Internationale Konferenz
für Erneuerbare Energien, Bonn
International Conference
for Renewable Energies, Bonn

WCTR Society

Deutsche Gesellschaft für
Technische Zusammenarbeit (GTZ) GmbH

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Federal Ministry
for Economic Cooperation
and Development

Transport in Developing Countries: Renewable Energy or Energy Reduction?

- Side Event at the Renewables 2004 Conference -

Organiser: World Conference on Transport Research
Chairman: Prof. Dr. Werner Rothengatter

A Reader

Bonn, June 3rd 2004

Transport in Developing Countries:
Renewable Energy or Energy Reduction?
- Side Event at the Renewables 2004 Conference -

Organisers / Speakers

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Co-Organiser	Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH Division 44 - Environment and Infrastructure Transport and Mobility
“Options for Environmental Friendly Modes of Transport in Developing Countries”	Lloyd Wright University College London
“Land Use and Transport Planning and Energy Consumption in Cairo”	Prof. Dr. Ing. Ali Huzayyin Cairo University
“Technical Options for Conventional and Renewable Energies in Transport in Developing Countries”	Reinhard Kolke HJS Fahrzeugtechnik Menden Formerly: Bundesumweltamt (BMU)
“Biomethane/Compressed Natural Gas – a Regenerative Fuel for Today and Tomorrow”	Dr. Ing. Franz-Martin Dübel IMAK – Institut für Marktentwicklung alternativer Kraftstoffe

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Table of Contents

GTZ Policy on Renewable Energies in Transport in Developing Countries

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May 2004

1. Energy for Transport in Developing Countries

Worldwide, the transport sector consumes about one third of the primary energy and produces one fourth of greenhouse gas emissions (GHG). After the energy sector, transport is the most important producer of carbon dioxide. In contrast to the energy sector, global energy consumption and GHG emissions of the transport sector are still increasing. The problem is even more severe in developing countries where an enormous growth is required to catch up with the industrialised world. Experiences show that economic growth is strongly correlated to growth in transport volumes. Evidently, transport seems to be a precondition to achieve economic prosperity.

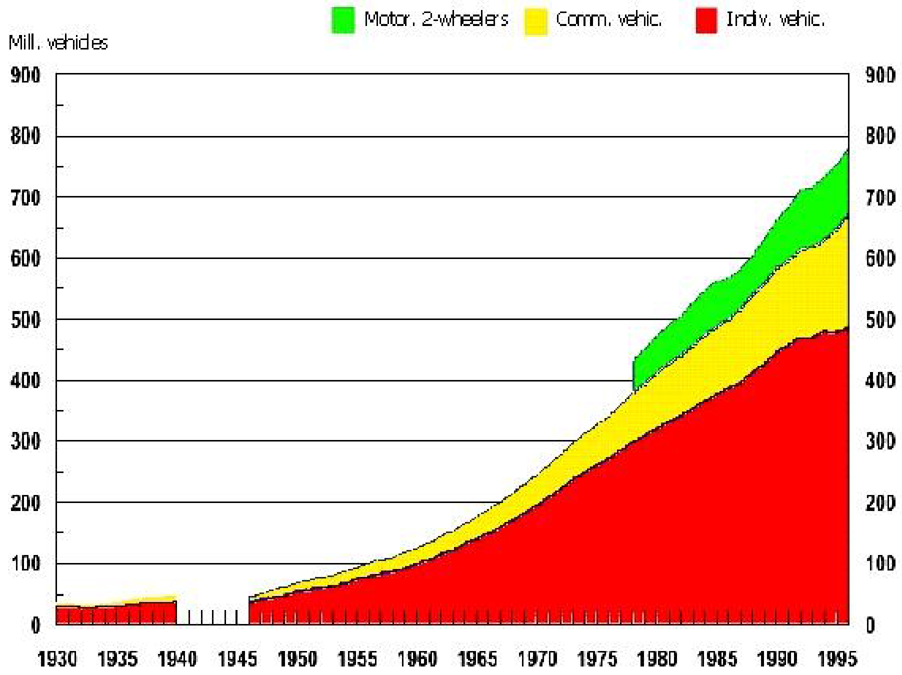

Figure 1: Motorisation trend worldwide from 1930 to 1995

However, the negative effects of transport such as emissions of greenhouse gases and pollutants are well acknowledged. Development strategies face a dilemma, since growth is highly desired, but not the negative effects of it. With regard to the topics of the Renewables 2004 Conference, GHG emissions and energy efficiency are of major importance. A sustainable transport strategy has to take into account the growing transport demands in developing countries and increase energy efficiency in order to minimise overall greenhouse gas emissions.

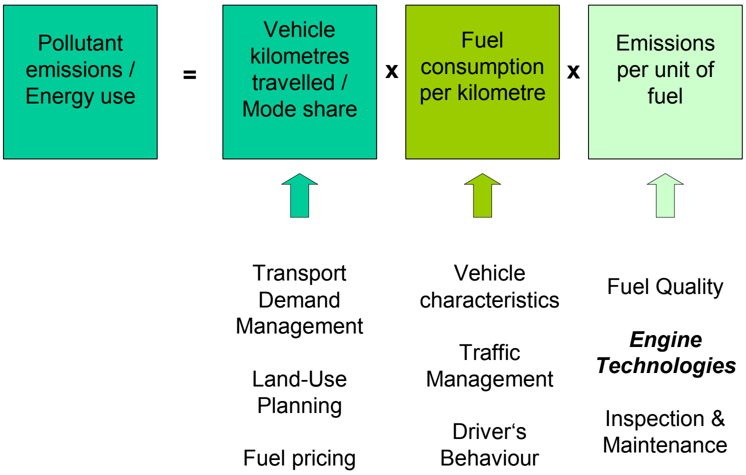

Figure 2: Energy Consumption is based on many factors

As depicted in Figure 2, transport emissions are dependent on the transport volumes, specific fuel consumption, and emissions per unit of fuel. The figure shows as well, that the transport planner has various leverage points in order to change emission volumes and energy consumption. This paper will focus on the most prominent measures such as

- Technical improvements and introduction of renewable energies,
- Modal shift to energy efficient means of transport,
- Measures to avoid transport through improved land-use planning
- Change of the economic frame conditions in transport.

2. *Technical Options for Conventional and Renewable Energies*

In industrialised countries public pressure has resulted in an increase of the energy efficiency of engines in transport, accompanied by improved emission regulations resulting in air pollution control technologies, such as three-way-catalytic converters, filters, etc. While emissions of pollutants largely decreased, fuel consumption and thus GHG emissions in transport increased, due to growing transport volumes and more powerful engines.

A significant share of the vehicle fleet in some developing countries consists of second hand vehicles purchased from industrialised countries. Therefore, the emission standards can be compared to those of used cars in the developed world. However, missing or insufficient inspection and maintenance of vehicles results in higher fuel consumption and emissions. An improved system of inspection and maintenance[1] would decrease CO_2-emissions by 3-7%. If additionally, emission standards, such as EURO II to IV are implemented, a significant decrease of pollutant emissions can be achieved in developing

[1] Sustainable Transport: A Sourcebook for Policy Makers in Developing Cities, Module 4b: Inspection & Maintenance and Roadworthiness

countries. Preconditions are the introduction of legal binding requirements for mandatory roadworthiness tests, combined with a set of regulations dealing with fines and other sanctions.

Additionally, driver training for an economically and ecologically sound driving style is a cheap method to save fuel and money contributing to road safety and greenhouse gas emission reduction. The average reduction of fuel consumption amounts to 10 %. Pay back periods of the training lessons are reasonably short. Nevertheless, the development of the market eco-driving is slow, at least on a European style.[2]

Next to the improvement of conventional engine technologies, a number of new and renewable technologies have the potential to enhance the energy efficiency of vehicles:

- **Natural Gas Vehicles (CNG)** produce 15 to 20 percent less GHG emissions than gasoline vehicles due to a 25 percent lower carbon content of natural gas compared to gasoline. A conversion of conventional engines is possible, but causes additional costs to the vehicle owner. No impact can be expected form the conversion of diesel powered heavy-duty vehicles. Another problem is refuelling and storage of gas. Since large-scale investments are necessary to build a countrywide refuelling network, the conversion of vehicle fleets, such as taxis or buses is recommended.

- **Liquefied Petroleum Gas (LPG)** has similar features as natural gas, regarding the environmental impacts, but GHG emissions are slightly higher. Since LPG is collected from oil wells, where it is usually burned, its supply is limited.

- **Biodiesel** has strong impacts on greenhouse gas mitigation, since no fossil carbon dioxide is burned. A 1998 biodiesel lifecycle study, jointly sponsored by the US Department of Energy and the US Department of Agriculture concluded that the use of biodiesel reduces net carbon dioxide emissions by more than 75% compared to petroleum diesel. This is due to biodiesel's closed carbon cycle[3]. However, negative environmental impacts can be expected from the side effects of agricultural production caused through monocultures, excessive fertiliser use etc. Presently, the high cost of biodiesel fuel is one of the principal barriers for its extensive, which can only be reduced by higher tax incentives. A long term cost reduction for developing countries is not expected. Biodiesel causes similar particulate emissions as Diesel engines. These can be reduced by particulate traps (e.g. on buses) in the same way as in Diesel vehicles.

- **Methanol** can be produced from natural gas or from wood or cellulose. Strong impacts on GHG emissions can be expected, if it is produced from biomass, which reduces emissions by 60% compared to petrol. However, there are little prospects that in the near future methanol will become price competitive with conventional fuels.

- **Ethanol** is produced by the fermentation of starch from grain and thus has strong impacts on CO_2 emissions. Worldwide, the largest application is the Brazilian Proalcool Programme, which is only viable with massive government

[2] http://www.ecodrive.org
[3] National Biodiesel Board, USA, http://www.biodiesel.org

subsidies. Additionally, negative environmental impacts are caused by large-scale monocultures in Brazil.

- **Hydrogen** as a source of transport energy is only reducing GHG emissions, if it is produced using renewable resources. The total life cycle shows, that using other fossil primary energy for the production of hydrogen does not result in a net CO_2 advantage. Despite its promising potentials as an environmental friendly source of energy in transport, the technology is presently not sufficiently developed for a widespread and cost efficient use in developing countries.

- **Fuel cells** can have an impact on GHG emissions, if renewable energies are used to produce the hydrogen. Presently, hydrogen technology is not sufficiently developed to be used on a large scale in industrialised countries. It is not advisable to introduce technologies in the South, which have not been sufficiently tested in the North regarding their technical and economical viability.

- **Electric Vehicles** have a strong potential impact on CO_2 emissions, depending on the mode of the electricity production. Countries such as Brazil, having a large share of hydropower are more favourable. Electric vehicles are less noisy and produce no local emissions. Disadvantage is still the limited range of the vehicle, which requires frequent refuelling. Therefore their usage makes sense in ecological very sensitive areas and in urban areas.

Even though the effects of new energy sources in transport might be promising, their potential for actual usage in developing countries is quite limited. Where natural gas is readily available, strong considerations should be given to replace diesel buses with CNG buses. Where natural gas or LPG is readily available, two stroke engine autorikshaws should be considered for replacement with CNG or LPG. Economic incentives should be provided in order to stimulate the introduction and acceptance of the fuels.

Regenerative sources of energy, such as biodiesel, methanol and ethanol are not price competitive to conventional fuels. A table produced by GTZ, given in the annex, shows that the prices before taxes of conventional fuels amount to 26 - 28 cents per litre, while the prices for regenerative fuels range between 30 and 66 cent.

Other technologies such as fuel cells and hydrogen engines are not sufficiently developed and are not yet ripe for a competition on the market. They cannot be recommended on a short term basis until further testing and development has been made in the industrialised countries and economic competitiveness with conventional fuels has been proved.

As technical improvements are limited in developing countries, planning approaches are needed to reduce energy consumption in transport in order to meet greenhouse gas reduction targets.

3. Options for Energy efficient Means of Transport

Individual means of transport have a higher energy consumption per person transported compared to public and non-motorised modes of transport. In general, passengers driving in cars in industrialised countries consume roughly 3 to 5 times more energy than passengers transported by public modes of transport[4]. Obviously, non-motorised means of transport use even less energy.

Thus, energy efficiency in transport can be increased tremendously by shifting passengers from individual to public modes of transport, and to non-motorized means of transport, especially in developing countries where motorisation is still in its infancy. Transport Demand Management (TDM) encompasses many measures, starting from traffic calming, alternative work schedules, encouragement of walking and cycling, road pricing and including the improvement of mass transport systems, just to mention a few. The module on Mobility Management in the GTZ Sourcebook on Sustainable Urban Transport[5] gives an overview on these issues.

Most important for Transport Demand Management is the choice of the system for mass transportation, since large-scale investments are related to its implementation. The experience in industrialised countries shows, that often mass rapid transit systems, such as metros, commuter rails or light rail transit are not economically viable. Practically no European mass transit system operates without large-scale subsidies. Investment costs are very high, if subterranean metro lines are to be constructed.

In developing countries the problems are more acute, since public funds are even scarcer than in industrialised economies. Appropriate solutions have been developed in Latin America, using high-quality busses for public urban transport. The Module on Bus Rapid Transit of the GTZ Sourcebook[6] indicates the following characteristics of the system:

- Segregated bus ways with transit prioritisation at intersections,
- Rapid boarding and alighting using pre-paid tickets,
- Clean, secure and comfortable stations with real time information displays and
- Modal integration of railways and non-motorised means of transport at the bus stations and terminals,
- "Soft" characteristics, such as marketing identity (brand) or advanced customer service

A comparison with conventional mass rapid transit systems shows, that Bus Rapid Transit can achieve comparable results to rail systems regarding carrying capacity and service while average speed is slower, mainly due to shorter distances between bus stops. The main advantage are significantly lower investment costs, especially if compared to subterranean Metro systems. Disadvantage is the large surface areas required by the buses in case of four-lane-operations.

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[4] Data used from Umweltbundesamt and Verkehr in Zahlen 2002/2003.

[5] Sustainable Transport: A Sourcebook for Policy Makers in Developing Cities, 2003, Module 2b: Mobility Management

[6] Sustainable Transport: A Sourcebook for Policy Makers in Developing Cities, 2003, Module 3b: Bus Rapid Transit.

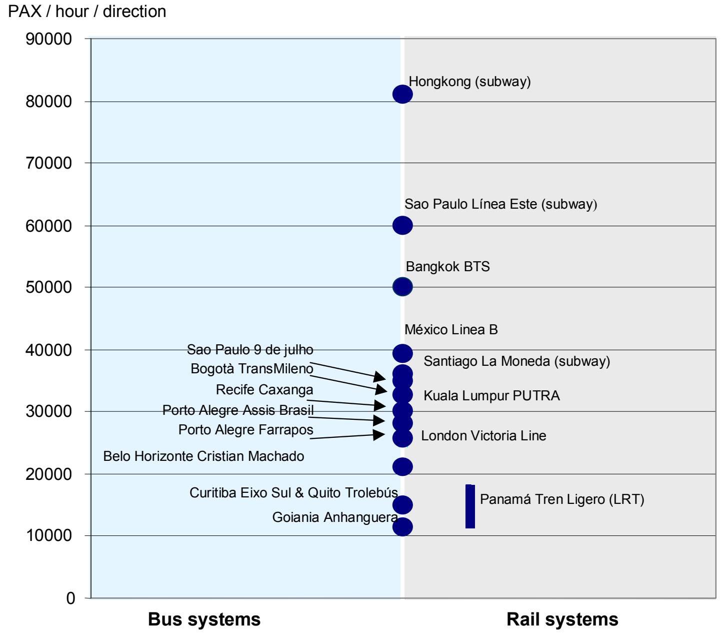

Figure 3: Comparison of Capacties for Rail and Bus systems

One of the most prominent examples is Bogotá's Bus Rapid Transit System, known as TransMilenio, which has achieved remarkable success since it's opening in December 2000. The TransMilenio system currently serves nearly one million passenger trips each day over 58 kilometres of exclusive bus ways. Nearly ten percent of TransMilenio passengers are former private vehicle commuters. Bogotá is one of the few cities in the world, which have dramatically gained public transport ridership. Perhaps most impressively, Bogotá has accomplished this achievement with a system that operates with no public subsidies.

Figure 4: Modern vehicles and up-to-date stations are key features of BRT-systems

4. Transport Avoidance through Land-Use Planning

The spatial development in industrialised countries can be characterised by a concentration in the cities, which took place during the industrialisation phase, followed by a process of massive sub urbanisation after the establishment of the automobile as the main mode of transport. During this period, urban sprawl did not only take place along the railway lines, but the entire suburban area around conurbations was used for settlements. Cars allowed for a decentralisation of urban functions, i.e. to live in the countryside in detached houses and commute to the urban centre for work.

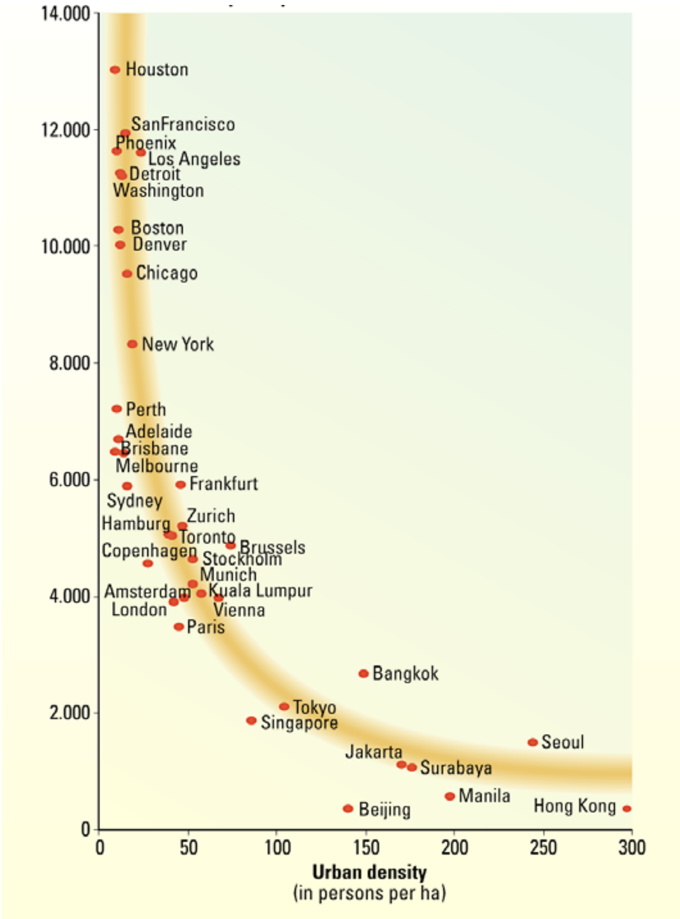

Figure 5: Annual car use per capita (1990) and urban population density **(Source: Kenworthy & Laube, et. al., 1999)**

Urban sprawl produced spatial structures, which imply long commuting distances and are less favourable to be served by public transport systems. Given the energetic advantage of public transport, suburbia is a settlement structure, which entails large-scale energy inefficiencies in transport. An international comparison of cities[7] shows that a tight nexus exists between urban density and car use (mileage). The higher the density, the lower the specific energy consumption in transport.

[7] Kenworthy, Laube 1999, depicted in: Sustainable Transport: A Sourcebook for Policy Makers in Developing Cities, 2003, Module 2a Landuse Planning.

Figure 6: Similar population but different size: The impact on transport is obvious

In developing countries the process of suburbanisation is still often in early stages. Even so called megacities, such as Cairo cover a surface which comprises only a small fraction compared to cities in industrialised countries, such as Los Angeles, even though both conurbations host approximately the same number of inhabitants. However, it can be expected, that in the future course of development, income in developing cities will increase and similar processes of sub urbanisation can be expected in the South, which have already taken place in the North.

Since spatial developments are very difficult to reverse, it is advisable to influence urban sprawl in a manner, which reduces future increases of energy consumption in urban transport. The target is a city of short travel distances. A number of urban and transport planning measures can be taken in order to achieve this goal. Here are the most important measures:

- Establishment of a regional administrative (and if possible as well political) entity, which is able to coordinate regional planning in and outside administrative city borders. Its main task is the design and strict control of regional land use schemes.

- Set up of regional development plans, using a concept of decentralized concentration, according to a system of corridors and points. While the main points are formed by the central business district, urban sub-centres and satellite towns, the corridors are rapid mass transit systems connecting these centres.

- Settlement patterns are determined by mixed land use, with high urban densities around public transport stations and green belts forming barriers against urban sprawl. New major developments have to be located near existing high capacity transit routes.

- An efficient public transport system and a traffic management scheme are preconditions for the functioning of the city. An improvement of facilities for non-motorised means of transport such as walking and bicycles is an important measure to make short trips more attractive.

- Economic incentives can be created in order to support the desired spatial development: taxes on land property, regional road pricing schemes and incentives for dense new developments. Subsidies for commuters are counter productive.

The city of short distances is liveable, needs less transportation, produces less external effects and consumes less energy in transport. If early measures are taken, mistakes made in industrialised countries during the last decades can be avoided in developing cities.

5. Economic Instruments[8]

The presently rising fuel prices demonstrate that the procurement of conventional fuels is a key problem for many developing countries, which are not producing oil themselves. In the transport sector more than 90% of transport modes use conventional fuels, which have to be imported. In low-income countries fuel imports often represent up to one third of all foreign imports, causing large imbalances of trade. Thus, measures to increase energy efficiency in transport have strong impacts on the whole economy of developing countries.

In addition, the fuel sector can be an important source of revenue for the state. Taxes on fuel and energy may comprise up to 36 % of all state taxes – or in the reverse case – fuel subsidies may form a burden of up to 8% of the state budget. Worldwide, the roads are financed by revenues from fuel taxation and fuel taxes form a basic issue of the road network development in developing countries. In European countries, the revenues for the road sector are more often than not also used to finance general government spending, such as social expenditures.

Therefore, pricing and taxation issues for conventional fuels are of primary importance. The GTZ booklet on International Fuel Prices and Taxation[9] covers all major countries and forms an information basis for political pricing issues in each of the 165 countries covered in the booklet.

Next to the issue of revenue collection, fuel taxes may serve as a means of environmental taxation. Economic instruments are most important to achieve improvements of energy efficiency in transport. The instruments may serve to reinforce or support the above-mentioned measures regarding introduction of renewable energy sources, transport demand management and transport avoiding land-use planning. Conventional taxes, such as fuel levy and vehicle licences fees may focus on the reduction of environmental effects of transport, e.g. by favouring more energy efficient engines. Transport specific instruments, environmentally oriented vehicle taxation, road tolls and spatial/temporal differentiated road pricing systems may serve as efficient tools to change regional transport patterns toward energy efficiency.

[8] Sustainable Transport: A Sourcebook for Policy Makers in Developing Cities, 2003, Module 1d Economic Instruments.
[9] International Fuel Prices; 3rd Editon May 2003.

6. Conclusions

The Renewables 2004 Conference Issue Paper[10] states that the cheapest and most sustainable energy source is the improvement of energy efficiency. This holds as well true for the transport sector in developing countries. Even though promising impacts from renewable sources of energy can be expected, uncompetitive prices and little testing in developed markets restrict their actual use. Therefore it is recommended, that renewable energy should be supported in applications, where the renewable energy source can substitute fossil energy and fuels directly, without conversion into an automotive fuel. Good examples are biogas-use or solar thermal energy for heating and cooking, or solar electricity for lightning.

However, there are a number of strategies to reduce energy consumption and thus improve energy efficiency in transport. They focus mainly on the fast growing cities in developing countries. Modal shift towards more energy efficient means of transport – or the retention of the existing high share of people walking, cycling or using transit – and the planning of cities with short distances are two issues, which will be of crucial importance in order to secure liveable cities.

To date, emission reductions from the transport sector have not played a significant role in the Kyoto mechanisms, such as the Clean Development Mechanism or Joint Implementation. Only very few transport related projects have been registered under these mechanisms. Action is urgently needed.

[10] Conference Issue Paper, Renewables 2004, p.12

7. References

Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung, December 2003, Materialien: *Transport und Verkehr – Zukunftsfähige Mobilität für eine gerechte und nachhaltige Entwicklung*, Bonn.

Sustainable Transport: *A Sourcebook for Policy Makers in Developing Cities*, The Sourcebook, a set of 20 printed modules on key topics of urban transport focusing on developing cities, is available in print. The Sourcebook is not sold for profit. Any charges imposed are only to cover the cost of printing and distribution. Further information and an order form can be retrieved from http://www.sutp.org/docs/sourcebook/sourcebook.aspx.

International Fuel Prices, 3rd Edition May 2003, The booklet produces comparative tables on fuel prices for over 165 countries. It contains special sections on fuel taxation for state financing, fuel subsidies and government tax calculation. The booklet is available in seven languages and comprises 114 pages. It may be downloaded free of charge from http://worldbank.org/transport or http://zietlow.com/docs/engdocs.htm

World Bank (1994): World Development Report 1994 – *Infrastructure for Development*, Oxford University Press, New York.

WBCSD – World Business Council for Sustainable Development (2001): *Mobility 2001 – world mobility at the end of the twentieth century and its sustainability*.

8. Annexes

Price and Tax Comparison of Alternative Fuels

(Germany, Dec. 2002, 1 US-$ = 1 €)

	Automotive fuels Price per litre (in Germany, EU-Cent per litre, December 2002)	Annual consumption in Germany in mio. tons (1)	World market price for crude oil at 27 € per barrel (2)	Hypothetical sales price without taxes (3)	Fuel tax per litre (4)	VAT (16 %) (5)	Actual sales prices per litre December 2002 (6) = (3)+(4)+(5)	Additional costs for engine-adaption (7)	Tax revenues from transport fuels 2002 (8)
Conventional fuels	**Global oil reserves : 50 years**								
	Regular gasoline	(8,4)	16 [6]	26	62	15	103	-	5 bn €
	Super gasoline	(18,8)	16 [6]	28	62	15	105	-	12 bn €
	Diesel	(28,6)	16 [6]	28	44	11	83	1500-2500 € [3]	13 bn €
	Fuel oil (light + heavy)	(35,4)	16 [6]	28	6	5	39		2 bn €
	Kerosene	(4,2)	16 [6]		0				0 bn €
Alternative fuels	**Global gas reserves : 60 years**								
	Liquified Petroleum Gas 6-8 bar (Butane-Propane)			42	15	8	44 - 55	2000 €	0 bn €
	Compressed Natural Gas 150 bar			25	12	7	(44)	1500-3500 €	2 bn € [13]
	Global coal reserves: 200-400 years								
	Coal liquification (32 per cent of all fuels in South Africa)		1 [15]		-		(40)		
	Conventional electricity for electric powered vehicles				-		17 / kWh	1000 € [21]	
	Renewable fuels								
	Green electricity for electric powered vehicles				-		22 / kWh	1000 € [21]	
	Bio-Diesel			66	0	10	76	0 [2]	0 bn €
	Vegetable oil		48 [7]	57	0	9	66		0 bn €
	Ethanol (Sugar Ethanol / Brazil)			(30-40)			(44)		
	Bio-Gas (Methane, CO2)				0				0 bn €
	Oxygen (Fuel cell)				0		n.a.	25000 € [4]	0 bn €

1 bn = 1000 million

1) In Germany: Fixed at 20 per cent of Super Gasoline tax till the year 2020
2) VW, BMW and Mercedes: Diesel-Version
3) Gasoline-Efficient-Version Peugeot 204, VW Lupo (3-litre vehicle)
4) favoured by General Motors Research (not yet in series production)*, CO-sensitive
5) Fuel reserves at current consumption and price level (according to MWV, reserves will last for more than 100 years at higher price levels)
6) 16 US-Cent/Litre = 27 US-$/barrel
7) Soy bean oil and palm oil are the "cheapest" vegetable oils worldwide A 5 per cent admixture with diesel is possible (EU-directive).
8) converted to prices per litre. At gas stations price is 66 Cents per kg, as 1 kg translates (in terms of power) to ca. 1,5 litres of Super-gasoline (400 gas stations)
9) favoured by Daimler-Chrysler research with the target: 2 litres diesel per 100 km*
10) Info: **www.clever-tanken.lu** (200 gas stations), price in Holland 44 cent/litre
11) not suitable in winter conditions (**www.camen-ev.de**)
12) Taxes from fuels (incl heating oils etc) in total 42.2 bn € (ref. ARAL-Taschenbuch), no tax compensation has yet been found for the use of alternative fuels
13) total of LPG and CNG 14) Abroad: Admixture with diesel up to 20 %
15) "Electricity coal" in South Africa is only about 8 € per ton with energy-equivalent of 1 Cent per litre
16) according to Mineralöl-Wirtschafts-Verband Hamburg MWV (Association of the German Petroleum Industry, **www.mwv.de**)
17) Sales price for diesel in South Africa 2002 (with guarantee of subsidy for producer if world price level for crude oil is below 30 $ per barrel)
18) From 01 January 2003 a 3 Cent per litre eco-tax increase is added
19) Main cultivation area Brazil (ethanol from sugar cane), L.Fulton/IEA-Paris (TRB 2004)
20) Prices MAINOVA / Frankfurt Main
21) Additional price for energy-bike (**www.nefkom.net/eebike**) + additional costs for mercury cells (which would triple the above mentioned costs)
*) Source: World Fuel Conference Washington D.C. 10/2003

Analysis of prices in column 6

1.) As of the alternative fuels, only CNG is competitive without governmental interventions. But engine adaptations and gas station networks are required.

2.) Abroad, liquefied coal (South Africa) and Ethanol from sugar canes (Brazil) are competitive at a crude oil price level of 30 $ per barrel.

3.) In Germany, up to now renewable fuels are only competitive at a 2 to 3-fold crude oil price level. This is counter balanced by tax reductions fixed up to the year 2020.

The Limits of Technology: Achieving Transport Efficiency in Developing Nations
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May 2004

Abstract

Emissions from the transport sector represent the fastest growing source of greenhouse gas emissions. There is little prospect that this situation will be resolved with a single technological fix. As developing nations quickly move to catch up with the motorisation levels of developed nations, the sheer number of private vehicles on the roadways will overwhelm any advances made by cleaner fuels. By the year 2030, there is projected to be more vehicles in the developing world than in developed nations. However, most developing cities today still have the basis for a more sustainable future. Public transport and non-motorised transport (walking and cycling) still command a dominant share of travel in developing cities. Thus, a key objective for local and international initiatives is to preserve existing mode shares. Unfortunately, most investment in reducing transport emissions relies exclusively upon achieving costly reductions only through fuel and propulsion system technologies.

Bogotá (Colombia) represents one of the best examples of a city that has developed a package of complementary measures to substantially reduce vehicle emissions and congestion. Bogotá's implementation of a high-quality bus rapid transit (BRT) system, bicycle infrastructure, pedestrian improvements, car-free events, and auto restriction measures all have contributed to an urban transformation in a period of just a few years. Initial projections of greenhouse gas reductions during the first 30 years of the BRT system's operation indicate reductions of approximately 14.6 million metric tons of CO2 equivalents.

This research presents a framework for evaluating the greenhouse gas emission reductions in the transport sector. This framework highlights three principal areas of emission reduction potential: 1.) Mode share (behaviour); 2.) Distance travelled (land-use/design); and 3.) Fuel efficiency (technology). Only by addressing all three components an optimum transport energy path can be achieved.

1. Introduction

The specter of rapidly growing private vehicle ownership and usage in developing nations casts a worrying shadow over the projected course of global greenhouse gas emissions. If nations such as China and India follow the same path of automobile dependence as developed nations, there is little that technological advances can offer to offset such a monumental increase in motorisation and its subsequent emissions. The resulting emissions from millions of new vehicles will overwhelm the reductions achieved through improved fuel and propulsion technologies.

However, most developing-nation cities today still have the basis for a more sustainable future. Public transport and non-motorised transport (walking and cycling) still command a dominant share of travel in developing cities. Unfortunately, the quality of these modes is often quite poor with regard to security, comfort, convenience, and prestige. The sum effect of inadequate public transport and difficult conditions for walking and cycling means that most developing-city citizens will move to to motorised vehicles as soon as it is economically viable to do so. Thus, a central tennent behind a more efficient and sustainable transport future in developing cities must be the preservation of existing mode shares for public transport and non-motorised options.

This article outlines the relative emissions impacts of technological-based solutions versus options related to the preservation of mode share and improvements in land use. The urban transformation of Bogota (Colombia) is used to illustrate the potential of low-cost, low-technology mechanisms to achieve dramatic improvements in urban mobililty and emission reductions. Ideally, a more optimum transport energy path can be achieved if mode share, land use, and vehicle and fuel technology are developed as a sustainable package. Relying exclusively on only one of these elements is unlikely to stem the negative impacts associated with the projected growth of motor vehicle usage in developing cities.

2. Trends in Developing-Nation Transport

2.1 Emissions and lLvels of Motorisation

Despite international concerns over global climate change and energy security, few effective remedies have been developed to curb fuel consumption from the transport sector. Current estimates show that the transport sector represents from 22 per cent to 24 per cent of global greenhouse emissions from fossil fuel sources, second only to the industrial sector. By all accounts, though, the transport sector is the fastest growing sector with respect to emissions. Table 1 summarises sectoral contributions to greenhouse gas emissions.

Table 1: Global greenhouse gas emissions from fossil fuel combustion by sector (1995)

Sector	Mega-tonnes (Mt) of carbon	Percent of total emissions	Average growth rate (1990-1995)
Industry	2,370	43%	0.4
Transport	1,227	22%	2.4
Residential buildings	1,171	21%	1.0
Commercial buildings	584	10%	1.0
Agriculture	223	4%	0.8
Total	5,577	100%	1.0

Source: Price et al. (1998)

The planet will soon reach a milestone of being resident to over 1 billion motorised vehicles. From 1995 to 2030, worldwide vehicle ownership is expected to grow by 228% to over 1.6 billion vehicles (OECD and EMCT, 1995). As noted in table 2, the bulk of this growth will take place in the developing world. Growth in motorised vehicle ownership is due to several factors with per capita income explaining potentially 70 per cent to 80 per cent of the increase (IIEC, 1996). Dargaya and Gately (1999) show that in the income range of US$ 2,000 to US$ 5,000 vehicle purchases jump sharply. Other factors affecting vehicle ownership growth are population growth, urbanisation levels, importation regulations, and the quality of alternative transport services.

Table 2: Expected growth in world vehicle ownership

	1995		2030	
Region	**Cars (000)**	**Vehicles (000)**	**Cars (000)**	**Vehicles (000)**
OECD countries	383,329	536,174	621,091	842,257
Non-OECD (developing countries)	111,255	240,357	391,755	781,130
Global Totals	494,584	776,531	1,012,846	1,623,387

Source: OECD and EMCT, 1995

The amount each vehicle travels also seems to be growing as well. Based on data from Newman and Kenworthy (1999), the growth in annual car use (kilometres) and average journey-to-work distances was evident in most parts of the world. While some researchers had previously projected that market forces would encourage a levelling off of distances travelled due to a dispersal of jobs to the suburbs (Gordon and Richardson, 1989), little evidence to date suggests that this is the case (Newman and Kenworthy, 1999). Schafer and Victor (1997) project that global travel distance will more than double from 1990 to 2020, and then redouble by 2050.

Despite the advent of more efficient fuel and propulsion technologies, such as hybrid-electric vehicles, petrol consumption has largely followed the increase in motorised vehicle usage. Table 3 provides a summary of world petroleum consumption (Davis and Diegel, 2002). The transportation sector consumes approximately 67 percent of world petroleum use (Davis and Diegel, 2002).

Table 3: World petroleum consumption (millions of barrels per day)

Year	United States	Total OECD	Total non-OECD	Total
1990	16.99	44.92	25.05	65.97
1995	17.73	44.96	24.92	69.88
2000	19.70	47.92	27.61	75.53

Source: Davis and Diegel, 2002

New technologies and new emission standards have allowed a stabilisation, and in some cases, a reduction in local air pollutants. Such pollutants as particulate matter, nitrogen oxides, and carbon monoxide are of particular importance to developing-city policy makers since the local health costs have significant ramifications on health care provision and economic development. The tightening progression of emission standards set by the European Union and the United States Environmental Protection Agency (USEPA) have led to cleaner air in the urban areas of developed nations. Table 4 gives the projected global trends in emissions of carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx). Interestingly, these figures illustrate an initial improvement based upon improved fuels and emission technologies, but such improvements are ultimately offset by the expected rise in vehicle ownership. Thus, even accounting for vast advances in vehicle technologies, the increasing number of vehicles will simply overwhelm these advances.

Table 4: Expected global trends in emissions of CO, HC, and NOx (million of tonnes)

Pollutant	1995	2000	2010	2020	2030
CO	201.6	178.4	121.6	123.1	154.2
HC	32.3	29.4	29.2	34.4	43.0
NOx	30.2	28.4	29.7	36.0	45.1

Source: OECD and EMCT, 1995

The extent to which developed-nation standards have contributed to lower emissions in developing nations is far from clear. In many nations, there are few controls on limiting the importation of older used vehicles. An older vehicle fleet in conjunction with poor maintenance practices and limited vehicle testing can mean that the impacts of motorisation on developing nations are many times worse than an equal level of motorisation in a developed nation.

There is one type of emission for which there is little doubt over its projected course. Greenhouse gas emissions, and particularly carbon dioxide (CO_2), are increasing at unprecedented levels. The emission control technologies that are somewhat stabilising local pollutants (CO, NOx, particulates, etc.) are doing little if anything to address rising CO_2 emissions. Further, as noted previously, the addition of rapid motorisation in developing nations has only exacerbated the trend set by the developed world:

> "In 1999, the last year for which data are available, the transport sector was the source of approximately 24 percent of global energy-related carbon dioxide emissions. This represents an absolute increase of 1017 million tonnes of carbon dioxide and a share gain of 2.4 percent since 1990. Worldwide, emissions of carbon dioxide from the transport sector are projected to grow at the rate of 2.5 percent each year through 2020. The growth rates of transport sector carbon emissions in the developing world and in economies in transition are projected to be even higher – 4.0 percent per year and 3.3 percent per year, respectively" (OECD and IEA, 2001).

Table 5 shows the projected trends in carbon dioxide emissions for both developed and developing nations. The OECD and EMCT (1995) project that by 2030 carbon dioxide emissions will grow to be nearly 70 per cent above the 1990 baseline. By contrast, the Kyoto Protocol calls for "Annex B" countries (principally OECD countries) to actually reduce overall emissions from the 1990 baseline. Additionally, by 2030, CO_2 emissions from non-OECD countries are projected to overtake emissions from the OECD.

Table 5: Projected growth in carbon dioxide emissions from the transport sector (billion of tonnes)

Region	1990	2000	2010	2020	2030
OECD countries	2.834	3.056	3.403	3.405	3.301
Non-OECD countries	1.135	1.585	2.092	2.670	3.426
Global totals	3.969	4.641	5.495	6.075	6.727

Source: OECD and EMCT (1995)

2.2 Public Transport

While private vehicle usage is reaching unprecedented heights, the same cannot be said of the state of public transport. In much of the world, public transit usage is decreasing at a fairly steady rate. In developing cities, continued penetration of motorised modes and general dissatisfaction with the quality of transit services has contributed greatly to the steady mode share loss. Table 6 documents the loss of public transport mode share across several cities. In general, public transport is relinquishing a 0.2 to 1.4 mode share percentage annually (WBCSD, 2001).

Table 6: Trends in mode share of public transport in selected cities

City	Earlier year	Public transport as a percentage of motorised trips	Later year	Public transport as a percentage of motorised trips
Bangkok[1]	1970	53	1990	39
Buenos Aires[2]	1993	49	1999	33
Kuala Lumpur[3]	1985	34	1997	19
Mexico City[4]	1984	80	1994	72
Moscow[4]	1990	87	1997	83
Sao Paulo[4]	1977	46	1997	33
Seoul[4]	1970	67	1992	61
Tokyo[4]	1970	65	1990	48
Shanghai[4]	1986	24	1995	15
Warsaw[4]	1987	80	1998	53

Source: 1. Barter (1999); 2. Secretaría de Transporte (2001); 3. City Hall Kuala Lumpur (2001); 4. WBCSD (2001)

A visit to any number of developing cities can quickly reveal the source of customer dissatisfaction with public transport and non-motorised options (Figures 1 and 2). Poor transit services in the developing world push consumers to private vehicle options. Public transport customers typically give the following reasons for switching to private vehicles:

1. Inconvenience in terms of location of stations and frequency of service;

2. Failure to service key origins and destinations;

3. Fear of crime at stations and within buses;

4. Lack of safety in terms of driver ability and the road-worthiness of buses;

5. Service is much slower than private vehicles, especially when buses make frequent stops;

6. Overloading of vehicles makes ride uncomfortable;

7. Public transport can be relatively expensive for some developing-nation households;

8. Poor-quality or non-existent infrastructure (e.g., lack of shelters, unclean vehicles, etc.)

9. Lack of an organised system structure and accompanying maps and information make the systems difficult to use; and

10. Low status of public transit services.

Figures 1 and 2. *The poor quality of public transport in developing cities creates great hardship for the citizenry.*

However, all of these problems can be rectified within the modest budgets of developing-nation municipalities. Cities such as Bogotá (Colombia), Curitiba (Brazil), and Quito (Ecuador) have dramatically improved transit services with simple solutions. In each case, the city relied upon low-cost improvements in public transit and non-motorised infrastructure rather than expensive tailpipe technologies.

In reality, virtually all developing cities possess a significant advantage in terms of achieving a more sustainable urban form. Most developing cities already posses a high mode share for public transit and non-motorised modes as well as a fairly high-density, mixed use design pattern. The challenge for these cities is to improve and modernise their transport systems in order to preserve their inherent advantages. Table 7 provides mode share data from a sampling of different developing cities.

Table 7: Mode share of urban transport in selected developing cities

City	Mode share (percentage of daily trips)			
	Non-motorised transport	**Public transport**	**Private motorised vehicles**	**Other**
Bamako, Mali (1984)	63	12	26	0
Havana, Cuba (1998)	57	27	6	11
Hanoi, Vietnam (1995)	54	4	42	0
Ouagadougou, Burkina Faso (1994)	52	3	45	0
Cairo, Egypt (1998)	36	47	17	0
Sao Paulo, Brazil (1997)	35	33	31	1
Santiago, Chile (1991)	20	56	16	9
Bogotá, Colombia (2000)	15	71	12	2

Source: Vasconcellos (2001), WBCSD (2001)

The loss of mode share from public transport and non-motorised options towards private vehicles is not pre-ordained. Municipal leaders who wish to transform their cities and provide efficient mobility can do so with a relatively low-cost and low-technology approach. To make this happen, the challenge is typically more political than technical.

Unfortunately, in developing nations such as China, policy making has seemed to take a different direction. Official policy in China has worked towards promoting vehicle use at the expense of non-motorised options. In recent years, China's vehicle ownership level has been growing by as much as 40 per cent each year (Whitelegg and Haq, 2003). The Mayor of Beijing exuded pride in the fact that the city's construction of a fifth and sixth ring road "beats the number of ring networks in Paris and Tokyo" (Gittings, 2002). The automobile is officially touted as a symbol of progress and modernity for China.

In cities, such as Shanghai and Guangzhou, that are promoting automobile manufacturing, bicycle mode share has fallen dramatically. In Shangahi mode share has gone from 33 per cent in 1995 to 27 percent in 2000; in Guangzhou mode share has fallen from 33 per cent in 1995 to less than 20 per cent in 2002 (Hook, 2002). Most major Chinese cities are actively discouraging bicycle use through priority measures for automobiles and through the neglect of non-motorised infrastructure. In December 2003, Shanghai officials announced a new policy of effectively banning bicycles from central portions of the city.

If China manages to reach a vehicle ownership level equal to that of the United States, the global vehicle fleet would grow by approximately 1 billion. If India was to do the same, then another 740 million vehicles would be added to the global fleet. Even at European ownership levels, China is still adding nearly 550 million vehicles. Clearly, decisions in developing cities today have profound global ramifications.

3. Framework for Transport Emissions

To understand the relative importance of behavioural (mode share) and land-use measures relative to technology measures in reducing greenhouse gas emissions, an appropriate analytical framework is needed. The International Energy Agency (IEA) and University College London (UCL) are currently working to development such a framework and to better understand contributions from each individual component.

As noted in Figure 3, all three elements (behaviour, land-use, and technology) have a basic role to play in determining overall emission levels.

Figure 3 Calculation of transport emissions for an individual mode

		Mode share (behaviour)		**Distance travelled (land-use/design)**		**Fuel efficiency (technology)**
Transport emissions per mode	**=**	**Number of vehicles**	**x**	**Distance travelled**	**x**	**Emissions per vehicle distance travelled**

These three broadly-defined variables each consist of several different components. For the case of public transport, the "mode share" is affected by at least two component categories:

1. Customer utility – This component includes system attributes such as cost, comfort, convenience, travel time, and security that encourage people to use a particular mode; and,
2. System capacity – The total capacity of the system effectively acts as the ceiling to the amount of mode share that is possible to achieve.

The "distance travelled" is affected by at least two component categories:

1. Land use changes – Transit-oriented-development (TOD) and complementary land-use policies can ultimately produce changes in travel distances by bringing destinations closer to trip origins and by allowing for a single trip to replace what was previously several separate journeys; and,
2. System design and management – The routing structure and the location of stations and terminals will directly affect the distance travelled; also, efficiently managing the number of vehicles operating at peak and non-peak times will produce savings.

The "fuel efficiency" is affected by at least two component categories:

1. Operational efficiency – The "smoothness" of the vehicle operations (number of stops, amount time idling, use of dedicated busways, etc.) will impact the fuel usage; and,
2. Vehicle efficiency – The type of propulsion technology, the type of fuel utilised, the materials and design of the vehicle, and the quality of the vehicle maintenance all directly impact the fuel usage rate.

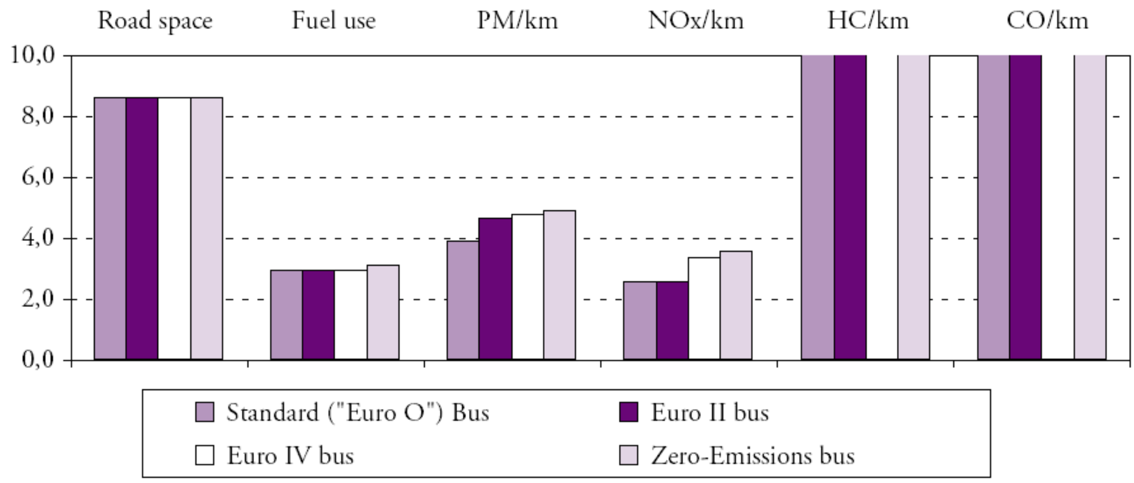
It is worth noting that "vehicle efficiency" is just one of many constituent parts in this emissions framework. However, too often this category is the only one pursued by both local and international groups seeking to reduce emissions and improve efficiency. Table 8 provides an overview of each of the component categories to public transport emissions.

Table 8 Overview of components affecting public transport emissions

Equation variable	Component Category	Components
1. Mode Share	1.1 Customer utility	▪ Customer service attributes that affect customer satisfaction including: affordability, appearance, awareness, clarity, comfort, convenience, integration with other modes, reliability, safety and security, vehicle type ▪ Operational efficiencies that affect travel time (dedicated busways, route structure, service frequency, dwell times, station location)
	1.2 System capacity	▪ Vehicle capacity ▪ Infrastructure capacity (stations, terminals, fare collection systems)
2. Distance Travelled	2.1 Land use	▪ Transit-oriented development ▪ Reinforcing land-use policies
	2.2 System design and management	▪ Dedicated busways ▪ Route structure ▪ Terminal and depot locations ▪ Management of number of vehicles at peak and non-peak times
3. Fuel Efficiency	3.1 Operational efficiency	▪ Dedicated busways (impact on both transit vehicles and mixed traffic vehicles) ▪ Route structure ▪ Dwell times ▪ Distance between stops ▪ Driver behaviour ▪ Vehicle control systems
	3.2 Vehicle efficiency	▪ Carbon content of fuel ▪ Propulsion system efficiency ▪ Vehicle design and materials (weight, aerodynamics, etc.) ▪ Vehicle mechanical maintenance

The International Energy Agency (IEA) has conducted some initial analysis to determine the relative impacts of mode share in comparison to different fuel and propulsion options. The IEA examined the emission impacts of shifting mode share by the capacity equivalent of one bus with a total capacity of 120 passengers. Even with the rather modest assumption of only a 50 per cent load factor for the bus and only eight per cent of the passengers having switched from private vehicles, the resulting emission reductions were substantial. The projected reductions in hydrocarbon and carbon monoxide emissions per kilometre were over ten times the emissions of a single bus[11] (IEA, 2002). The reduction per kilometre of particulate matter, nitrogen oxides, and carbon dioxide (fuel use) ranged from two times to four times the emissions of a single bus (Figure 4).

Figure 4: Impacts of mode shifting to public transport



Remarkably, the level of emissions reduced did not change significantly with buses of strikingly different emission standards. Buses with Euro 0, Euro II, Euro IV, and fuel-cell technology all produced roughly the same results. This result occurred because the relative impact of the tailpipe standard (and thus the fuel and propulsion choice) was overwhelmed by the impact from mode switching. The IEA study notes that:

> "Regardless of whether a bus is 'clean' or 'dirty', if it is reasonably full it can displace anywhere from 5 to 50 other motorised vehicles..." (IEA, 2002, p. 12)

> "Certainly, a cleaner bus will yield lower emissions, but in this scenario the emission reductions from technology choice are overshadowed by reductions from mode switching (and the resulting 'subtraction' of other vehicles)...Dramatic reductions in road space, fuel use, and most emissions can be achieved through displacing other vehicles with any bus, even the 'Euro 0' buses typically sold in the developing world." (IEA, 2002, p. 48)

The IEA results do not imply that fuel and propulsion technology should be ignored in achieving lower emissions. However, the results do suggest that these technologies alone only address a relatively small portion of the total emission reduction potential. Improving the efficiency of the transport sector and reducing emissions revolves around a full set of factors, including the many factors that are most important to customers such as cost, comfort, convenience, and security.

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[11] The IEA study notes that this high level of emission reductions is achieved "because diesel buses emit very low levels of these pollutants compared to two and three-wheelers" (IEA, 2002, p. 47).

4. The Transformation of Bogotá, Colombia

4.1 Background

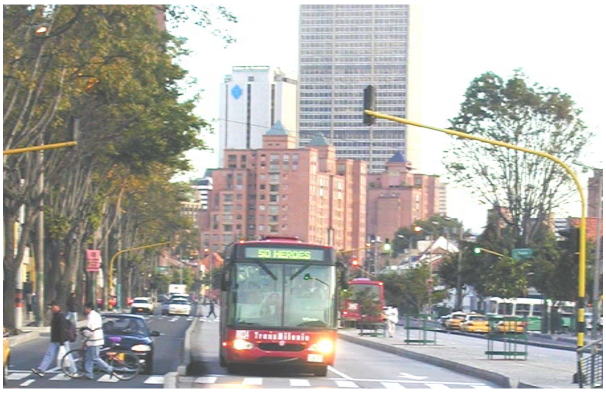
The IEA research indicates that perhaps the most effective emission strategy is a synergistic package of low-cost measures that encourage mode shifting, more efficient land use, and improved fuel and propulsion technology. The recent transformation of the transport sector in Bogotá (Colombia) provides perhaps the best world example of this premise in action.

Prior to 1997, Bogotá was not unlike most other large developing cities. The "public" transport sector was entirely in the hands of thousands of private operators. Fifeteen to thirty year old buses and mini-buses roamed the city in an uncoordinated fashion competing for passengers who were largely captive to an uncomfortable, insecure, and wholly unpleasant service.

In reality, Bogotá seems a rather unlikely place for creating a new standard in sustainable urban transport. As a large, densely-populated city with 7 million inhabitants and approximately 230 inhabitants per hectare, Bogotá has its own share of developmental issues, including high levels of unemployment and a history of violence. The violence in part stems from a nation that has been engaged in a virtual civil war for the past four decades.

Figures 5 and 6: *Bogotá went from this to...*

Nevertheless, thanks to a series of dynamic mayors Bogotá has become a world leading example of sustainable transport. Mayor Enrique Peñalosa presided over a three-year term (1997-2000) that witnessed a dramatic transformation of the city (Figures 5 and 6). After decades of failed metro plans, the mayor led a process to build a high-quality "surface metro" system using bus-based technology.



…this, in just three years.

This concept is known as "Bus Rapid Transit" (BRT). BRT gained its initial prominence with its application in Curitiba (Brazil) beginning in 1974. The general idea of BRT is to create *a mass transit system using exclusive right of way lanes that mimic the rapidity and performance of metro systems but utilises bus technology rather than rail vehicle technology* (Wright, 2003). BRT essentially emulates the performance and amenity characteristics of a modern rail-based transit system but at a fraction of the cost. To achieve this level of quality, BRT systems tend to focus on an array of features that enable a city to transform a standard bus service into a mass transit system. These features include:

- Exclusive right of way lanes
- Rapid boarding and alighting
- Free transfers between lines
- Pre-board fare collection and fare verification
- Enclosed stations that are safe and comfortable
- Clear route maps, signage, and real-time information displays
- Modal integration at stations and terminals
- Clean vehicle technologies
- Excellence in marketing and customer service

The Bogotá BRT system, known as TransMilenio, included an initial phase with 40 kilometres of dedicated busways that was delivered at a cost of US$ 5.3 million per kilometre, considerably less than rail-based options. Most BRT systems today are being delivered in the range of US$ 500,000 to US$ 10 million per kilometre. By contrast, elevated rail systems and underground metro systems can cost from US$ 50 million per kilometre to over US$ 200 million per kilometre. The lower cost allowed Bogotá to finance the initial phase largely through existing local resources and not through international loans. A portion of the national petrol tax in Colombia is dedicated to financing local transit.

The system now features 58 kilometres of busways and 309 kilometres of feeder routes, moving over 800,000 passengers per day. Additionally, by achieving peak capacities of over 36,000 passengers per hour per direction, TransMilenio has changed how transport planners previously viewed the capacity potential of bus-based systems. TransMilenio is also making money, and does so while providing an affordable single fare of approximately US$ 0.37. Through a competitive bidding process, the system features multiple private sector operators. Oversight for the system is provided by a non-profit public company, TransMilenio SA, which employs a small team of approximately 80 persons to manage the BRT system for the entire city. A separate concession was also awarded to a private firm handling fare collection. Operators are compensated based upon the kilometres travelled, which is recorded by a geographical positioning satellite (GPS) system. The system functions with no operating subsidies, even with each private sector operator financing Euro II, articulated buses.

Of course, to optimise public transport's contribution to any city, it is best integrated with complementary measures. Bogotá thus also features nearly 300 kilometres of new, high-quality cycle ways. In a few short years, bicycle mode share has increased from approximately 0.4 per cent to over three per cent of all trips. Likewise, public space has been reclaimed to provide better pedestrian access.

Figure 7: *As many as two million of the city's inhabitants take to the streets during Bogotá's weekly car-free Sundays.*

Bogotá has also gained fame for its development of car-free events. Each Sunday 120 kilometres of arterial roadways are closed to private motorised vehicles (Figure 7). In their place, as many as two million inhabitants take to the streets as cyclists, skaters, and strolling families. The festive atmosphere of the Sunday “ciclovía” (bicycle street) is credited with creating a great sense of community and citizen culture in the city. Bogotá is also holds the world’s largest car-free weekday event, covering the entire expanse of the city’s 28,153 hectares. The first car-free day during a weekday was held in February 2000. The day has become institutionalised through a public referendum. On 29 October 2000, 63 per cent of the voters in Bogotá approved a referendum to make the February car-free day event permanent. Additionally, Bogotá is also home to what is called the world’s longest pedestrian corridor, “Alameda Porvenir”. This 17-kilometre stretch of pedestrian and bicycle paths connects several lower-income communities to shops, employment, and public services.

Bogotá’s success with non-motorised and public transport modes is also due to a highly synergistic implementation of transportation demand management (TDM) techniques, which have acted to discourage private vehicle usage. Each week day the city restricts 40 per cent of all autos entering the city during the morning (06:00 to 09:00) and evening (16:30 and 17:30) peak periods. The reduction is achieved by not allowing autos with license plates that end in certain numbers to enter on a particular day (Table 9). Emergency vehicles, diplomatic and presidential vehicles, and public utility vehicles are exempted.

Table 9: License plate restrictions in Bogotá

Day of week	License plates ending with these numbers are restricted from use
Monday	1, 2, 3, 4
Tuesday	5, 6, 7, 8
Wednesday	9, 0, 1, 2
Thursday	3, 4, 5, 6
Friday	7, 8, 9, 0

The city has also dramatically reformed its control on parking. On-street parking has been eliminated from most streets, with privately contracted firms providing off-street parking services. In many cases, the previous parking bays have been converted into more attractive public space (Figure 8).

Figure 8: *Bogotá has converted much of its previous parking space to public space.*

4.2 Bogotá's Emission Impacts

Bogotá's broad package of sustainable transport options allows a relative comparison of the emission impacts from different mechanisms. In turn, this type of comparative analysis can be used in other cities to prioritise investments towards the most effective solutions. The results of a Bogotá emissions analysis will also help international agencies target the most cost-effective mechanisms to reduce greenhouse gas emissions. In fact, a current proposal to the Global Environment Facility (GEF) calls for a detailed emissions analysis of Bogotá's BRT system. The TransMilenio system is also the subject of the first transport initiative being brought forward as a project of the Clean Development Mechanism (CDM) under the "ERUPT" programme of the government of The Netherlands. If the CDM proposal is successful, Bogotá would be the first site of a transport project receiving credits as Certified Emission Reductions (CERs).

As a system-based approach to public transport, the TransMilenio system is able to address virtually all the possible components in an emissions reduction effort, as outlined earlier in Table 8. Specifically, TransMilenio is achieving emission reductions through the following mechanisms:

- Increasing the share of public transport ridership by dramatically improving the quality of service (in terms of travel time, comfort, security, cleanliness, etc.);
- Replacing 4 to 5 smaller buses with a larger articulated vehicle;
- Requiring the destruction of 4 to 8 older buses for every new articulated vehicle introduced into the system;
- GPS controlled management of the fleet allowing the optimisation of demand and supply during peak and non-peak periods;
- Encouraging transit-oriented development around stations and along corridors; and,
- Emission standards currently requiring a minimum of Euro II emission levels with a future schedule requiring eventual Euro III and Euro IV compliance.

Bogotá is one of the few cities in the world that is registering a significant increase in public transport ridership. According to a study by Steer Davies Gleave (2003), ten per cent of ridership on Bogotá's BRT system comes from persons who previously drove a private vehicle to work. The quality of TransMilenio is such that even middle- and higher-income travellers are utilising the system. The older mini-buses that dominated Bogotá prior to TransMilenio were largely not an option that discretionary transit users would frequent.

Figure 9: *In phase 2 of TransMilenio, for every new articulated vehicle introduced into the system, 7.0 to 8.9 older vehicles are destroyed.*

Like much of Latin America and elsewhere in the developing world, Bogotá's public transport sector has historically not been highly regulated. The result has been a large proliferation of small private sector operators who compete aggressively with one another for a relatively captive transit market. Such market conditions can create relative inefficiencies in which an oversupply of small vehicles translates into congestion and high levels of contamination. Prior to TransMilenio, over 22,000 public transport vehicles of various shapes and sizes plied the streets of Bogotá. In order to rationalise the system, companies bidding to participate in TransMilenio were required to scrap older transit vehicles. During the first phase of TransMilenio, the winning bids agreed to scrap approximately four older vehicles for each articulated vehicle introduced (Figure 9). In the second phase, the successful bids committed to scrapping between 7.0 and 8.9 older buses for each new articulated vehicle. The destruction of older vehicles prevents the "leakage" of these vehicles to other cities.

Each articulated vehicle in TransMilenio has a capacity of 160 passengers. The vehicles are currently achieving a load factor of approximately 80 to 90 per cent. The older public transport vehicles in Bogotá come in a variety of sizes, from micro-buses to full-sized conventional buses. Table 10 summarises recent data collected on characteristics of public transit vehicles in Bogotá.

Table 10: Characteristics of public transit vehicles in Bogotá

Vehicle type	Passenger capacity	Fuel consumption (km / litre)	Passengers per vehicle-kilometre travelled (IPK)
TransMilenio articulated bus, Euro II diesel	160	1.56	5.20
Conventional bus, diesel	70 – 80	2.14	1.00 – 2.27
Conventional bus, Gasoline	70 – 80	1.53	1.00 – 2.27
Medium-sized bus, diesel, models 1995-2004	27 – 45	5.02	0.90 – 2.24
Medium-sized bus, diesel, 1980 model	27 – 45	3.96	0.90 – 2.24
Medium-sized bus, gasoline, 1980 model	27 – 45	2.64	0.90 – 2.24
Micro-bus, diesel	13 – 19	5.54	0.60 – 1.44
Micro-bus, gasoline	13 – 19	3.43	0.60 – 1.44

Source: Martínez, 2004

The differences in "passengers per vehicle-kilometre travelled" are quite telling. The relative efficiency of operating a coordinated system in larger vehicles translates into economic advantages for the operators. By closely controlling the supply of vehicles during peak and non-peak periods, TransMilenio avoids wasteful trips. By contrast, the existing informal operators drive as much as 16 hours each day regardless of passenger flows. As long as the operator's marginal costs (mostly fuel costs) are covered, it makes sense to continue operating. However, this approach leads to the efficiencies associated with congestion and an oversupply of vehicles.

The CDM proposal developed for the TransMilenio system provides an estimate of emission reductions achieved due to mode shifting and energy efficiency gains. The study does not include any emission reduction projections emanating from land-use changes. The proposal develops a baseline scenario (Bogotá without the TransMilenio system) and a project scenario (Bogotá with the TransMilenio system). In the project scenario the analysis also accounts for expected emission increases due to industrial emissions from the construction of concrete busways and the added energy process emissions from the scrapping of older transit vehicles. The emission reductions are principally achieved through carbon dioxide (CO_2) reductions, but the impacts of methane (CH_4) and nitrous oxide (N_2O) are also included. Table 11 summarises the study's results for the period of 2001 through 2016. The annual reductions increase significantly over the period due to the continued expansion of the TransMilenio system.

Table 11: Projections for greenhouse gas emission reductions from Bogotá's TransMilenio system (tons of CO_2-equivalents)

Year	Baseline scenario **(tons of CO_2-eq.)**	Project scenario (tons of CO_2-equivalents)					Total annual **reductions (tons of CO_2-eq.)**
		Private buses	**Trans-Milenio**	**Cement production**	**Vehicle scrapping**	**Project scenario total**	
2001	1,580,925	1,450,471	74,510	27,355	12,646	1,564,982	15,943
2002	1,567,044	1,440,392	85,256	0	11,476	1,537,124	29,920
2003	1,557,493	1,387,571	95,236	7,339	15,587	1,505,733	51,760
2004	1,558,716	1,357,836	99,840	20,683	17,792	1,496,150	62,566
2005	1,562,152	1,212,356	145,198	0	29,732	1,387,286	174,866
2006	1,556,963	1,199,327	147,550	0	30,864	1,377,741	179,222
2007	1,551,663	1,184,314	149,898	0	31,902	1,366,113	185,550
2008	1,552,519	1,173,484	152,260	0	33,060	1,358,804	193,715
2009	1,556,270	1,165,207	154,597	13,010	34,300	1,367,115	189,155
2010	1,586,795	1,034,346	177,373	12,543	45,606	1,269,868	316,927
2011	1,616,032	854,166	210,317	5,671	57,902	1,128,056	487,976
2012	1,612,589	823,534	217,029	0	63,387	1,103,950	508,639
2013	1,608,863	815,339	217,048	7,072	65,309	1,104,768	504,095
2014	1,662,188	713,824	249,013	0	76,639	1,039,476	622,712
2015	1,661,548	688,882	252,482	0	78,240	1,019,604	641,944
2016	1,666,696	639,111	253,477	0	76,203	968,791	697,905
Totals	25,458,456	17,140,160	2,681,084	93,673	680,645	20,595,562	4,862,894

Source: CAF, 2004

Thus, for just the period of 2001 through 2016, the TransMilenio system is expected to reduce greenhouse gas emissions by a total of 4.86 million metric tons of CO_2 equivalents. The period of 2001 through 2016 represents the period over which the construction of the entire system will take place. By 2016, there will be 388 kilometres of exclusive busways constructed in Bogotá. These projections are most likely to be conservative values given that the impacts from land-use changes are not included. Further, the life of the project can be extended significantly as much of the infrastructure will have a duration of 20 to 30 years before requiring complete renovation and/or reconstruction. Thus, the relative amount of emission reductions realised in the year 2016 can be expected to continue for many additional years. Based on this assumption, an extrapolation of the project through the year 2030 yields a total emission reduction of 14.6 million metric tons of CO_2 equivalents.

Although land-use impacts have yet to be quantified on the TransMilenio system, there is already evidence to suggest that the effect could be quite significant. Large commercial centres are being constructed along the corridors, especially near terminals and stations. Forthcoming research indicates increases in residential property values are directly proportional to proximity to TransMilenio stations (Rodriguez and Targa, forthcoming, 2004). The densification of commerce, employment, and residences along the TransMilenio corridors will likely yield reductions in both the number of trips undertaken as well as the average distance of each trip.

The results from TransMilenio are likely to be influential in justifying similar initiatives elsewhere. The project confirms the significant synergies that can be realised by following an emissions reduction strategy based on a “systems” approach. If the city had only upgraded the vehicle technology without the development of higher-quality transit service, priority busways, enclosed stations, and a new business model for transit operations, then the emission reductions would likely have been significantly less impressive.

4.3 The Potential for Replication

The extent to which other cities will be able to realise similar amounts of emission reductions will depend upon many local factors including the relative efficiency of existing bus operations and the percentage of commuters likely to switch to a higher-quality service. However, given that Bogotá has achieved a dramatic transformation of its transit services at a relatively economic cost and with largely local financial resources, there would appear to be much potential for replication elsewhere. Already, in conjunction with the National Department of Planning and the World Bank, the Colombian government is preceding with bus rapid transit projects in six additional cities, including Barranquilla, Bucaramanga, Cali, Cartagena, Medellin, and Perreira.

Bogotá has also captured attention from city officials in other nations as well. Over one thousand city officials from over 50 countries have visited the new Bogotá in the past few years. New BRT systems are already in operation in Jakarta (Indonesia) and Leon (Mexico). Cities as diverse as Accra (Ghana), Cape Town (South Africa), Dakar (Senegal), Dar es Salaam (Tanzania), Delhi (India), Dhaka (Bangladesh), Guatemala City (Guatemala), Lima (Peru), Mexico City (Mexico), and Santiago (Chile) are now either constructing or are planning a BRT system, in part due to the Bogotá experience.

The experience of Bogotá as well as that of Curitiba (Brazil) has also been influential in the developed world. Bus rapid transit systems may be one of the best examples of technology transfer from the developing south to the developed north. Already basic systems have been developed in cities such as Brisbane (Australia), Nagoya (Japan), Ottawa (Canada), and Rouen (France).

5. The International Response

Transport policy decisions made today in developing nations will have profound ramifications on any possible attempt to control global greenhouse gas emissions. Additionally, these policies will also in part determine the extent to which other key developmental objectives, such as health levels, economic efficiency, and overall quality of life, are realised in developing cities. Once policies are orientated exclusively towards motorisation and techonological control strategies, then it will be extremely difficult to later shape more sustainable alternatives. As the developed world has discovered, moving commuters away from private vehicles to public transport and non-motorised options is quite difficult and costly.

Thus, given the potential impact of short-term decisions on the long-term future of developing-city transport, it would be expected that the international community would be strongly backing the sort of low-cost solutions that have shown such promise in cities like Bogotá. To an extent, international recognition of lower-cost and lower-technology providing significant impacts is beginning to occur. The German Overseas Technical Assistance Agency (GTZ) has developed a sustainable transport sourcebook covering a range of practical options for developing-nation cities.[12] Likewise, the United States Agency for International Development (USAID) is supporting BRT initiatives in such cities as Accra

[12] For more information on the GTZ Sourcebook, see www.sutp.org.

(Ghana), Cape Town (South Africa), Dakar (Senegal), Delhi (India), and Jakarta (Indonesia).

However, compared to other sectors, the transport sector has received relatively scant attention as an effective means towards emission reductions and greater energy efficiency. Further, when local governments and international organisations have invested in transport initiatives, the overwhelming tendency has been toward fuel and propulsion systems. It is thus worth asking if we have been looking for transport CO_2 reductions in all the wrong places.

To date, two major international agreements have been brought forward to curb greenhouse gas emissions. At the 1992 United Nations Conference on Environment and Development (UNCED), member nations developed the United Nations Framework Convention on Climate Change (UNFCCC). By 1994, 186 countries had ratified the convention, putting the document into force. Although the convention was essentially a non-binding agreement, the UNFCCC did include a mechanism allowing participation by developing nations in emission-reducing projects. The mechanism, known as “Activities Implemented Jointly” (AIJ), encouraged investment towards developing nation projects as a means to stimulate a future emissions trading market. Remarkably, though, of the 186 AIJ projects put forward, none addressed emissions in the transport sector (JIQ, 2002).

Subsequently, in 1997, the Kyoto Protocol was drafted. The protocol calls for developed nations to reduce emissions by an average of 5.2 per cent from a 1990 baseline. While ratification of the agreement remains stalled, several nations and organisations are proceeding with mechanisms that involve projects in developing nations as well as economies in transition. The initiatives inspired by the Kyoto mechanisms are being developed under the framework of the “Clean Development Mechanism” (CDM) and “Joint Implementation” (JI). These new mechanisms permit investors to gain Certified Emission Reductions (CERs) by investing in emission reducing projects in developing nations and economies in transition.

However, once again the transport sector has largely been ignored. CDM and JI projects are being supported by the government of Finland, the government of The Netherlands, and a World Bank programme called the Prototype Carbon Fund (PCF). Of the seven CDM projects and five JI projects sponsored by the Finnish government, none are in the transport sector. Likewise, within the ERUPT programme of The Netherlands there are 18 CDM projects and 8 JI projects, none of which are transport related. The World Bank created the Prototype Carbon Fund (PCF) to help stimulate the growth of a more robust market for emissions trading. To date, the PCF has funded nine CDM projects and four JI projects, none of which are transport related (JIQ, 2004). The recent proposal submitted to the Dutch government on the Bogotá TransMilenio system would be the first such project in the transport sector.

The Global Environment Facility (GEF) is amongst the world’s largest grant-making facilities to fund projects alleviating global environmental problems. The GEF’s resources of over US$ 2 billion are intended to catalyse demonstration initiatives that eventually lead to replication globally. The fund is managed by a central secretariat along with its implementing agencies which include the World Bank, United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and regional development banks. However, the transport sector was one of the last sectors that the GEF climate change programme has addressed. Further, the GEF’s operational strategy for transport was largely prepared by special interests from the fuel cell industry, and thus has focused much of the early investments towards fuel and propulsion system solutions (GEF, 2001).

One of these initial projects included a US$ 60 million investment by UNEP to finance 46 fuel-cell buses in developing cities such as Beijing, Cairo, Mexico City, Sao Paulo, and Shanghai. The actual project cost totals US$ 120 million when matching funds from private sector fuel and vehicle firms are included. Thus, the end result is 46 buses at a cost of approximately US$ 2.6 million per bus. However, given that in nations such as China the hydrogen for the fuel-cell buses will likely be derived from largely coal-based electricity, the overall greenhouse gas emissions will actually be higher than if a standard diesel vehicle was utilised. If instead the US$ 120 million investment was applied towards bus rapid transit systems, then anywhere from 23 to 240 kilometres of a BRT system could have been financed. In fairness, though, the GEF is now moving towards a more “systems” based approach to transport initiatives. The World Bank is currently leading GEF-financed BRT projects in Lima, Mexico City, and Santiago.

The list of world-wide technology-focused initiatives is extensive. The US government has committed to funding fuel-cell research at a level of US$ 1.3 billion. By contrast, projects focused on mode switching to public transport or supporting non-motorised infrastructure are typically small in both number and size. It is possible that simply improving the state of developing-nation sidewalks could be one of the most effective long-term measures, both from the perspectives of cost and overall development. However, it is unlikely that any global sidewalks initiative is on the horizon anytime soon. The reasons for the apparent bias towards higher-technology solutions is likely due to a complex set of reasons:

- Establishing baselines in the transport sector can be quite difficult as mode shares, particularly with regard to motorisation, are fairly dynamic in nature.
- Private sector opportunities largely reside in fuels and vehicles; system type upgrades such as improved customer service either do not have large commercial opportunities or such opportunities tend to be local in nature.
- Public transport and infrastructure for sidewalks and cycleways tend to be largely “public” goods with less perceived opportunity for private firms to gain emission credits.
- Technological solutions (tailpipe technologies, fuels, propulsion systems) can appear to be simple black box solutions that are intrinsically easier for public officials to understand than a broader systems approach.
- Higher-technology options are perceived as being “sexier” and more “modern” by many political officials.

Most of these perceptional issues can be overcome. Bogota has demonstrated that a systems-based approach is not only significantly more effective in reducing emissions but can also be quite profitable as well. The transport sector should become a more viable option for local and international organisations seeking to achieve core economic, environmental, and social objectives.

6. Conclusions

Emissions from the transport sector represent the fastest growing source of global greenhouse gas emissions. There is little prospect that this situation will be resolved with a single technological fix. As developing nations quickly move to catch up with the motorisation levels of developed nations, the sheer number of private vehicles on the roadways will overwhelm any advances made by cleaner fuels.

Given such circumstances, it is surprising that relatively little action has been taken in this area. To the extent that transport emissions are being addressed at all, local and international attention is still mostly focussed on fuel and propulsion system solutions. However, a more promising alternative is a systems-based approach as achieved in Bogota. Low-cost, low-technology solutions that focus on providing higher-quality public transport and viable non-motorised options will help preserve sustainable transport mode shares in developing cities. Technology is still part of an optimised approach but within a package that includes attention to mode share and land use as well.

Access and mobility are basic to modern life and play a significant role in realising development and an improved quality of life. The promotion of exchange and movement does not need to conflict with our economic, environmental, and social goals. However, the road to transport efficiency will necesitate a multi-faceted approach that is not solely technology dependent.

7. References

Barter, P. (1999), *An international comparative perspective of urban transport and urban form in Pacific Asia: The challenge of rapid motorisation in dense cities*, Doctoral dissertation. Perth: Murdoch University.

CAF (Corporación Andina de Fomento) (2004), *Urban mass transportation system: TransMilenio, Bogotá, Colombia*, Clean Development Mechanism Project Design Document, Caracas: CAF.

City Hall Kual Lumpur (2001), *Draft structure plan Kuala Lumpur 2020*. Kuala Lumpur: City Hall Kuala Lumpur.

Dargaya, J. and Gately, D. (1999), Income's effect on car and vehicle ownership, worldwide: 1960-2015, *Transportation Research Part A*, 33: 101-138.

Davis, S. and Diegel, S. (2002), *Transportation data energy book: Edition 22*. Oak Ridge, TN, USA: Oak Ridge National Laboratory.

GEF (Global Environment Facility) (2001), *Operational program number 11: Promoting environmentally sustainable transport.* Washington: GEF.

Gittings, J. (2002), Colossal road expansion gets the not-so-green light, The Guardian, 29 October 2002.

Gordon, P. and Richardson, H.W. (1989), Gasoline consumption and cities: a reply, Journal of American Planning Association 55(3): 342-345.

Hook, W. (2002), Does it make sense for China to motorize?, *Sustainable Transport*, Fall 2002, 14: 2, 19, 29.

IEA (International Energy Agency) (2002), *Bus systems for the future: achieving sustainable transport worldwide*, IEA: Paris.

IIEC (International Institute for Energy Conservation) (1996), *The World Bank and transportation*. Washington: IIEC.

JIQ (2004), Planned and on-going JI / CDM projects, *Joint Implementation Quarterly*, 10(1): 14.

JIQ (2002), AIJ pilot projects, *Joint Implementation Quarterly*, 8(4): 14.

Newman, P. and Kenworthy, J. (1999), *Sustainability and cities: Overcoming automobile dependence*. Washington: Island Press.

OECD (Organisation for Economic Cooperation and Development) and ECMT (European Conference of Ministers of Transport) (1995), *Urban travel and sustainable development*, Paris: OECD.

OECD (Organisation for Economic Cooperation and Development) and IEA (International Energy Agency) (2001), *An initial view on methodologies for emissions baselines: Case study on transport*. Paris: OECD/IEA.

Price, L., Michaelis, L., Worrell, E., and Khruschch, M. (1998), Sectoral trends and driving forces of global energy use and greenhouse gas emissions, *Mitigation and Adaptation Strategies for Global Change*, 3: 263-319.

Rodriguez and Targa (forthcoming) (2004), The value of accessibility to Bogotá's bus rapid transit system, *Transport Reviews*, 24(5).

Schafer, A. and Victor, D. (1997), The past and future of global mobility, *Scientific American*, 277(4): 58-61.

Secretaría de Transporte (2001), *Area Metropolitana de Buenos Aires*. Presentation at the Ministry of Infrastructure and Housing of Argentina, October 2001.

Martínez, A., Personal communication with Aleida Martínez Palacio, Manager, Sí 99, Private operating company within the Bogotá TransMilenio system.

Steer Davies Gleave (2003), Estimation of private vehicle trips replaced by TransMilenio: Phase II report, SDG: Bogota.

Vasconcellos, E. (2001), Urban transport, environment and equity: The case for developing countries. London: Earthscan.

Whitelegg, J. and Haq, G. (2003), *The Earthscan reader on world transport policy and practice*. London: Earthscan.

WBCSD (World Business Council for Sustainable Development) (2001), *Mobility 2001: Mobility at the end of the twentieth century and its mobility*. Geneva: WBCSD.

Wright, L. (2003), Bus rapid transit. In GTZ (Deutsche Gesellschaft fur Technische Zusammenarbeit) (2003), Sustainable transport: A sourcebook for policy-makers in developing cities. Eschborn: GTZ.

Technical Options for Conventional and Renewable Energies in Transport in Developing Countries By Reinhard Kolke

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[1] Head of Research and Development Department at HJS, an international market leader in the field of catalytic retrofitted systems. This competence is now being utilized for the conception of a retrofitted diesel particulate filter system. The most essential feature of this system is the HJS-sintered metal filter. The system has been designed in such a way that it works completely self-sufficiently – supplied by the battery of the vehicle – and the vehicle runs practically "SOOT-FREE" after being installed. As Deutsche Bundesstiftung Umwelt awards innovation prize to innovative entrepreneurs, Hermann J. Schulte proprietor and managing director received the Environmental Prize 2003 for the developed diesel particulate trap.

Abstract

Efficient technologies and the local use of renewable (thermal and electric) energy can produce more energy services or higher CO_2 emission reductions with the same monetary expenditure. In this regard the first priority is to promote fuel efficiency technologies based on EURO 3 and EURO 4 technologies and to improve and produce cheaper biomass, solar thermal and photovoltaic systems than the current production.

1. Introduction

Besides the energy sector, transport is the second most important producer of carbon dioxide (CO_2). In contrast to the energy sector, energy consumption and CO_2 emissions of the transport sector are still increasing. The problem is even more severe in Developing Countries where an enormous growth is required to catch up with the industrialised world. Experience shows that economic growth is strongly correlated to a growth in transport volumes. Transport seems to be a precondition for economic prosperity.

Additionally to the urgent need to disconnect economic growth from growth in transport volumes and energy consumption, many Developing Countries face not only the growing dependence on energy imports, but suffer from different kinds of typically high emission levels, especially

- diesel-particulates and nitrogen oxides from diesel vehicles and stationary diesel generators,
- hydrocarbons and benzene from all kind of petrol engines (2-stroke, 4-stroke) and additionally particulate matter emissions from two stroke engines, like motorcycles.

Therefore an integrated strategy for developing countries must focus on

- the reduction of energy consumption and CO_2 emissions
- in combination with a significant decrease of air pollution.

2. Air Pollution Standards for Future Vehicles

Exhaust gases from road traffic cause a whole range of environmental problems, which call for urgent action to reduce emissions. Nitrogen oxides (NO_x) are among the causes of forest dieback and – together with hydrocarbons, which are likewise emitted by motor vehicles – are precursors of photo oxidants, which give rise to summer smog (ozone). They also advance the excessive accumulation of nutrients (eutrophication) in lakes and inland waterways. Benzene and diesel particulates are carcinogenic substances whose high concentrations particularly in the vicinity of heavily used roads in metropolitan areas is a cause for concern. Different than in Industrialized Countries, carbon monoxide (CO) is still a cause of air pollution and needs to be reduced.

Directives 98/69/EC and 98/70/EC lay down limits for exhaust gases from passenger cars and light commercial vehicles to be attained by 2000 (EURO 3) and 2005 (EURO 4), as well as fuel quality requirements. It is a safe assumption even today that this tougher emissions legislation and better fuels will reduce airborne emissions from road traffic in the coming years, even in what are now highly polluted inner cities, and this despite a projected increase in mileage. Moreover, there are moves in the pipeline to introduce a EURO 5 emission standard for diesel-powered cars, which would be equivalent to EURO 4 for petrol-powered cars, as a final step towards attaining the requisite air quality objectives. Therefore some main strategies should focus on a fast introduction of European emission regulations as well to achieve significant reductions in air pollution (Fig. 1).

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
1. Passenger Cars / Light Duty Vehcicles																	
European Union ←	Euro 1		Euro 2				Euro 3					Euro 4					
Proposal for Developing Countries											Euro 3			Euro 4			
2. Motorcycles																	
European Union				Euro 1						Euro 2			Euro 3				
Proposal for Developing Countries											Euro 1		Euro 2			Euro 3	
3. Heavy Duty Vehicles																	
European Union ←	Euro 1		Euro 2				Euro 3					Euro 4			Euro 5		
Proposal for Developing Countries											Euro 3			Euro 4			Euro 5

Fig. 1: Proposal for Emission Regulations in Developing Countries based on the Availability of the Technology in Developing Countries

Any use of alternative fuels from crude oil, from other fossil resources or from renewable resources must always offer a competitive option for achieving environmental operative targets in future if it reduces not only airborne emissions but also makes a sizeable contribution to cost-effective cuts in **carbon dioxide emission levels** and **resource consumption**.

3. Comparison of Technical Options

The following chapters will compare the different alternatives of technical options to reduce greenhouse gas emissions as well as air pollution and noise.

3.1 Petrol and Diesel

Consumption of motor petrol and diesel fuels make the sector one of the biggest consumers of petroleum products with the corresponding CO_2-emissions. Even emissions due to evaporation and combustion also make a sizeable contribution to atmospheric pollution. This applies not only to ozone precursors such as hydrocarbons and nitrogen oxides, but also to benzene and diesel particulates, both of which are classified as carcinogenic. For environmental and health reasons a drastic reduction in this traffic induced pollution and CO_2 - emission is an urgent necessity. In principle there are different possible technical measures for the use of these fossil fuels to achieve healthy air, such as the improvement of conventional vehicle technology and the reformulation of conventional fuels.

Greenhouse Gases, Limited Emissions

The CO_2-emission reduction for passenger cars can be reached by application of different measures related to the combustion process and the mechanics of the engines. But also measures concerning the rolling-resistance force of the tires and the aerodynamic resistance of the body can reduce CO_2 significantly. The technological measures for additional improvements of the energy use for Heavy Duty Vehicles are more limited because the efficiency is for economic reasons already high in comparison to passenger cars. But even for HDV further improvements of CO_2-emissions can be reached by engine improvements, the reduction of the rolling-resistance and the weight reduction for semi-trailer and goods trailer.

In the past, the standards for the exhaust emissions of passenger cars were strengthened stepwise every few years (EURO 1…EURO 4). This concept was based on the experience that the manufacturers of passenger cars construct the vehicles in such a way that the emissions are with a safety margin below the limits. This level of emissions was then regarded quasi as a new definition of common available technology and was taken as a basis for negotiations about a next step of standards. Proceeding in this way the common available technology changes only slowly. On the one hand this approach has an advantage for the manufacturer, because the legally required changes are only small. On the other hand each of these new legal requirements following in intervals of two or three years leads to additional costs because for each step changes in production have to be made and expenses for new certifications incur.

In developing countries, air pollution emissions from petrol and diesel cars can be reduced significantly, if European emission regulations are introduced as soon as possible (Fig. 1). This strategy should be assisted with the introduction of a retrofit program for closed loop catalytic converter for passenger cars and with a retrofit program for particulate traps for heavy-duty vehicles (esp. buses) and passenger cars.

In addition to vehicle technology measures, innovative fuels could make an important contribution as a primary measure in reducing environmental pollution levels. The reason being, that fuel modifications can take effect quickly and have a particularly marked impact in the case of existing vehicles on the road.

On the motor petrol front the focus is on reducing benzene and aromatics content, sulphur content and vapour pressure, and on admixtures of oxygen-containing compounds. For diesel fuels the key areas, in addition to a reduction in density, are reducing polyaromatics and sulphur content and improving ignition properties (cetane number). Particularly harmful substances in the fuel and in the resulting emissions, such as carcinogenic, persistent or accumulable substances, are to be minimised.

Costs, Other Restrictions

The introduction of new emission standards, e.g. EURO 3, does not require higher expenses for exhaust gas aftertreatment than EURO 2. More expensive particulate traps or selective catalytic reduction will not be necessary for these steps. But beside that, the use of particulate traps in busses can reduce urban particulate emission significantly. The additional investment cost is about 2-3 % of the investment cost of a bus in Industrialized Countries.

To promote vehicles with low fuel consumption, it can be useful to introduce driver training and provide consumer information about the fuel consumption and the CO_2-emission of different vehicle types.

3.2 Natural Gas

Natural Gas can be used compressed at 200 bar (2,900 psi) as Compressed Natural Gas (CNG) or liquefied at -162° C (260° F) as Liquefied Natural Gas (LNG). Because the production of CNG is technologically easier for fleet applications, cheaper and with lower fuel consumption than LNG (incl. fuel production), most worldwide applications focus on CNG vehicles. The technical possibilities to use CNG in engines depends on continuous gas quality, such as methane content corresponding to high octane rating, which are ideal requirements for spark-ignited engines.

Greenhouse Gases, Limited Emissions

Natural gas resources will reach up to the year 2050 and beyond. Worldwide large quantities of natural gas are burnt off and therefore wasted.

The comparison of the primary energy use for the production processes of CNG and petrol shows that the primary energy consumption for both fuels is comparable. In its demonstration project for CNG-usage UBA considered a scenario of 10 % NG heavy-duty vehicles in a fleet and calculated a slight increase of equivalent greenhouse gas emissions of +0,07 %. It can be concluded, that the use of NG in heavy duty vehicles will not result in a significant increase of greenhouse gases, even though the fuel consumption is about 2 5% higher compared to the fuel consumption of diesel vehicles. A 25 % lower carbon content of natural gas in comparison to petrol or diesel fuel can explain this.

The main advantages of natural gas use in busses are very low emissions of NO_x and particulate matter (PM) compared to diesel buses. The PM emission is below the detection limit and reaches the level of diesel vehicles equipped with particulate traps. In passenger cars, the emissions of CNG vehicles must be compared to petrol vehicles and do not reach any significant reductions.

Costs, Other Restrictions

It must be noted that the implementation of CNG into a heavy-duty vehicle is more than just converting and installing a gas-powered engine. Refuelling and storage of the gas must be carefully considered to meet the operational and safety requirements. For storing compressed natural gas at 200 bar pressure, a large tank is needed. The kind of heavy-duty vehicle for which the use of natural gas is often used is the urban bus where the tank is usually installed on the roof. Using CNG in passenger cars can result in a reduction of useful space inside the vehicle because of the storage tank.

Natural gas engines cause additional capital costs for the vehicle’s engine and the storage tank system and further cost for the compression of natural gas, covering investment, operation and maintenance of the filling station. The present additional retail prices for heavy-duty vehicles with natural gas engines and storage system (e.g. buses for urban transportation), are between 8 to 16 % for a heavy-duty vehicle with natural gas engine compared to a diesel bus.

To store natural gas, it has to be compressed to 200 bar (2,900 psi) at the filling station. The configuration of the filling station according to the individual demands of the customer is of great importance to minimise the costs.

When looking at the project from the environmental aspect, the promotion of gas-powered vehicles is useful wherever they help in our cities to reduce both the particulate emissions hazardous to health and the nitrogen oxide emissions, which contribute to the formation of summer smog (ozone). Promoting gas-powered passenger cars seems to make sense also where diesel-fuelled cars are concerned which cover great distances throughout the year like for instance taxis do.

3.3 Liquefied Petroleum Gas (LPG)

In principle, LPG can be used in the same engines as NG. In contrast to NG, which is stored under high pressure (200 bar, 2,900 psi), LPG can be used at much lower pressures (max. 10 bar, 145 psi).

Greenhouse Gases, Limited Emissions

LPG is a by-product from crude oil. It occurs with the exploitation of crude oil and has to be separated from the crude for transport, or is a by-product in refineries. Each metric ton of crude oil results in 2 to 4 kilograms of LPG. Even, if it is just an energy loss of 0.2 to 0.4 % of the exploited crude oil, it is one of the easiest possibilities to save fossil fuels in the energy chain. Using LPG in transport instead of burning it as a waste gas at the oil fields or in the refinery will save other fossil fuels immediately. The use of LPG results in a comparable energy efficiency for the energy chain of exploitation, refinery and use as petrol and diesel.

The emissions during use of LPG in the vehicles are comparable to the emissions of petrol engines and similar to the emissions of heavy-duty natural gas engines.

Costs, Other Restrictions

At the moment most LPG passenger cars are dedicated concepts, which can run on petrol fuel and LPG. Heavy-duty vehicles and buses are optimised to LPG use only.

The biggest fleet of LPG buses is running in Vienna. The additional costs for a bus with LPG engine is around 9 % compared to a standard diesel bus. For the use of LPG there are no higher additional costs for the filling station in comparison to a filling station for diesel fuel, as needed for a bus fleet, but additional safety requirements are necessary for handling LPG in workshops.

4. Hydrogen (H_2)

Hydrogen is usually used as compressed hydrogen (CH_2) with 200 bar or liquefied hydrogen (LH_2) at -252° C (422° F). H_2 is a secondary energy, which means that it has to be produced from other fossil or non-fossil energy sources.

Greenhouse Gases, Limited Emissions

It is often proposed to use hydrogen in road transport instead of carbon containing gases because of the CO_2 advantage. Evaluating the total fuel life cycle shows that using other fossil primary energy for the production of H_2 do not result in a net advantage. Hydrogen is either produced from natural gas with efficiency losses and higher CO_2 emissions than the direct use of NG for automotive propulsion or by using hydroelectric power where again the electricity could be used directly more efficiently.

Hydrogen as a fuel for road applications will have its main advantages when producing it with renewable resources, such as electricity from renewable energy or from biomass.

It is true, that from the environmental point of view there is an urgent need to introduce technologies using renewable power sources for producing heat and electricity. From the environmental point of view - also taking into account that the Industrialized Countries have to reduce their greenhouse gases by up to 80 % until 2030 - there is no necessity for the rushed market introduction of hydrogen within the framework of an efficient climate policy. The main steps toward a sustainable use of energy are the

- efficient use of energy and a
- local use of renewable energy sources

with highest priority. Efficient technologies and the local use of renewable (thermal and electric) energy can produce more energy services or higher CO_2 emission reductions with the same monetary expenditure. In this regard the first priority is to promote fuel efficiency technologies and to improve and produce cheaper solar thermal and photovoltaic systems than the current production.

The adaptation of the electricity demand to the solar supply with differentiated price structures according to the supply and with special intermediate storage systems (e.g. cooling equipment, disconnectable heating pumps) can reduce the solar surplus during daytime. This will allow to use the energy produced on sunny days or during windy periods in periods of missing offer of the renewable energy. Is was also concluded, that the production of hydrogen from solar power can only be of interest from the environmental point of view, if the solar share of the fossil and the renewable electricity generation reaches more than 40-50 %.

Hydrogen can be used in internal combustion engines or fuel cells. If hydrogen is used in an engine, emissions of CNG-engines are comparable to hydrogen engines, regarding the exhaust emissions of the relevant NO_x and PM emissions. Instead of using a combustion engine research efforts are made to use hydrogen fuelled fuel cells in vehicles, which can be in principle more efficient than using methanol in a fuel cell.

Costs, Other Restrictions

Hydrogen from renewable sources will have additional costs in comparison to the costs needed to generate renewable electricity. The energy content of gaseous hydrogen is reduced to 65 % of the solar production electricity. The costs including transport will be twice the costs of the solar electricity. Using liquefied hydrogen results in a 50 % reduction of the solar electricity and causes more than 4 times of the costs of solar electricity.

It can be concluded, that the use of electricity from renewable sources (e.g. photovoltaic, wind power) should be used directly, which is cheaper and has more environmental benefits than the production of hydrogen from this electricity.

If hydrogen is produced or available it can be used for the production of reformulated sulphur free petrol and diesel fuels in refineries and can result in an overall emission reduction for the whole vehicle fleet running on reformulated petrol.

5. Electric Vehicles (EV)

The most comprehensive field test study about EV's was made with about 60 vehicles on the German Baltic island Rügen. The comparative eco-balance was performed by the German ifeu - Institute for Energy and Environmental Research Heidelberg.

Greenhouse Gases, Limited Emissions

Energy consumption and emissions of the vehicles depend on a large number of parameters. The most important of these energy consumption parameters are the driving energy, the battery consumption (internal resistance consumption, battery heating, recharging energy, efficiency of charging, self-discharge), the secondary energy consumption (charging converter) and the additional heating.

The comparison of electric motorcars with conventional cars is for EV's very dependent on the electricity generation in each country. The advantages of the electric motorcar over the conventional car include that the electric car does not generate emissions which are toxic to humans and which damage physical assets directly at the site of deployment. The electric cars contribute to a lower degree to summer smog and nitrogen input into soils and water bodies. The disadvantages of the electric motorcar include that it has a higher acidification potential and a stronger climatic impact, if electricity is produced from fossil sources. These disadvantages increase with decreasing daily kilometre performance and can only be compensated under special conditions of deployment such as very frequent short distance drives.

Costs, Other Restrictions

The EV has to be compared with the best available technology of internal combustion engines. Because of the EV's advantage of local zero emission, the comparisons are made between the additional costs of an EV, which are dominated by the battery costs, and the additional costs for an EURO 4-standard, in comparison to a current vehicle. While the additional incremental cost of EURO 4 in comparison to EURO 2 are negligible, the battery costs for the EV can result in more than 2,000 US$ for the additional incremental lifetime cost of the battery for an EV.

The use of EV's make sense in ecological sensitive areas or enclosed indoor facilities which have a proven need for zero emissions. In typical road traffic situations, highest priority should be given to the introduction of stringent emission limits, such as the EURO 3 or EURO 4 standards for petrol vehicles.

6. Fuel Cells (FC)

At the moment, FC vehicles are discussed as one of the most promising technologies for the future. Hydrogen, methanol and even petrol are discussed as fuels for the vehicles. Further differentiation must be done for the different possibility of producing the fuel.

Greenhouse Gases, Limited Emissions

The efficiency of the fuel cell vehicle and their costs will be one of the main problems on its way to become the car of the future. The German Federal Environmental Agency (UBA) did investigations for different cars of the future, based on the assumption of a likely development. The comparisons were made relative to a competitive fuel efficient vehicle with petrol engine and compared this to two types of vehicles,

- the fuel cell vehicle with compressed hydrogen storage and
- the fuel cell vehicle with methanol and reformer.

The calculations showed, that the weight for the storage system and the propulsion components (engine, fuel cell, reformer, etc.) will be between 2 and 3 times higher than for the petrol fuelled car of the future.

The main advantage of the fuel cell vehicle is the very low emissions. But efficient EURO 4 vehicles will give already noticeable emission reductions of about 50 %, up to 85 % compared to a EURO 2 vehicle. The reduction of the direct emissions is sufficient for achieving air quality targets. A further reduction of the direct emissions will not be necessary, if all vehicles will comply with this emission standard. Comparing the directly and indirectly caused emissions, the fuel cell vehicles with very optimistic fuel consumption data can reduce emissions further.

Costs, Other Restrictions

To calculate the avoidance costs for passenger cars in comparison to a today available EURO 2 standard vehicle, the emission reductions are compared to the vehicle extra costs in order to determine the relationship between benefits for the environment and costs. As in the long term the most important necessity will lie in the reduction of greenhouse-relevant

CO_2 emissions, the following results summarise the calculations for the reduction of greenhouse gases. Even with the most successful development of fuel cell technology for transport, the costs for avoidance of the greenhouse gas CO_2 can rise up to 200 US$ per metric ton. The avoidance costs are at least 83 US$ per metric ton of CO_2 more than the avoidance costs of an efficient vehicle with internal combustion petrol engine and EURO 4 emissions.

UBA made further comparisons of the costs and the possible emission reductions of fuel cell buses, which will be driven with hydrogen, and buses with internal combustion engine and natural gas (NG). While the first system can reduce the critical emission components of NO_x and particulate matter (PM) in comparison to a diesel bus completely, the natural gas bus can reduce NO_x for 85 % and PM more than 99 %. The cost comparison shows that fuel cell technology is not a technology for public busses in the foreseeable future.

However, fuel cell technology is a promising future technology. But a differentiated look at the use of fuel cells is required from an environmental point of view, according to the energy services, which they are going to provide, and the available or foreseeable alternatives in each case. The fuel cell use in the stationary area appears to be sensible and capable of development, since they can already convert fossil energy sources (e.g. natural gas) into electricity and heat or coupled with cooling production much more efficiently than previous power plants or heat producers.

7. Roadmap for Developing Countries

Environmentally sustainable transport will not be possible to achieve without **managing traffic growth**. With respect to everyday personal travel, changes in land use and infrastructure supply, which allow for more densely populated and mixed use settlement patterns will result in lower transport needs and shorter trips. Regarding vacation and leisure trips the appeal of locations closer to home should be increased.

This does not mean that the necessary technological innovations will be introduced easily, but the main key technologies are available. The following recommendations show principles for a roadmap:

1. Introduce lead free and further improved fuels (98/70/EC) for an important contribution and as a primary measure in reducing environmental pollution levels. Fuel modifications can take effect quickly and have a particularly marked impact in the case of existing vehicles on the road.
2. Introduce fuel-efficient EURO 3 technologies immediately and EURO 4 in the mid-term, based of an adoption of EC regulation 98/69/EC.
3. Introduce a retrofit program for closed loop catalytic converters for used petrol cars without emission control to reduce emissions per vehicle by more than 80 %.
4. Use fuel-efficient diesel technology using retrofit particulate traps for buses and for passenger cars.
5. Use fuel-efficient natural gas or liquefied petroleum gas engines, if a local infrastructure is available.
6. Driver training for an economically and ecologically sound driving style is a cheap method, especially for vehicle fleets with busses, trucks and passenger cars, to save fuel and money whilst contributing to road safety and greenhouse gas emission reduction.
7. Use biomass (e.g. biogas), as well as thermal and electric renewable energy sources locally in non-transport applications with highest priority to reduce greenhouse gas emissions with high cost efficiency.