.01/L @ 0.1L/km = $0.2/km^3</td>
<td>Lower or comparable</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>Slightly higher</td>
<td>Slightly more</td>
<td>$5.4/L^4 @ 0.07/km = $0.4/km</td>
<td>Lower or comparable</td>
</tr>
<tr>
<td>Ethanol</td>
<td>Slightly higher</td>
<td>Same</td>
<td>$13/L^5 @ $0.1L/km = $1.3/km</td>
<td>Similar</td>
</tr>
<tr>
<td>Electric</td>
<td>Higher</td>
<td>+50-100%</td>
<td>Less 20%^6</td>
<td>Less 60%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>Significant</td>
<td>+15-25%</td>
<td>Cheaper^7</td>
<td>Comparable</td>
</tr>
<tr>
<td>Hybrid</td>
<td>Same</td>
<td>+100%^8</td>
<td>$0.56/km^9 (less 30%)</td>
<td></td>
</tr>
</tbody>
</table>

1 Fuel efficiency figures taken from Transportation Table of the National Climate Change Process (1999). Alternative and Future Fuels and Energy Sources for Road Vehicles.
2 Price differential in the UK for petrol with 50ppm sulphur
3 This is at dedicated LPG filling stations. Cost per km for LPG from converted stations would be $0.54/km
4 From virgin vegetable oil. From collected waste oil could be higher. This does not include duty.
5 Directly converted US costs. Note this includes large subsidies to ethanol producers. Canadian figures indicated HK$2-2.5/L more than petrol.
7 Honda Civic CX has city driving efficiency of 11 litres per km (gasoline equivalent)
8 Difficult to estimate. For Prius, Toyota is reportedly subsidising the costs heavily.
9 Based on Toyota Prius with efficiency of 18L per km fuel efficiency
<table>
<thead>
<tr>
<th>Technology</th>
<th>Infrastructure</th>
<th>Vehicle/capital</th>
<th>Operating</th>
<th>Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>ULSD</td>
<td>Baseline</td>
<td>Baseline, $2.3M\textsuperscript{10}</td>
<td>Baseline, &lt;$6/L\textsuperscript{11}</td>
<td>Baseline</td>
</tr>
<tr>
<td>Water diesel blend</td>
<td>Baseline</td>
<td>Baseline, Few % more per litre</td>
<td>Not known</td>
<td></td>
</tr>
<tr>
<td>CRTs</td>
<td>N/A</td>
<td>$25,000-40,000</td>
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<td>Euro 3</td>
<td>Same</td>
<td>Additional $10,000</td>
<td>Same</td>
<td>Same</td>
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<tr>
<td>Biodiesel</td>
<td>Slightly higher</td>
<td>Same</td>
<td>$5-6/L</td>
<td>Same or lower</td>
</tr>
<tr>
<td>Natural gas</td>
<td>Significant</td>
<td>+30-35% of baseline</td>
<td>Not known but likely to be cheaper</td>
<td>Same or slightly higher</td>
</tr>
<tr>
<td>Trolley Bus</td>
<td>Significant</td>
<td>$3.7M</td>
<td>Slightly higher</td>
<td>Similar</td>
</tr>
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</table>

\textsuperscript{10} Cost for new double decker Euro II bus

\textsuperscript{11} Franchised bus companies do not pay diesel duty and get bulk discounts from oil companies.
<table>
<thead>
<tr>
<th>Participant</th>
<th>Organisation</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>BACON SHONE John</td>
<td>Central Policy Unit</td>
<td>L</td>
</tr>
<tr>
<td>BARRON Bill</td>
<td>CUPEM, University of Hong Kong</td>
<td>C</td>
</tr>
<tr>
<td>BLAY John</td>
<td>Citybus</td>
<td>B</td>
</tr>
<tr>
<td>BOULTON Andy</td>
<td>Dennis (HK) Ltd</td>
<td>B</td>
</tr>
<tr>
<td>CANNON James</td>
<td>Energy Futures Inc</td>
<td>B</td>
</tr>
<tr>
<td>CHAN HF</td>
<td>HK Institution of Engineers</td>
<td>H</td>
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<tr>
<td>CHAN Howard</td>
<td>Environment &amp; Food Bureau</td>
<td>L</td>
</tr>
<tr>
<td>CHEN Margaret</td>
<td>Clear The Air</td>
<td>T</td>
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<tr>
<td>CHENG Brian</td>
<td>Consumer Council</td>
<td>B</td>
</tr>
<tr>
<td>CHENG Daniel</td>
<td>Dunwell Enviro-tech (Holdings) Ltd</td>
<td>H</td>
</tr>
<tr>
<td>CHENG Eric</td>
<td>Dept Electrical Engineering, HK Polytechnic University</td>
<td>C</td>
</tr>
<tr>
<td>CHENG L K</td>
<td>Green Power</td>
<td>L</td>
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<tr>
<td>CHENG Wing Kuen</td>
<td>Dept Mechanical Engineering, University of Hong Kong</td>
<td>B</td>
</tr>
<tr>
<td>CHEUNG Allen</td>
<td>Caltex</td>
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<td>CHEUNG K C</td>
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**Groups**

- C = passenger cars
- T = Taxis
- L = Light Goods Vehicles & Minibuses
- H = Medium & Heavy Goods Vehicles
- B = Buses

**Facilitators**: Lindsay Pickles, Li Ho Kin, Tony Wu, Christine Loh, Suzanne Skinner and Lisa Hopkinson

**Translators**: Vincent Wong and Peggy Yung
APPENDIX 6: REPORT OF THE 18 MAY 2001 WORKSHOP

1. INTRODUCTION

The workshop was held at the Academy of Medicine in Wong Chuk Hang on Friday 18th May. Participants at the workshop were invited to use either Cantonese or English and translation was given for the benefit of other participants. Participants at the workshop were invited to join one of the following interest areas.
- Passenger Cars – Red Group
- Taxis – Blue Group
- Light Goods Vehicles (LGV) – Yellow Group
- Medium and Heavy Goods Vehicles (HGV) – Green Group.
- Buses – Brown Group

Group sessions were held in working rooms away from the workshop forum. Discussions held in the group sessions were presented to the whole workshop so that all could share in and contribute to the ideas generated during the day.

2. PROGRAMME

<table>
<thead>
<tr>
<th>MORNING</th>
<th>AFTERNOON</th>
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<tr>
<td>• Introduction by Allen Choate, The Asia Foundation &amp; Christine Loh, Civic Exchange.</td>
<td>• Continue Creative Thinking</td>
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<td>• Introduction to Value Management</td>
<td>• Presentation of Group Ideas</td>
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<td>• Workshop Objectives</td>
<td>• Summary &amp; Discussion)</td>
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<tr>
<td>• Identification and Sharing of Key Issues &amp; Concerns</td>
<td>• Action Plans)</td>
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<tr>
<td>• Presentations – Implementing Technologies Questions &amp; Discussion</td>
<td>• Presentation &amp; Discussion of Action Plans</td>
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<tr>
<td>• Creative Thinking &amp; Idea Generation</td>
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3. INTRODUCTION BY CHRISTINE LOH & ALLEN CHOATE

Allen Choate noted that this Workshop was distinctive because it was a rare opportunity for stakeholders coming from a wide range of sectors and interests to meet together in an effort to identify common concerns and goals. The workshop was significant because it is one part of a larger on-going project that seeks to build and implement a feasible and practical action plan for improving Hong Kong’s air quality.

Christine Loh noted that this was an unusual event for Hong Kong, bringing different stakeholders together to discuss policy issues relating to air pollution. She thanked the participants for their willingness to attend and share their ideas and knowledge with others.

4. INTRODUCTION TO VALUE MANAGEMENT

Value Management is a systematic and analytical approach to addressing and solving a problem. It works within a structured environment, where participants are encouraged to collectively and creatively enhance their individual capability. Using constructive overlap between different interests, a common point of synergy is sought.

There are many different voices in the community saying different things and the structured approach requires participants to listen and appreciate others points of view.
before they practise divergent thinking to consider all possible ideas and options. Only then, can they collectively converge to a consensus and preferred option.

Participants were invited to
1. Enter into discussion sincerely and enthusiastically
2. Give freely of their experience
3. Confine their discussion to the problem and not to digress
4. Actively listen to other participants
5. Be patient with other participants and seek to understand the other participants point of view

By having a consensus, there is a greater chance that some of the recommendations identified by the workshop can progress. This is particularly important in a government context.

This workshop was quite an unusual event for Hong Kong - there are very limited opportunities for such a diverse group of people to sit down and talk issues through.

5. OBJECTIVES OF THE WORKSHOP

The purpose of the workshop is to consider how to reduce vehicle emissions in Hong Kong. The study is limited to Hong Kong vehicle generated pollution:-
- not looking at possible pollution from Guangdong.
- not considering other forms of transport, traffic control measures or switching from one form of transport to another (ie road to rail).

In detail, the objectives of the workshop were:
1. To gather ideas on how to pursue ways to improve the vehicle emissions.
2. To develop action plans to take vehicle emissions strategies forward.
3. To provide a network for ongoing development of strategies

6. PARTICIPANTS
One of the success factors of group problem solving is the selection of a group of people who collectively have the best possible knowledge and understanding to resolve issues and evaluate solutions relating to the problem. Not everyone who is involved in the issue can be present at the workshop. It is, however, essential to have all the stakeholders - who will be affected by decisions made during the study - represented. Representatives of transport operators, vehicle suppliers, government regulators and environmental organisations were invited together with proponents of alternative technologies. Over 90 people attended the workshop. The participants, who are listed in Appendix A, were invited to contribute their knowledge of the Industry, their technical, intellectual and creative resources and their experience to contribute effectively to solve the problem of continuing and increasing vehicle pollution in Hong Kong.

7. KEY ISSUES AND CONCERNS

Following the introduction session, participants were invited to join their interest group and discuss the key issues about vehicle pollution that concerned them. A spokesperson from each interest area then shared their group’s key issues and concerns with the whole workshop. A composite list of key issues and concerns was compiled and a copy posted in each work room to focus the minds of participants on what collectively were felt to be key issues.

Table 6.1. - Table of Key Issues (collective)

| • Traffic congestion        | • Reduction of ground level air pollution |
| • Inspection and maintenance for all vehicles | • Awareness or acceptance of new technology by trade organizations |
| • Infrastructure           | • Lack of respect for vehicle maintenance profession |
| • Dirty diesel             | • Sustainability of new technologies |
| • Transparency of process in choosing technologies | • Co-operation between government and trade |
| • Public awareness of environmental concerns and health | • Refuelling or vapour leakage at petrol stations |
| • Cost: who pays?          | • Enforcement efficiency |
| • Clean fuels are expensive | • Quick fix attitude - no long term view |
| • Need to do quickly        | • Present transport system geared towards diesel or internal combustion |
| • Safety                   | • Acceleration is addictive - people want to accelerate i.e. driving behaviour and attitudes |
| • Government policy        | • More stringent regulations ASAP |
| • Town planning-mobility   | • Realistic and achievable targets |
| • Need for new technologies/availability | • Education and training |

Details of the key issues and concerns for each interest area is given in Annex 1.

8. PRESENTATIONS
The Workshop heard presentations from people knowledgeable in the following areas of new technology.

Participants were reminded that their task was to actively listen to the presentations, to listen with all their attention, to make notes, link thoughts and question how “can we” resolve issues. Structured questions were encouraged at the end of the presentation session and participants were requested to write down their question to ensure it was focussed.

Cleaner Diesel & Retrofit Technologies: Kong Ha – EPD

Implementation of Cleaner Diesel in Hong Kong

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<tr>
<th>Sulphur Diesel Content</th>
<th>Implementation</th>
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<tr>
<td>0.2% Sulphur Diesel</td>
<td>1 April 1995</td>
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<tr>
<td>0.05% Sulphur Diesel</td>
<td>1 April 1997</td>
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<tr>
<td>Preferential tax treatment for Ultra Low Sulphur diesel (0.005% S) -regular diesel tax HK$2.00 -ULSD tax HK$1.11 -Difference of the tax HK$0.89</td>
<td>7 July 2000 (100% available by all fuel stations by August 2000)</td>
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<tr>
<td>0.035% Sulphur Diesel</td>
<td>1 January 2001</td>
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<tr>
<td>Zero Sulphur Diesel (&lt;10ppm S)</td>
<td>Under consideration</td>
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Implementation of Retrofit Technologies

Government actions:-

- Assist Pre-Euro diesel vehicle owners to install approved devices
- Less than 4 tonnes diesel vehicle program started September 2000 and will last till October 2001
- 2 devices with over 30% particulate reduction approved
- HK$1,3000 trap that needs regular cleaning
- HK$4,000 – HK$7,500 DOC with vehicle owner paying the amount over HK$1,300
- About 10,000 diesel vehicles installed
- Over 4 tonnes diesel vehicles DOC trial close to completion
- Will assist vehicle owners in installation
- Higher particulate efficiency trap technologies trial ongoing at Government Euro I and Euro II vehicles
- Biodiesel and NOx reduction trap trials ongoing

Implementation of Retrofit Technologies on buses

- Started Diesel Oxidation Catalyst (DOC) trial in 1995 with KMB
- DOC reduces particulates by over 30%, HC and CO by over 80% respectively
- Franchised bus companies voluntarily installing DOC on about 2,300 Pre-Euro and Euro I buses (about 2,000 installed)
- High particulate efficiency trap (up to 90%) under evaluation on Euro II buses
- Other technologies such as water blended diesel are under evaluation

Electric & Hybrid Vehicles: Dr Eric Cheng– Dept Electrical Engineering, Hong Kong Polytechnic University
Electric Vehicles (EVs) are zero emission, can recover energy through braking, have low noise pollution and instant start and direct drive. EVs on the road include GMEV1, Ford Ranger EV, Chrysler EV, Toyota RAV4EV, Honda EV, Nissan Altra, Nissan FEV11, PIVCO Citybee, Mercedez Benz Smart. Nissan also has new prototype EVs using lithium-ion batteries. A 2-passenger “hypermini” 2.5m long, 62mph, 81 mile range, designed to meet European, Japanese and North American safety standards.

The Hong Kong Polytechnic University has purchased an electric golf cart and are working on improving motors, controller and regenerative braking facility. The 2 seater EV, with a top speed of 50km/h and range of 80km per charge, is especially designed for low cost use in remote locations such as NT. GP batteries have donated an electric car licensed for driving on roads, which is powered by Nickel Metal Hydrate batteries 144V, from GP Batteries, manufactured in Hong Kong.

Other work at HKPU includes switched reluctance motors (SRM), battery electric technology, power conversion, magnetic coupling, battery tunnel. Their mission is to develop a testing centre for EVs, develop fuel cell technology, develop all electric technology, develop a battery charging card system.

EVs offer a quiet, pollution-free option, are far cleaner than gasoline powered vehicles. However EVs are not pollution free – produce indirect environmental impact. Range is limited – need improvement in battery, electric motor and power conversion.

Hybrid Electric Vehicles (HEV) combine the internal combustion engine of a conventional vehicle with the battery and electric motor of an EV. With “perfect” (100%) HEV component efficiencies, can achieve 424 mpg. With high efficiency (33%) 140mpg, and without regenerative braking 70mpg.

Hybrids available include Toyota Prius, Honda Insight, GM Precept. Toyota Prius now selling in Japan for under $16,500. Production tripled to 3000/month. Japanese co buys 260 to save fuel, operating costs. Toyota has started selling hybrid coaster bus in Japan. 21 and 24 passenger versions, 1500 cc gasoline engine generates power for electric drive. APS Systems hybrid transit bus – propane/electric hybrid system, 40ft low floor transit design, 210 mile range in hybrid mode, 40kW rotary engine/generator, Nickel-Cadmium batteries.

Parallel configuration HEVs have a direct mechanical connection between the PU and the wheels, and an electric motor that drives the wheels. The vehicle has more power because both the engine and the motor supply power simultaneously. The motor regenerates the batteries, so no need for a generator, and because the power is directly coupled to the road, it can be more efficient.

Series configuration HEVs transfer power from chemical energy to mechanical energy, to electrical energy and back to mechanical energy. The engine never idles which reduces vehicle emissions, and drives a generator to run at optimum performance. The design allows for a variety of options when mounting the engine and vehicle components. Some series hybrids do not need a transmission.

Advantages of HEVs are that regenerative braking helps minimise energy loss; engines can be sized to accommodate average load, not peak load, which reduces engine’s weight; fuel efficiency is greatly increased; emissions are greatly decreased; HEVs can reduce dependency on fossil fuels because they run on alternative fuels and special lightweight materials used to reduce overall vehicle weight of HEVs.
Bio Fuels: Dennis Leung – Dept Mechanical Engineering, University of Hong Kong

- Biofuels are liquid or gaseous fuels produced mainly from biomass or agricultural products. Ethanol, propanol, biodiesel or purified biogas. They are used to replace or supplement traditional petroleum based transportation fuels.

- The main advantage of Biofuels is that they are renewable - do not contribute to global warming. They have a cleaner combustion, reduce air pollutant emissions, are biodegradable and non-toxic in nature and can be used in existing vehicles with little or no modification to engines and fuelling systems. Vehicles using Biofuels can use existing refueling stations/facilities.

- The disadvantages of Biofuels are that they cost more than conventional petroleum fuels. The NOx emission of Biofuels may be slightly higher and they are good solvent and may attack some rubber parts.

- Ethanol is produced from biomass such as corn, starch etc. It is mainly used in gasoline vehicles with proportion from E10 to E100. More than 6 billion gallons/year are used and there are more than 3 trillion miles on road usage record. Countries using ethanol include Brazil (E22-E100); Sweden (E100); USA ((E10-E85); Malawi (E10); Mexico (E10); China and Thailand (under trial test)

- Biodiesel is produced from vegetable oil, animal fats or recycled oil. It is used as a substitute for diesel. More than 300 million gallons/year are used and there are 350 million miles on road usage record. Countries using Biodiesel include Australia (B100); Canada (B2-B100); France; (B5-B30); Germany (B100); Sweden (B2-B100); USA (B20).

- The constraints of Biofuels usage in Hong Kong are that the cost of Biodiesel is higher at (HK$5-6/L) Vs ULSD (HK$5.9/L pump price with duty). The cost of Ethanol is slightly higher than gasoline. There are currently no distribution networks. A slightly higher NOx emission may worsen the present air pollution problem due to high NOx level. The use of Biofuels is warranted by car manufacturers at low % only.

LPG & Natural Gas: Martin Wong – Independent Consultant

- Nearly 7800 taxis out of 18000 have been replaced by LPG. There are 13 LPG filling stations up to now, and 5 of which are of large LPG dedicated stations and 4 more dedicated stations are being constructed with more sites planned some time this year. Further, some 20 petrol service stations have been planned to provide LPG filling facilities. LPG mini-buses are on trial with a view to replacing diesel mini-buses in the future.

- There are potentials for the development of Natural Gas Vehicles (NGV) in Hong Kong. However, infrastructure, storage terminals, distribution systems, refueling stations & equipment, gas quality, approval of vehicles, training of NGV technicians, risk assessment, legislative changes, gas safety standards and enforcement duties must all be considered. Although NGV is a practical alternative, there is always a “trade-off” between risk of hazards and environmental benefits. It is important for Government to plan ahead and look into the necessary requirements well in advance, so as to ensure successful introduction of NGV in Hong Kong.
NG can be applied to most types of vehicles either in the form of Compressed Natural Gas (CNG) or proposed Liquefied Natural Gas (LNG), although it requires the necessary infrastructure and careful considerations. NG can also be a fuel for hybrid vehicles and fuel cells. NG is now available at Black Point and the strategic landfill gas at NENT, WENT and SENT can be purified, liquified and stored on-site for distribution.

LNG is a cryogenic liquid and has a liquid to gas ratio of about 1 to 620. It is important from a risk point of view to consider LNG vehicles going through tunnels and densely populated areas. CNG vehicles are less restrictive from a risk point of view, and therefore can be applied to most types of vehicles, but they require more storage space for CNG cylinders compared with diesel tanks.

At present, Hong Kong has no infrastructure for NG storage terminals and distribution systems, however, the Towngas transmission and distribution network is originally designed for NG service, and therefore it can be used as a common carrier system, once NG is available with the security of supply.

The (LNG) terminal at Qingtoujiao could be completed for piped gas supply to Hong Kong by 2005. In addition, there are some areas where NG or LFG is readily available and planning could start on considering sites for NG storage terminals and refueling stations at suitable locations. This would include all landfill sites and vehicle fleet operators with own depots for NG refueling facilities.

Landfill sites, NT west, NT east and certain large vehicle fleet operators could be considered for LNG or CNG storage terminals and refueling stations as they require large storage areas.

LNG is normally distributed by cryogenic road tanker whereas CNG can be distributed by tube-trailers or cylinder packs in ISO container trucks, or by means of a pipeline system for supplying NG to suitable stations which are equipped with compressors to build up the required pressure for refueling.

Gas quality is also another important issue to ensure fuel efficiency and consistency for end users as well as to comply with the legal requirements on gas composition.

Training of NGV technicians and provision of NGV workshops will need the necessary attention and arrangements for the introduction of NGV in the future.

**Fuel Cells: James Cannon – Energy Futures Inc**

Fuel cells are electrochemical devices capable of converting hydrogen and oxygen gases directly into electricity without combustion. The process is highly efficient and the only byproduct besides electricity is water. Like a solar photovoltaic power cell to which it is frequently compared, a fuel cell has no moving parts and produces no noise or pollution.

There is no free hydrogen gas on earth, but unlimited supplies can be extracted from other sources, such as water or hydrocarbons. When hydrogen is extracted from water using solar energy, and then reconverted to water and electrical energy in a fuel cell, the overall energy cycle is endlessly sustainable. Thus, fuel cells offer a potentially permanent solution to the world’s energy needs.

Harnessing hydrogen fuel cell energy to power automobiles is now a high priority of nearly every major automotive manufacturers around the world. Although the technology is not
yet commercial, about 30 prototype fuel cell automobiles and 10 buses are currently operating. More are being built each year as the technology rapidly matures. About $5 billion in research and development capital is being invested annually for automotive fuel cell development, an enormous sum for an industry that, for all intents and purposes, is only about a decade old. Limited sales of commercial fuel cell vehicles will undoubtedly begin during the next decade.

- Nearly every fuel and propulsion technology used in transportation today—from gasoline internal combustion engines powering automobiles to jet turbine powered airplanes—has been discovered or invented within the last 200 years. As these fuels and technologies continue to evolve, the world has already begun to move into the era of sustainable energy based on the fuel cell.

**Discussion & Questions & Answers**

Kong Ha – On the USEPA website, hybrid ranks best in fuel consumption but not in emissions. Can Eric elaborate on this?
Eric Cheng? – it depends on design, whether parallel or series. The efficiency of conversion governs emissions.

John Bacon-Shone – Cross boundary traffic, which form a significant part of vehicle emissions in Hong Kong, will continue to use dirty diesel from the mainland. Which of the alternative fuels are available across the boundary – natural gas seems a good solution but what about the others?
Dennis Leung –Biofuels are compatible with normal diesel/gasoline so if there is no supply in PRC, the vehicles can still use normal diesel/gasoline until they come back to Hong Kong.
Richard Lee – There are more pollution problems in PRC than HK. In Guangzhou already using LPG buses and taxis. On 18th April Chinese made an announcement that they would be adding ethanol to petrol.
Martin Wong – Once the LNG terminal [in Shenzhen] is completed in 2005 I am sure it will be used for Natural Gas Vehicles. The Chinese government is very keen on environmental problems, and plan for piped gas to other parts of Guangdong. Once they have the infrastructure it shouldn’t be a problem.

John Blay – Martin Wong mentioned that the Towngas distribution system would possibly change to natural gas. Any commitment on that?
Martin Wong – No commitment at present. However the towngas system was originally designed for natural gas. Conversion would take some years.

Margaret Chen – Are LPG and natural gas the same? Could a LPG system feed into a natural gas one?
Jim Cannon – Can produce hydrogen from both natural gas and LPG. The former is how 99% of hydrogen in industrial sector is currently produced.

**9. CREATIVE THINKING**

Each Interest Area was asked to consider how they would like to see Hong Kong in 10 years time and creatively seek ways to achieve that vision. Discussion continued over and after lunch and in the afternoon, each Group was asked to consider the ideas generated during
this session and apply the key areas of concern to evaluate these ideas. They were then invited to present the collective view of their Group.

**Passenger Cars – Red Group**

<table>
<thead>
<tr>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Move toward lowering emissions</td>
</tr>
<tr>
<td>• Cars and fuels are options to lower emissions</td>
</tr>
<tr>
<td>• Not one solution to lowering emissions</td>
</tr>
<tr>
<td>• Consider short, medium and far out solutions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Can use government incentives or duties</td>
</tr>
<tr>
<td>• Consider infrastructure requirements</td>
</tr>
<tr>
<td>• Consider different fuels as solutions. Not just one</td>
</tr>
<tr>
<td>• 10-20% of vehicle fleet for passenger cars over 10 years old: possible buy back</td>
</tr>
<tr>
<td>• Hybrids are possible solution</td>
</tr>
<tr>
<td>• Increase price of car ownership</td>
</tr>
<tr>
<td>• Strengthen incentives scheme</td>
</tr>
<tr>
<td>• Impediments to biofuels</td>
</tr>
<tr>
<td>• Warranties from car manufacturers</td>
</tr>
<tr>
<td>• Distribution/fuelling stations</td>
</tr>
<tr>
<td>• Price</td>
</tr>
</tbody>
</table>

**What incentives can Hong Kong use to promote hybrids and alternative vehicles?**

- Make all alternative fuel vehicles tax free or tiered tax tied to emissions (annual road tax)
- Government fleets switching to electric vehicles for passenger services
- Eliminate or lower first registration tax on hybrids
- Education—adverts at refuelling stations and dealers
- Relaxing government specifications for alternative vehicles (so more models & types)
- Set up high-level government task for cleaner vehicles & fuels
- Conversions of existing vehicles to alternative fuels: should be make easier (may be problematic)
- Change the Towngas system to CNG & promote CNG vehicles (usable in China)
- Government mandate for cleaner petrol (like ULSD)

**Getting old cars off the road**

- Pay people premium to retire/ give up cars 8-10 years
- Penalize or higher road tax on older vehicles but this may disproportionately affect older people & increase abandonment of vehicles

**Taxis – Blue Group**

- Education & training
- Resolve conflict between trade and supplier
- Force/convince supplier to educate/train mechanics for LPG vehicle maintenance
- Build more LPG friendly stations
- Review the tendering for more competitors
- Lower maintenance and recurrent cost
- Minimise unnecessary insurance premium
- More publicity of policy and technology
- Funds from government to inform press
- Focus on a macro view of new technologies
- Coordinated planning by government departments
- Urban planning
- Adopt new technologies smoothly
- Work on closing the gap between transport, EPD and public
- More efficient and effective discussion period before adopting policy
- Educating general public
- Press continually informed of debate
- Long term strategy approach by government
- Publicise ongoing research
- Public Civic Exchange papers in newspapers
- Eliminate the lack of public knowledge
- Conduct some preparation works to ensure the infrastructure available
- Work together – EPD, public, companies
- Hold more workshops in future with a free lunch and visit

### Light Goods Vehicles – Yellow Group

**Top priority**
- Push non franchised buses to Euro III standards
- Lower fuel prices/taxes to encourage switch
- Short term solution – maintenance/cleaner fuel
- Government should do more – be more aggressive/proactive
- LPG vans pilot scheme
- Long term government policy
- Incentives for owners of old vehicles to change to new models
- Educate people about alternative technologies
- Establish a HK energy department
- Train more mechanics
- Establish a vehicle emission research centre
- Promote biofuels, LPG, electric, EURO III engines & hybrids
- Subsidize environmental vehicles
- Government to sell subsidized environmental vehicles
- Subsidize local Research & Development
- Reward program for cleaner vehicles
- Add more seats inside the vehicle/ bus, so that each ride can earn more $$$
- Maintain vehicles and keep records centrally
- Reward individuals who report smoky vehicles
- Severe punishment for using red oil
- There should be an examination for occupational drivers (training)
- Use battery vehicles

**Second priority**
- Promote zero sulphur diesel
- Drivers to be able to recharge their batteries at fuel/ petrol station
- Legislate to force the sector to change their vehicles (No. of yrs)
- The license fee should be increased according to the level of emissions from that vehicle

**Third priority**
- Switch to fuel cells
- Develop or encourage long-term government policy
- Free maintenance by government

**Wild ideas**
- Feeder routes/smaller scale rail system/monorail
- Electric cable car on ground or in air
- Tighten up the smoke level from 60 HSU to 50 or 40 or even lower—same principle in petrol emissions
- City/street ventilation system (exhaust by say drainage)
- City air purifying system
- Street artificial rain
- Alternate days for even or odd number vehicles
- Magnetic train
- Cut down bus service during off peak hours
- How about using hydro-electricity?
- Is it possible to use solar power vehicle?
- Elevated Road/ Railway, less infrastructure/ limit the number of vehicles
- Tall buildings block the spreading of pollutants

### Medium and Heavy Good Vehicles – Green Group

**2001-2011**

1. Build stakeholder/public consensus
2. Quantity Problem
   - High emissions - pollution - health
   - Noisy - traffic exhaust
   - Congestion
   - Poor town planning
   - Lack of knowledgeable mechanics
   - Poor mobility management — good
   - High percentage of diesel
   - Poor enforcement
   - No total pollution load
   - Unwillingness to pay
   - Overall policy coordination (port development?)

**2011**

1. dirty diesel: cheap v. dear
   - same price
   - incentives
   - supply: USLD
   - alternative fuels
   - alternative technology
2. ban combustion
3. engine technology intolerant of dirty diesel
4. zero emission vehicles in urban areas
5. pedestrian and bicycle zones: vehicle free areas
6. HK’s own research on what works
7. user pays—road pricing for all roads at “full” cost
8. use IT to minimize trips (trip planning), mobility tracking, town planning and track emissions
9. improve emissions of off-road sources
10. nuclear fuels
11. emissions trading on individual basis
12. restrictions of commercial vehicles of times
13. improved fuel efficiency
14. management of utility maintenance systems
15. road planning-reduce time on roads (again IT can apply to road pricing and transfer points)
16. SAR or district wide AQO enforcement
17. car pooling
18. low loading—right vehicle for job
19. efficiency in commercial vehicle parking
20. port rail system
21. public awareness

**2011 solutions**
1. reduction of trips
   • reposition of HK as port?
   • Use of it to minimize/ routing emissions
   • Road mileage pricing—“full” cost
   • Car pooling
2. technology
   • immediately improve diesel fleet (70%)
   • more stringent control for heavy vehicles
   • retrofit
   • incentives—early replacement
3. vehicular maintenance/training
4. raise status of drivers and mechanics to promote professionalism
5. fuel
   • need of alternative fuel infrastructure
   • test engines/fuels in HK and fuel consumption devices
   • policy on energy/fuel

Buses – Brown Group

VISION
• Set emission reduction targets: zero emissions
• Include a range of technologies to lower emissions: eg Natural Gas, fuels cells

HOW TO GET THERE?
1. Government to set emission reduction targets and provide incentives and framework for the private sector to meet emission targets
   • Government to acknowledge externalities (eg pollution and social costs)
   • Set up regulatory framework for alternative technologies
   • Help with infrastructure
   • Provide funding for training
   • Public education
   • Provide dedicated road space for environmentally friendly transport
2. Government to provide a TOTAL ENERGY STRATEGY
3. Private sector
   • Improve currently operating vehicles through retrofit
   • Use of intermediate technology – CNG, CNG hybrid, LPG, diesel hybrid
   • Need for demonstration fleets
   • Private sector champions needed

10. SUMMARY & DISCUSSION

The ideas from each interest group could be identified within 5 common themes, which ran through each Groups presentation. These were summarised and presented to the workshop in the discussion period.

Themes

| New Technologies | Incentives |
• Fuel cell ultimate goal
• All technologies to be considered
• Use of intermediate technologies promoted"
  CNG, CNG hybrid, LPG, LPG hybrid
• Bus group to improve current operating vehicles
• Demonstration fleet
• Private sector champions: buses and others?
• Use of IT to minimize routing and vehicle emissions
• Government champions

• Subsidize environmental vehicles
• Lower price
• Tax free/lower tax
• Free registration
• Subsidize maintenance
• Government fleets to switch to electric
• Make conversions easier
• Premium to give up old cars
• Tax penalty on older cars
• Incentives for early retirement of older vehicles
• Value technicians to raise status and quality

Garth Harris proposed that the Government needs a taskforce that coordinates things at top level to make sure it works. This is more than just energy, includes education etc.

Wong To confirmed he is a supporter of environmental technology. He promotes an Australian technology which has shown good results to the Guangzhou taxi association. He is frustrated by government policy which pinpoints diesel taxis. He received letter that by 2005 all diesel has to change. He worries about increased costs. Regarding the duty concession on LPG, he is worried that when the incentive has gone it will be difficult for taxi drivers to continue business. Diesel tax increase will increase costs for taxi drivers.

11. ACTION PLANS

The themes were used to create Action Plans, which, given that Participants could join the discussion and identification of Action Plans for the Theme of their choice, collectively presented the results of the workshop as a whole.

New Technologies
Action Plans were divided into what could be done now and what in the intermediate term.

Now - Encourage fleet operators to implement all retrofit technologies
- Introduce biofuels
- All large fleets must adopt AF vehicles by a set % on a date to be fixed
- Demonstration fleets for: CNG, diesel hybrid, LPG
- Invite fuel cell prototypes to HK

**Intermediate**
- Plan and put in place fuelling and distribution system for intermediate vehicles (such as NG or CNG) that can accommodate hydrogen in the future:
  - Plan systems for eventual shift to hydrogen
- Demonstrate fuel cell fleets (government or private) when available

**Incentives**
For Incentives, participants considered what could be done, who was to do it and by when.

**What**
- Incentives for alternative technology vehicles
  - Performance based (doesn’ t depend on fuel, age or type of vehicle – give incentive based on performance)
  - Franchised buses
    - As they pay no taxes, count as capital in calculation of profits
    - Government to fund retrofit technologies or give fare increase
    - Fund differential cost between alternative bus and normal bus
  - MGV/HGV
    - Reduction in Annual Licence Fees/First Registration Tax/Fuel duty
    - Subsidy to replace old trucks
    - Costs of new technology must be made comparable to existing costs

**Who:**
- Government Bureaux including Environment & Food Bureau, Economic Services Bureau, Transport Bureau, Finance Bureau, Health & Welfare Bureau, Innovation & Technology Commission

**When:**
- Immediately. Implementation depends on technology – short term solutions asap, others may take longer.

**Education & Training**
The Group looking at education & training considered who could take forward various ideas and by when. The consensus is that education and training must start as soon a possible and continue.

- Establish more consensus: building forum to resolve conflicts
  *Who:* non-profit NGOs  *When:* on-going
- Journalist training courses—editors and reporters—for a professional linkage
  *Who:* press associations and universities  *When:* on-going
- Establish education unit as core component of CV/CF task force
  *Who:* government  *When:* ASAP
- Demonstration project and related education and press
  *Who:* all parties  *When:* as needed
- Education Department (ED) and vocational training. Add issue to the curriculum.
- To train more technicians who can repair LPG vehicles. Apart from occupational training program, there should be another school that can provide training program, the ideal school is Lee Wai Lei Industrial Institution
- The supplier should provide enough information for the technician (car repairing) about how to repair those vehicles
Who: ED, VTC and HKIVE and suppliers    When: ASAP and ongoing
• Driving schools—theory exam —Transport department
• The Government should upgrade the driving technique of the driver in order to maintain the safety on road.

Who: HKSM, Government    When: ASAP and ongoing
• Use of GPS to avoid traffic congestion and other new technologies

Who: private sector    When: ASAP
• Life long learning for mechanics and mechanic certification. CPD based & renewable.
• For those technicians (car repairing), they should be taught about the new technologies regularly

Who: VTC, HKIVE, motor manufacturers    When: ASAP
• Press for alternative vehicles and fuels. Intensify and sustain such adverts and television
• The Government should pass the message of environmental protection to the public through the multi media so as to raise people’s attention

Who: government and private sector    When: ASAP and ongoing

Regulation & Planning
This group considered that it was extremely important for Hong Kong to establish an Energy Policy. From this overview, a number of plans relating to other themes could evolve in a coherent manner.

1. Broad energy policy regarding fuels. Also addresses the economic, environmental and social costs.
   How: Define the issue. Study the issue. Consult the public to set terms of reference. Multi-party study process eg. Involvement of government departments
   Who: Government to initiate, eg, with a commission to carry out the process
   When: as soon as possible

2. Legislation and planning
   Idling engines—Government adopts measures as soon as possible
   Traffic management and electronic road pricing. Government to release the results of its study and open to the public for discussion of adequacy.

Infrastructure and Research & Development

Infrastructure (Natural Gas)
• Decision on common carrier policy
• Land planning – sites
• Land premium/incentive
• Identify ways so that CLP gas and landfill gas can be allocated to CNG
• Set up gas delivery system for filling stations at suitable locations eg bus depot
• Set up gas quality standard (including mainland)
• Set up gas regulations and standards, especially safety
• Set up training certification facilities for CNG
**Infrastructure**

1. Legislate to force the vehicle producer to provide training course/ support regarding the maintenance of the vehicle
2. Provide systematic/ suitable training for the field

   1. Increase the no. of strategic gas/ fuel stations (ask for the field’s opinion)
   2. Establish movable gas/ fuel station
   3. Increase the no. of supplier that can provide reliable and safe service
   4. Deduct the tax of environmental friendly fuel (newly imported)
   5. Re-assign the route of bus

**R & D**

1. Strengthen the communication between the Government, drivers as well as other countries
2. Approve the testing/ using of new products. Ideally subsidize would be provided for using those products.

**Other New Technologies**

- Facilities for charging electric
- Smart card payment system

   1. Increase the no. of strategic gas/ fuel stations (ask for the field’s opinion)
   2. Establish movable gas/ fuel station
   3. Increase the no. of supplier that can provide reliable and safe service
   4. Deduct the tax of environmental friendly fuel (newly imported)
   5. Re-assign the route of bus
Annex 1 – Key Issues & Concerns

Passenger Cars – Red Group
• Carbon monoxide from petrol
• Traffic congestion – less mobility concentrates pollution
• Age of vehicles
• Maintenance
• Car design
• Durability of parts
• Public awareness of environmental concerns
• (how and which cars are chosen and when they are used)
• Driving style (“Acceleration is addictive”)
• People like luxury cars – choice education
• Refuelling station emissions – time of day compounds emissions from stations
• How to increase consumer awareness of green fuels and cars
• How to improve fuel quality or introduce better fuels
• Reducing noise
• Do we need vehicles with so much power in Hong Kong
• Increasing long and short term public awareness (to influence government)
• Incentives and regulation

Taxis – Blue Group
• Maintenance costs by suppliers
• Increased cost of operation
• Increase of capital
• Effect on performance
• Criteria of selection of technology
• Harmful side effects of new technology
• Assuming a solution
• Build acceptance by public and user
• Transparency of choice
• Speed of implementation
• Infrastructure support
• Transition
• No one knows – lack of information of solutions
• Resources weak – maintenance restricted to licensed (dealers?)
• LPG policy wrong?
• Ignore new technology (diesel) (does this mean the concern is we ignore new technologies or the concern is that we should focus on diesel?)
• LPG limited supply
• EPD doesn’t cooperate
• No overall transport policy
• Let the people know (of all available chinese) how, why and what to do
• The Government’s policy in a long run – what? Y/N
• Testing (LPG)
• The performance/ quality of the service provided
• Level of safety
• Urge the increase of the no. of gas/ fuel stations (infrastructure) (not enough so far)

Light Goods Vehicles & Minibuses – Yellow Group
• Infrastructure
• Cost/Economic
• Government policies in balancing interests of all parties
• Effectives of the changes in improving the environment
• Sustainability of the technologies
• Capital/ running cost
• Environmental problem
• Establish an information center for maintenance and different technologies
• The Government’s policy is not up-to-date (need to be reviewed/evaluated regularly)
• Short-term solution: Training/maintenance/cleaner fuel – P1
• The Government should do more – aggressive practice – P1
• Light Goods Vehicle – P1
• LPG (Vans) pilot scheme – P1
• Long-term Government Policy – P3
• short term greed will slow or kill alternative technologies
• old technologies and infrastructure won’t change fast enough
• government will not mandate reductions or give adequate support to operators
• public will not pay higher cost in short term for longer health
• need to step back “behind” current problems —analyse or discuss how we got there—quick fixes are of no use
• health risks to air quality not communicate or understood enough
• maintenance
• cleaner fuel
• better engine design
• exhaust after treatment
• alternative fuel

Medium & Heavy Goods Vehicles—Green Group
• Cleaner fuels are expensive
• Dirty diesel available cheaply
• Vehicle maintenance
• Mobility
• Town planning
• Vehicle age
• Not innovative enough
• Lack of up to date equipment
• Driver awareness i.e. idling engines
• Lack of relevant specialists
• Policies
• Emission standards across vehicles
• Stakeholders not organized (lack of clout)
• Polluter pays inconsistent
• Cross border
• Legislation
• Enforcement efficiency
• Education-stakeholders public
• Incentives
• Relevant technologies not used
• Automotive career discounted
• Licensing of mechanics and garages
• Renewable: attitudes among stakeholders
• Acceptance of technologies among trade
• Social costs of pollution

Buses—Brown Group
• In short term recognize existing technologies such as Internal Combustion Engine rather than new technologies
• Cost who pays? Government needs to clarify if the polluter pays
• Inspection/Maintenance programme necessary even for new engines
• Government set zero emission standards within 5 years
• Government to have zero or ultra low emission program
• Need for bus replacement with new technologies
• Dedication of existing transport system to diesel or Internal Combustion Engines
• Reduction of ground level air pollution as soon as possible
• Need for introduction of Euro III or IV buses ASAP
• Targets must be realistic and achievable in a market economy
• Better policing of emissions
• Routine emissions tests for all vehicles
• Incentives for new technologies
• Health and other pollution costs: when will the critical point be reached?
• Traffic control necessary
• Investigate alternative energy: zero emission
• Use filters and alternative technologies to reduce pollution
• Timescale critical—what can be delivered fastest
• Ways to control bus idling emissions
• Even cleaner diesel technologies
• Importance of public education or engagement—lack of information for stakeholders
• Government avoidance of wasteful competition—no account of environmental issues
• Reduction of passenger vehicle miles by the community
• Reducing pollution at source: fuel/traffic efficiency
• Diesel duty exemption for buses—encourages them to use diesel
APPENDIX 7: EXAMPLES OF CLEANER VEHICLE MODELS AVAILABLE WORLDWIDE

Table 7.1: Electric Vehicles

<table>
<thead>
<tr>
<th>Company &amp; Vehicle model</th>
<th>Vehicle type</th>
<th>Battery type</th>
<th>Range (miles)</th>
<th>Purchase price (USD)</th>
<th>Fuel economy (kWh/100 miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Motor 1999 EV1</td>
<td>Two seater</td>
<td>PbA</td>
<td>79 @ city; 79 @ highway</td>
<td>$33,395 (sale); $399/month (lease)</td>
<td>30 @ city; 25 highway</td>
</tr>
<tr>
<td>General Motor 1999 EV1</td>
<td>Two seater</td>
<td>Ni-MH</td>
<td>79 @ city; 79 @ highway</td>
<td>$43,995 (sale); $499/month (lease)</td>
<td>49 @ city; 51 @ highway</td>
</tr>
<tr>
<td>Honda EV Plus</td>
<td>Compact sedan</td>
<td>Ni-MH</td>
<td>100 @ city; 84 @ highway</td>
<td></td>
<td>26 @ city; 29 @ highway</td>
</tr>
<tr>
<td>Nissan – 2000 Altra EV</td>
<td>4 passenger van</td>
<td>Li-ion</td>
<td>120</td>
<td>$50,999 (sale); $599/month (lease)</td>
<td>26 @ city; 29 @ highway</td>
</tr>
<tr>
<td>Nissan – 2001 Altra EV</td>
<td>4 passenger wagon</td>
<td>Li-ion</td>
<td>80</td>
<td></td>
<td>26 @ city; 29 @ highway</td>
</tr>
<tr>
<td>Solectria Corp. 1999 Force</td>
<td>4 passenger sedan</td>
<td>Ni-Cd</td>
<td>106 @ city; 71 @ highway</td>
<td>$10,500</td>
<td>13.7 @ city</td>
</tr>
<tr>
<td>Solectria Corp. – 2000 &amp; 2001 Force</td>
<td>4 passenger sedan</td>
<td>PbA, Ni-Cd or Ni-MH</td>
<td>50-80 @ PbA; 85-136 @ NiCd; 105-170 @ NiMH</td>
<td>13.7 @ city</td>
<td></td>
</tr>
<tr>
<td>Solectria Corp. – Citivan</td>
<td>Delivery service van</td>
<td>PbA</td>
<td>40</td>
<td>$29,000</td>
<td>8.5 @ city</td>
</tr>
<tr>
<td>Toyota – E-COM</td>
<td>Small Sports Utility Vehicle</td>
<td>Ni-MH</td>
<td>60</td>
<td></td>
<td>38 @ city; 44 @ highway</td>
</tr>
<tr>
<td>Toyota – 1999 &amp; 2000 RAV4-EV</td>
<td>Sports Utility Vehicle</td>
<td>Ni-MH</td>
<td>125</td>
<td>$42,000 (sale); $599/month (lease)</td>
<td>29 @ city; 37 @ highway</td>
</tr>
<tr>
<td>Ford - 1999 Ranger EV</td>
<td>Light duty pickup</td>
<td>PbA or Ni-MH</td>
<td>72 @ city; 77 @ highway</td>
<td>$349 to 450/month (lease)</td>
<td>38 @ city; 44 @ highway</td>
</tr>
<tr>
<td>Ford – 2000 Ranger EV</td>
<td>Light duty pickup</td>
<td>PbA or Ni-MH</td>
<td>72 @ city; 80 @ highway</td>
<td>$35,500 (sale); $449/month (lease)</td>
<td>38 @ city; 44 @ highway</td>
</tr>
<tr>
<td>Ford – 2001 Think</td>
<td>Two-seater electric car</td>
<td>Ni-Cd</td>
<td>53</td>
<td>32 @ city; 41 @ highway</td>
<td>54 @ city; 72 @ highway</td>
</tr>
<tr>
<td>Chevrolet – S-10 NiMH</td>
<td>Light-duty pickup</td>
<td>Ni-MH</td>
<td>96 @ city; 96 @ highway</td>
<td>$32,995</td>
<td>94 @ city; 86 @ highway</td>
</tr>
<tr>
<td>Chevrolet – S-10 L/A</td>
<td>Light-duty pickup</td>
<td>PbA</td>
<td>47 @ city; 35 @ highway</td>
<td>$32,995</td>
<td>45 @ city; 41 @ highway</td>
</tr>
</tbody>
</table>

Key: PbA = lead acid; Ni-MH = Nickel Metal Hydride; Li-ion = Lithium Ion; Ni-Cd = Nickel Cadmium


Table 7.2: Hybrid Electric Vehicles (HEVs)

<table>
<thead>
<tr>
<th>Company &amp; Vehicle model</th>
<th>Vehicle type</th>
<th>Fuel and battery type</th>
<th>Range (miles)</th>
<th>Purchase price (USD)</th>
<th>Fuel economy (mpg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toyota – Prius</td>
<td>5 passenger compact</td>
<td>11.9L petrol engine + Ni-MH battery</td>
<td>570</td>
<td>$20,450</td>
<td>52 @ city; 45 @ highway</td>
</tr>
<tr>
<td>Honda – Insight</td>
<td>2 seaters</td>
<td>10.6L petrol + Ni-MH battery</td>
<td>600 to 700</td>
<td>$18,880 to $20,000</td>
<td>61 @ city; 70 @ highway</td>
</tr>
<tr>
<td>Nissan – Tino</td>
<td>5 passengers car</td>
<td>13.2L petrol + Li-Ion battery</td>
<td>750</td>
<td>$30,000</td>
<td></td>
</tr>
<tr>
<td>Ford – P2000</td>
<td>5 passengers mid-sized family sedan</td>
<td>Direct-ignition diesel engine + Ni-MH battery</td>
<td>&gt;420</td>
<td>63 mpg</td>
<td></td>
</tr>
<tr>
<td>Ford – Prodigy</td>
<td>5 passengers sedan</td>
<td></td>
<td>660</td>
<td>72 mpg</td>
<td></td>
</tr>
<tr>
<td>Ford – HEV Escape</td>
<td>Sports utility vehicle (SUV)</td>
<td></td>
<td>&gt;500</td>
<td>$18,185-$21,360</td>
<td>40 mpg</td>
</tr>
<tr>
<td>DaimlerChrysler – ESX3</td>
<td>5 passenger mid-sized sedan</td>
<td>1.5L diesel + Li-Ion battery</td>
<td>400</td>
<td>$20,000</td>
<td>72 mpg</td>
</tr>
<tr>
<td>GM – Precept</td>
<td>5 passenger family sedan</td>
<td>1.3L diesel + Ni-MH battery</td>
<td>500</td>
<td>80 mpg</td>
<td></td>
</tr>
<tr>
<td>Lombardini FIM SpA</td>
<td>Bus (6-metre long)</td>
<td>1.4 L diesel + permanent magnet, liquid cooled, three phase alternator</td>
<td>290 @ rural; 400 @ urban</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orion VI Low Floor HE Bus</td>
<td>32-seat bus</td>
<td>Diesel + advanced PbA battery</td>
<td>400</td>
<td>$550,000</td>
<td></td>
</tr>
<tr>
<td>Nova – Allison-RTS Hybrid Bus</td>
<td>Bus (52 passengers)</td>
<td>Diesel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toyota – Coaster Hybrid Bus</td>
<td>24-seat bus</td>
<td>1.5 L petrol + Ni-MH battery</td>
<td>240 @ urban</td>
<td>31.95 million yen (1997)</td>
<td></td>
</tr>
<tr>
<td>Hino Motors</td>
<td>Bus (56 passengers)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. “mpg” – mile per gallon (on gasoline)
Table 7.3: Compressed Natural Gas (CNG)\(^4\)

<table>
<thead>
<tr>
<th>Company &amp; Vehicle model</th>
<th>Vehicle type</th>
<th>Fuel type</th>
<th>Range (miles)</th>
<th>Purchase price (USD)</th>
<th>Fuel economy (mpgge)(^5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DaimlerChrysler – 2000 Dodge Ram Wagon</td>
<td>Passenger van</td>
<td>CNG</td>
<td>225 @ city; 300 @ highway</td>
<td>$27,335</td>
<td>12 @ city; 16 @ highway</td>
</tr>
<tr>
<td>DaimlerChrysler – 2001 Dodge Ram Wagon, Dodge Ram Maxi Wagon</td>
<td>Passenger van</td>
<td>CNG</td>
<td>200-300</td>
<td>$27,675 to 30,680</td>
<td>15 @ city; 17 @ highway</td>
</tr>
<tr>
<td>DaimlerChrysler – 2000 Dodge Ram Cargo Van</td>
<td>Service van</td>
<td>CNG</td>
<td>225 @ city; 300 @ highway</td>
<td>$24,220</td>
<td>12 @ city; 16 @ highway</td>
</tr>
<tr>
<td>DaimlerChrysler – 2001 Dodge Ram Van, Dodge Ram Maxi Van</td>
<td>Service van</td>
<td>CNG</td>
<td>200-300</td>
<td>$24,485 to 26,620</td>
<td>12 @ city; 16 @ highway</td>
</tr>
<tr>
<td>Ford – Ford E-450 Cutaway</td>
<td>Passenger van</td>
<td>CNG</td>
<td>148-238</td>
<td>$38,235</td>
<td>12 @ city; 15 @ highway</td>
</tr>
<tr>
<td>Ford – F-150 (2000) 12</td>
<td>Light-duty pickup</td>
<td>CNG</td>
<td>175 @ city; 325 @ highway</td>
<td>$21,825</td>
<td>11 @ city; 15 @ highway</td>
</tr>
<tr>
<td>Ford – F-150 (2001)</td>
<td>Light-duty pickup</td>
<td>CNG</td>
<td>200-300</td>
<td></td>
<td>11 @ city; 15 @ highway</td>
</tr>
<tr>
<td>Ford – F-150 (2001)</td>
<td>Light-duty pickup</td>
<td>CNG + petrol bi-fuel</td>
<td>100-175</td>
<td></td>
<td>11 @ city; 14 @ highway</td>
</tr>
<tr>
<td>Ford – 2000 Econoline</td>
<td>Service van</td>
<td>CNG</td>
<td>150 @ city; 275 @ highway</td>
<td>$22,940</td>
<td>11 @ city; 14 @ highway</td>
</tr>
<tr>
<td>Ford – 2001 Econoline</td>
<td>Service van</td>
<td>CNG</td>
<td>150-275</td>
<td></td>
<td>11 @ city; 14 @ highway</td>
</tr>
<tr>
<td>Ford – Crown Victoria 2000</td>
<td>Full-sized sedan</td>
<td>CNG</td>
<td>100 @ city; 175 @ highway</td>
<td>$26,765</td>
<td>15 @ city; 22 @ highway</td>
</tr>
<tr>
<td>Ford – Crown Victoria 2001</td>
<td>Full-sized sedan</td>
<td>CNG</td>
<td>100-175 (up to 200-300 miles with optional tank)</td>
<td>$29,015</td>
<td>15 @ city; 23 @ highway</td>
</tr>
<tr>
<td>Honda Civic – GX 2000</td>
<td>4-door compact sedan</td>
<td>CNG</td>
<td>150 @ city; 200 @ highway</td>
<td>$20,230</td>
<td>28 @ city ; 34 @ highway</td>
</tr>
<tr>
<td>Honda Civic – GX 2001</td>
<td>4-door compact sedan</td>
<td>CNG</td>
<td>220 to 245</td>
<td>$20,600</td>
<td>28 @ city ; 34 @ highway</td>
</tr>
<tr>
<td>GM – Chevy 2001 Cavalier</td>
<td>4 door sedan</td>
<td>CNG + petrol bi-fuel</td>
<td>160</td>
<td></td>
<td>17 @ city; 23 @ highway</td>
</tr>
<tr>
<td>GM – 2000 Chevrolet 4WD &amp; GMC Sierra Bi-Fuel CNG Crew Cab Pickup</td>
<td>Light-duty pickup</td>
<td>CNG + petrol bi-fuel</td>
<td>150 for CNG and 400 for Gasoline</td>
<td>17 @ city; 23 @ highway</td>
<td></td>
</tr>
<tr>
<td>GM – 2000 Chevrolet C/K &amp;</td>
<td>Light-duty pickup</td>
<td>CNG + petrol bi-fuel</td>
<td>150 for CNG and 400 for</td>
<td>17 @ city; 23 @ highway</td>
<td></td>
</tr>
</tbody>
</table>


\(^5\) mpgge – mile per gasoline gallon equivalent
<table>
<thead>
<tr>
<th>Brand/Model</th>
<th>Type</th>
<th>Fuel</th>
<th>Price/Range</th>
<th>Mileage</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMC Sierra Bi-Fuel</td>
<td>Sub-compact</td>
<td>CNG Bi-fuel</td>
<td>560</td>
<td></td>
</tr>
<tr>
<td>GM – Chevrolet Cavalier</td>
<td>4 door sedan</td>
<td>CNG</td>
<td>125 @ highway</td>
<td>$23,135</td>
</tr>
<tr>
<td>Toyota – CNG Camry (2000)</td>
<td>Transit/Shuttle bus (49 passengers)</td>
<td>CNG</td>
<td>425</td>
<td>$150,000 to $185,000</td>
</tr>
<tr>
<td>Toyota – CNG Camry (2001)</td>
<td>Transit/Shuttle bus</td>
<td>CNG</td>
<td>300</td>
<td>$90,000 to $130,000</td>
</tr>
<tr>
<td>Blue Bird – CSRE (2000)</td>
<td>School bus (84 passengers)</td>
<td>CNG</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Blue Bird – 2000 LTC 40</td>
<td>Transit/Shuttle bus (49 passengers)</td>
<td>CNG</td>
<td>525</td>
<td></td>
</tr>
<tr>
<td>OmniTrans - School bus</td>
<td>Low-floor transit bus</td>
<td>CNG</td>
<td>$190,000 +</td>
<td></td>
</tr>
<tr>
<td>Champion - SoLo</td>
<td>Low-floor shuttle bus (30 passengers)</td>
<td>CNG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orion – Orion VI</td>
<td>Flow-flat floor bus</td>
<td>CNG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volvo – B10L Bus</td>
<td>Low-floor articulated bus</td>
<td>CNG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volvo - FL 618 42R Rear leaf</td>
<td>Platform &amp; Box truck</td>
<td>CNG</td>
<td>400 to 480</td>
<td></td>
</tr>
<tr>
<td>MAN – NL202</td>
<td>35 seat Low floor bus</td>
<td>CNG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OmniTrans - Service Truck 1</td>
<td>Heavy duty service truck</td>
<td>CNG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OmniTrans - Work Truck</td>
<td>Heavy duty pick-up truck</td>
<td>CNG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freightliner – FL70</td>
<td></td>
<td>CNG</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Table 7.4: Fuel Cell Vehicle

<table>
<thead>
<tr>
<th>Company / Vehicle model</th>
<th>Vehicle type</th>
<th>Fuel</th>
<th>Fuel cell type</th>
<th>Range (miles)</th>
<th>Other remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>DaimlerChrysler – NECAR 4</td>
<td>5 passenger Compact car</td>
<td>Liquid hydrogen</td>
<td>PEMFC</td>
<td>280</td>
<td>Launch to be tested since 1999, and plan for delivery by 2004</td>
</tr>
<tr>
<td>DaimlerChrysler – NECAR 5</td>
<td>5 passenger Compact</td>
<td>Methanolized hydrogen MH2</td>
<td>PEMFC</td>
<td>248</td>
<td>The 1st vehicle of an entire fuel cell system with methanol reformer. Launched in 2000 and plan for delivery by 2004</td>
</tr>
<tr>
<td>DaimlerChrysler – Jeep Commander 2</td>
<td>Sport Utility Vehicle</td>
<td>Methanolized hydrogen MH2</td>
<td>PEMFC</td>
<td>155</td>
<td></td>
</tr>
<tr>
<td>DaimlerChrysler – NEBUS</td>
<td>City bus</td>
<td></td>
<td></td>
<td>155</td>
<td>The 1st Mercedes Benz fuel cell driven bus to operate on city streets since 1997</td>
</tr>
<tr>
<td>EvoBus GmbH – Citaro</td>
<td>Low floor city bus (70 passengers)</td>
<td>Compressed hydrogen</td>
<td>PEMFC</td>
<td>186</td>
<td>Expected to be delivered by the end of 2002</td>
</tr>
<tr>
<td>GM – HydroGen1 (Opel Zafira 3rd generation)</td>
<td>5-seat Compact van (i.e. minivan)</td>
<td>Liquefied hydrogen</td>
<td>PEMFC</td>
<td>250</td>
<td>Chosen to be the pace car for the marathon race at the 2000 Summer Olympics in Sydney; and intend to have a “production ready” fuel cell vehicle by year 2004</td>
</tr>
<tr>
<td>GM – Percept FCEV</td>
<td>5 passenger Family sedan</td>
<td>Hydride hydrogen storage system</td>
<td>PEMFC</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>BMW – 7 Series</td>
<td>Passenger sedan</td>
<td>Liquefied hydrogen</td>
<td>APUFC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ford – P2000</td>
<td>Midsize family sedan</td>
<td>Liquid or compressed hydrogen</td>
<td>PEMFC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nissan – R’nessa</td>
<td>Sport utility vehicle</td>
<td>Methanol-reformer &amp; Li-Ion battery</td>
<td>PEMFC</td>
<td></td>
<td>2nd generation fuel cell vehicle by 2000 and a commercial model in 2003</td>
</tr>
<tr>
<td>Honda – FCX-V1 &amp; FCX-V2</td>
<td>V1 (hydrogen); V2 (methanol reformer)</td>
<td></td>
<td>PEMFC</td>
<td></td>
<td>Start in 2003 for sale in Japan and the U.S.</td>
</tr>
<tr>
<td>Toyota – Fuel Cell RAV4</td>
<td>Sport utility vehicle</td>
<td>Methanol and Hydrogen</td>
<td>PEMFC</td>
<td></td>
<td>Plan to launch a commercial FCV in 2003</td>
</tr>
</tbody>
</table>

**Key:** PEMFC = Proton Exchange Membrane Fuel Cell; APUFC = Auxiliary Power Unit Fuel Cell